THE WILD GOOSE ASSOCIATION

PROCEEDINGS OF THE
FOURTEENTH ANNUAL TECHNICAL SYMPOSIUM

23 — 25 OCTOBER 1985
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THE WILD GOOSE ASSOCIATION

The Wild Goose Association (WGA) is a professional organization of individuals and organizations having an interest in Loran (Long Range Navigation). It is named after the majestic birds that navigate thousands of miles with unerring accuracy. The WGA was organized in 1972 and its membership now includes hundreds of professional engineers, program managers, scientists and operational personnel from all segments of government, industry, and the user community throughout the world, working for the advancement of Loran.

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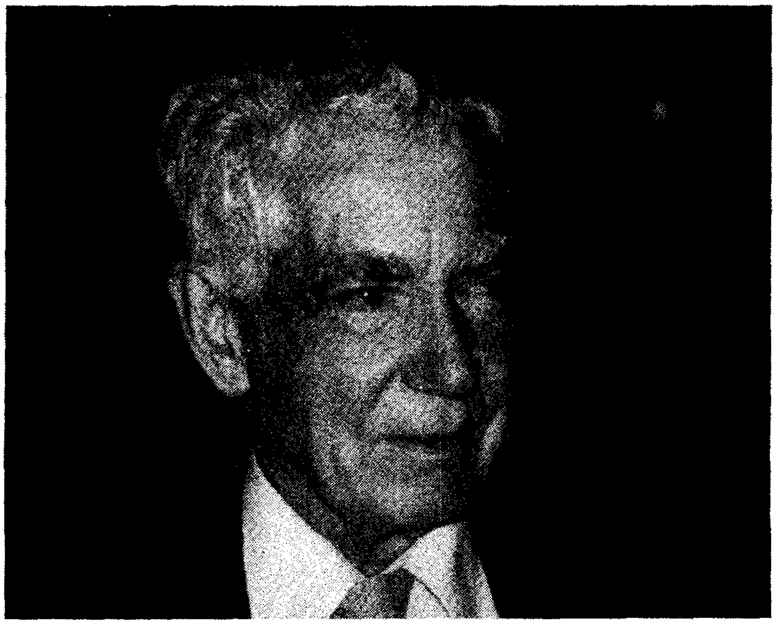

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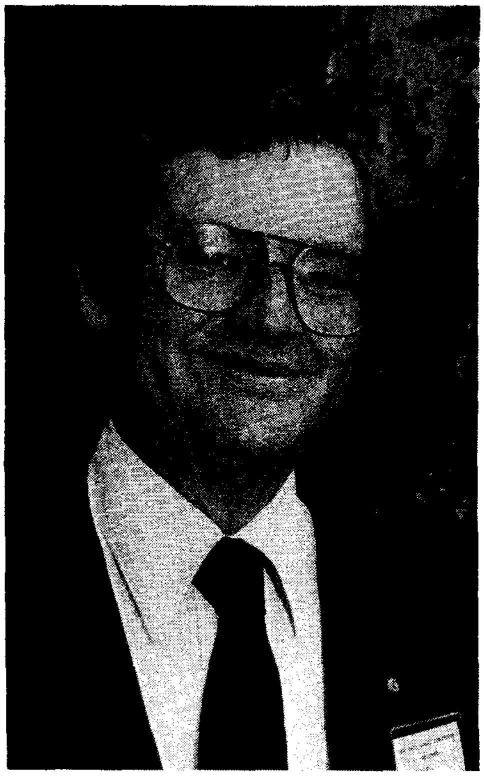

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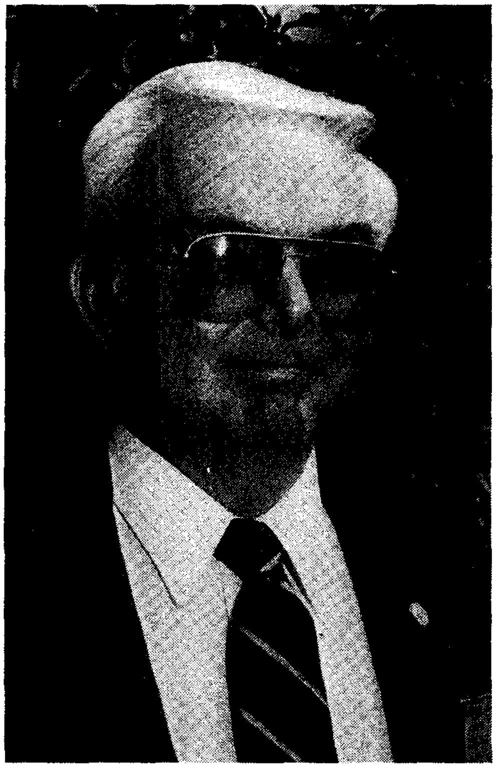

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Keynote

RADM T.J. Wojnar, USCG

Thursday Luncheon

James Atkinson

Banquet

Dr. Lodewijk vandenBerg

Friday Luncheon

LTG James Thompson, USA (Ret.)

TECHNICAL SESSION No. 1 - PLANS, POLICY AND PROGRAMS

Session Chariman - David C. Scull
Department of Transportation (RSPA)

SESSION CHAIRMAN

Mr. David Scull

SPEAKERS

(l to r) Chick Longman, Bill Polhemus, Dave Scull (back) Jerry Bradley, Paul Burket, RADM Ted Wojnar and Carl Andred (for Ed McGann)

KEYNOTE ADDRESS

Delivered By: RADM Theodore J. Wojnar, USCG
Chief, Office of Navigation
U.S. Coast Guard

At: The Fourteenth Annual Technical Symposium
Wild Goose Association
Santa Barbara, CA
October 23, 1985

Not too many years ago Loran-C Navigation Systems were considered to be strictly for military applications. The user equipment was expensive and not well suited to the civil community's needs. A few believers, many of them members of this Wild Goose Association, collaborated in solving the problems which stood in the way of widespread civil use of this promising radio navigation system.

Today, Loran-C is a fully matured and widely used system. The Civil Marine community has turned Loran-C into an all weather navigation system throughout the coastal confluence zone. In the past few years there has been a virtual explosion of Loran-C usage by the General Aviation community. The terrestial user is emerging here in the United States and internationally. New applications are being developed for Loran-C because of its virtually unbeatable combination of repeatable accuracy, excellent coverage and low user cost.

This enormous amount of activity has taken place because of the outstanding cooperation among government, industry and users; all with an eye toward the ultimate benefit and best interest of the navigator. As you all know, the Wild Goose Association has worked closely with the U.S. Coast Guard for more than a decade to make Loran-C the highly reliable system we have today.

It is with these thoughts in mind that I express my appreciation to your distinguished organization for inviting me to be your keynote speaker today. It's always a pleasure to get together with people who share an interest in the radionavigation system of the future, Loran-C, a system for the twenty-first century.

Yes, I believe Loran-C is a system of the future and from the looks of it, many others think so too. Loran-C continues to grow in appeal, both here and abroad. Worldwide, new stations are under construction and older stations are being modernized. The number of marine, air and overland users, in this country and internationally, continue to grow, with a rapidity unheard of in Loran history.

In Europe, we see an expanding Loran-C network which may soon cover the continent and its surrounding waters. As many of you know the French Loran-C system became operational in the Rho-Rho navigation mode earlier this year. In November, we will begin testing Sylt as an additional secondary in the French chain. The addition of Sylt will provide the third station necessary for navigation, using normal Loran-C receivers. Pre-operational testing will start at Sylt this week and the chain will be operational for experimental hyperbolic use by mid-November. We expect to continue these tests until January 1986. There is even some thought on the part of the French and the Irish of possibly adding a station in Mizzen Head to the chain.

The recently formed North Atlantic Loran working group is promoting Loran-C in Europe. This group consists of representatives from governments and companies interested in developing Loran-C in the "Old Country". They were the prime movers behind the Sylt test.

We are also witnessing the spread of Loran-C in the Middle East. Not only are the Saudi and Suez chains currently in full operation the Egyptians are now considering a new Loran-C chain. Last April at the IALA conference in Brighton, the Egyptian delegate arrived prepared to sign a contract to have a Decca chain constructed for a critical waterway in his country. After discussing the plan with other delegates, primarily British, he was convinced that he should seriously consider Loran-C instead of Decca. He then came to us for advice and also contacted Ed McGann of Megapulse who was also at the conference. We have since sent a package to Egypt presenting several Loran-C system configurations for their consideration.

There is also Loran-C activity in the Far East. The People's Republic of China contracted with Megapulse for a "turn-key" system covering the South China Sea. They visited Coast Guard headquarters last year to discuss their interest in Loran-C and were taken on a tour of one of our stations. I hope to see this system made available to all users when it becomes operational.

Within this international arena, IALA, the International Association of Lighthouse authorities has long utilized its expertise to guide international radionavigation planning. In response to the proliferation of radionavigation systems worldwide, and in recognition of the complexities involved with worldwide radionavigation planning, an IALA radionavigation planning group has been established to develop a worldwide maritime radionavigation plan.

It is IALA's belief that maritime navigation planning can no longer be done on a country-by-country basis, but must be global in scope. This IALA plan will provide a statement of the minimum operational requirements necessary in radionavigation systems utilized for maritime transportation. It will be coordinated with the national plans of member nations and with planning groups representing other navigational and transportation interests. IALA's preliminary statement of operational requirements is a testament to the foresight and quality of planning that went into our Federal Radionavigation plan, as they drew heavily from our experience.

This past March, at the request of the Soviet Union, I led a group of five Coast Guard representatives to a bilateral Loran-C meeting in Moscow. In addition to a general technical exchange and a discussion on the development and use of low frequency radionavigation systems. the Soviets expressed interest in developing a joint agreement regarding coordination of the assignment of group repetition intervals (GRI) for new Loran chains.

The Russians have expanded their system to 13 operational transmitting stations, with two more under construction. As you can see, the growing use of Loran-C extends into the Soviet Bloc as well, even though we see its expansion driven more by its military use than by civil need. As a result of these meetings both sides agreed to:

1) Speed a mutual understanding to minimize or eliminate harmful interference.

2) To exchange information and to develop a joint agreement regarding coordination of the assignment of GRI's for new chains.

3) To coordinate the planning for new systems.

4) The Russians agreed to prepare and provide technical and operational parameters, including station location for publication in the U.S. booklet, "Radionavigation Systems".

We in the U.S. are also quite active in building for the future. The Coast Guard's long-range plans for radionavigation are twofold: To continue to support world-wide radionavigation system development and operations: and to develop new systems in response to national maritime, aviation and terrestrial user requirements.

Our efforts with Loran-C will be aimed primarily at the improvement of existing service while reducing program costs. In support of this objective five stations are or will soon be receiving new solid-state transmitters to replace aging tube-type transmitters. The solid-state transmitter will improve the consistency of the pulse shape, decrease down time, increase power output, and reduce operating and maintenance costs.

The remote operating system (ROS) installations continue to move along as well. As you know, Raymondville has been remotely operated for some time. Now, Searchlight, Grangeville, and Fallon are operated by remote control and will soon be reduced in manpower. When ROS program is complete, some 83 billets will have been transferred for use in other vital Coast Guard missions.

As a result of these efforts with improved transmitters, and timing and control equipment, the cost of doing business is going down while the product is improving. These important improvements become even more critical in the very tight budget climate we face today.

The Coast Guard continues to work together with the Federal Aviation Administration (FAA). We are currently finalizing a memorandum of agreement for the establishment of radionavigation service for civil aviation users in the National Aerospace system. Under this agreement, the Coast Guard will ensure that its Loran-C operational procedures are consistent with the FAA's requirements. The FAA, in turn, will integrate Loran-C into the National Aerospace system. Loran-C is currently approved for enroute navigation in some areas. Two goals remain to bring Loran-C into full use: Approval of Loran-C for use as a nonprecision approach aid, and complete Loran-C coverage of the mid-continent gap.

The FAA administrator, Don Engen, has announced that he will conduct a precision approach record book flight in the Boston area on 4 November 1985. This will be the first instrument flight rules (IFR) non-precision approach using Loran-C. The FAA indicates that non-precision approaches will be ready for approval at six additional airports with pilot monitors installed, shortly after this flight.

To fill the mid-continent Loran-C gap, five to six stations would be necessary. Each station is estimated to cost about eight to ten million dollars. Transmitter locations have not been determined, but the FAA recently transferred $120,000 to the Coast Guard to perform a survey of existing coverage and make preliminary site selections. The FAA and Coast Guard will soon set up a project team for this effort.

The FAA has also designated funds in their 1986 budget to dual-rate Port Clarence, Alaska. The FAA estimates the addition of Port Clarence to the Gulf of Alaska chain will increase Loran-C coverage in Alaska by 93,000 square miles.

One of the most interesting challenges for the future is the requirement by the Federal Radionavigation plan for 8-20 meter accuracy in the harbor and harbor approaches. Some years ago the Coast Guard began a long-range research and development project to evaluate various methods to provide this accuracy. The Coast Guard is now completing tests with one of the methods, differential Loran-C. This past year our research and development center demonstrated a prototype system in New London, CT, using a Digital VHF correction signal. Next year the center will demonstrate an improved version in Hampton Roads, Virginia.

The integration of this radionavigation system into our existing optical and acoustic aids to navigation system in American's waterways will be evaluated through WAMS the Coast Guard's Waterways Analysis and Management System.

Loran-C users are also looking to the future of overland systems. Nissan Motors, Motorola and II Morrow have developed automatic vehicle tracking and locating systems based on Loran-C; NOAA has begun using Loran-C to monitor the position of their large weather buoys; the National Weather Service has started using Loran-C on weather balloons to determine wind speed and direction; MCI is now using the precise time of Loran-C for synchronization of their satellite communications network; and the list goes on and on. I am constantly impressed with the way Loran-C has transcended its original purpose as a coastal maritime radionavigation system to become responsive to so many user needs.

Today, I have enjoyed highlighting the work of many nations who continue to work towards using Loran-C to its fullest potential. We are witnessing the growth of Loran-C both in the international arena, as more and more countries come to appreciate its high level of cost effectiveness, accuracy, and adaptability; and in the arena of accurate time and timing control. I'm convinced Loran-C is a system for the twenty-first century.

I thank you very much for offering me the opportunity to keynote this our 15th Wild Goose Association convention. I'm sure some of what I've said will engender our discussion over the next two days. I look forward to hearing your views during the three technology sessions, topped off by an excellent panel discussion on Friday. Historically, the Wild Goose Association has been a front runner for technical advances in Loran radionavigation systems. The rate at which technology is developing demands that you do your work with an open mind, with full government, industry and user cooperation and always-always with an eye to the best interests of the navigator.

THANK YOU.

RECENT INTERNATIONAL DEVELOPMENTS IN LORAN-C

Edward L. McGann
Racal-Megapulse, Inc.
Bedford, Massachusetts

ABSTRACT

The greatly exaggerated "death" of Loran-C has had no apparent influence upon new systems being installed in France, Saudi Arabia and The Peoples Republic of China. With FAA interested in closing the "mid-continent gap" and the rapid explosion of Loran-C avionics, the "old" system is entering a new phase of user acceptance. Advancements in VLSIC electronics will drop the prices to mass market levels and open up further application areas such as vehicle location systems to Loran-C. Loran-C may indeed be the worlds terrestially based navigation system of the twenty-first century.

INTRODUCTION

The American philosopher and writer Mark Twain once remarked after reading an erroneous obituary of himself that "the reports of my demise are greatly exaggerated". The same can be said of Loran-C. While many observers over the years have characterized Loran-C as a dying system, the truth is that the number of users have increased over the past ten years by more than two orders of magnitude - from a few thousand to a few hundred thousand. Furthermore, it is not only an internationally accepted marine aid-to-navigation but is now rapidly becoming the most effective and attractive aircraft aid-to-navigation system for both enroute and non-precise approach applications. In the United States Loran-C airborne equipment is the fastest growing and most active avionics market. User equipment performance is exceptional and the prices are very affordable. The intense competition between twenty to thirty manufacturers results in high performance user equipment at minimal prices.

Because of the attractiveness of the user equipment performances and prices, the pressure is building for more effective and expanded signal coverages around the world. New stations are in operation in Saudi Arabia and in France and expanded coverages are projected soon for the "mid-continent gap" of the United States, Europe, Russia, and China. In the future it is possible to anticipate activities in the Middle East, Far East, South America and Africa.

Certainly the future of Loran-C depends on the decisions made regarding the Global Positioning System (GPS) by the United States government and its perceived acceptance by the rest of the world. And, in the long term, the use of Loran-C will be conditioned by the new satellite systems that are finally internationally accepted and sponsored. What is now becoming clear, however, is that most governments are moving toward national policies in which there will be a preferred satellite-based system and a preferred terrestial-based system. Considering that in the next twenty to thirty years Loran-C will be the most widely used aid-to-navigation and position-fixing system in the world (excluding beacons) not only for marine and aircraft navigation but for vessel traffic management, automatic vehicle monitoring and for common grid, wide area surveys and other operational activities. It is almost certain to become the preferred international terrestial-based system. It is also possible that Loran-C signals will become widely used for communication of information that is complementary to navigation such as differential signal correction information. Potentially Loran-C transmitting stations might even be used as pseudolites in a mixed terrestial/satellite system. Not a bad future for a system so often considered as dead.

HISTORY OF LORAN-C DEVELOPMENT

The evolution of Loran-C can be described in terms of three phases.

Phase I - Spanning from the mid 1950's to the early 1970's, this phase saw the initial deployment of Loran-C by both the U.S. and the USSR to serve primarily military purposes. The users were indeed mostly military but some major vessels, sophisticated fisherman and some eastern European airlines made use of the signals in the later years of the period.

Phase II - Essentially was spurred by the declaration of Loran-C as an official national maritime system in the United States and joined in by Canada. The timely evolution of solid state electronics during this phase led to effective and affordable user equipments as well as new transmitter designs which could be sized to meet specific coverage requirements and would operate efficiently and without trained support personnel in attendance.

During this phase which extended from the early 1970's to the early 1980's the number of users in the United States alone grew from a few thousand to where it is now approaching 200,000 while the estimate of users in other areas grew to an estimated 50,000 to 75,000.

Not only were substantial marine and aircraft user communities developed but evolutionary activities took place on various system applications such as vessel traffic management and automatic vehicle location.

Phase III - Stretching from now into the future this phase will see the momentum carrying forward with a continued growth in the number of users and in the applications in which Loran-C is used. The actual growth and expansion that will take place will, as was mentioned earlier, be conditioned in the relatively near term by how various nations view the prospects and acceptability of GPS or any of the many competitive satellite systems both commercially operated or nationally sponsored. Certainly many nations will select a route of nationalism even if GPS or GLONASS (the USSR system) or other nationally sponsored system is made available to the world. These nations will want a system operated totally under their own control or under the control of a group of neighboring nations. These nations will choose Loran-C. Others, even if they are allied with the United States, may not wish to become solely dependent on a system operated by the U.S. military for their commerce and maritime safety as well as for their military commitments. These nations too will choose Loran-C as the terrestial-based local cornerstone of their aid-to-navigation system mix. Also, those nations who determine that GPS is not the best satellite system for their needs will adopt Loran-C as an interim system until a more acceptable and afforable satellite system is deployed.

Finally, however, the longevity of Loran-C will most probably be determined by how long the "prudent mariner" theorem of having more than one system available for use remains a technically and economically viable alternative.

Loran-C user equipment costs while already well within the range of all but the least affluent potential user will continue to decrease. With proven performance and low price, widely available user equipment represents the real driving force behind the expansion in the use of Loran-C. If the governments involved can provide the signals, the users can afford the equipment to meet their needs.

PRESENT STATUS OF LORAN-C

With the exception of radio beacons, Loran-C is presently the most widely used radio aid-to-navigation in the world. There are nearly 200,000 users in the United States alone - both marine and aircraft - with an estimated 50,000 to 75,000 additional users throughout the rest of the world. Figure 1 illustrated the worldwide coverage including the new signals available in France and Saudi Arabia. As shown, the coverage also extends over most of the coastal areas of the United States including Alaska and Canada, the North Atlantic and some of Western Europe, the Eastern Mediterranean as well as the areas around Japan and the mid Pacific.

PRESENT POLICIES REGARDING LORAN-C

The only existing formal international policies regarding Loran-C are those pumulgated by the United States. Operationally, marine regulations exist in the United States which require vessels over 1600 gross tons to carry Loran-C receivers or equivalent navigation aids while operating in U.S. waters or calling at U.S. ports. In the U.S. airspace, Loran-C has been approved as a supplementary, interim navigational aid for enroute navigation in those defined areas where proper signals exist. In addition, regulations and procedures are now being derived by the Federal Aviation Adminstration which will permit the use of Loran-C for non-precision approaches in approved areas.

Regarding future availability of the Loran-C system, the 1984 edition of the Federal Radionavigation Plan (FRP) co-authored by the Departments of Defense and Transportation proposes a mix of systems for the future. In the proposed scenario put forth in this FRP, in-country Loran-C will remain in operation for a fifteen year transition period after any decision is made to phase it out in favor of the Global Positioning System (GPS). The FRP proposes a 1986 decision time IF all economic, technical and operational questions regarding GPS have been answered by that time. This schedule appears unrealistic and most observers feel that a better

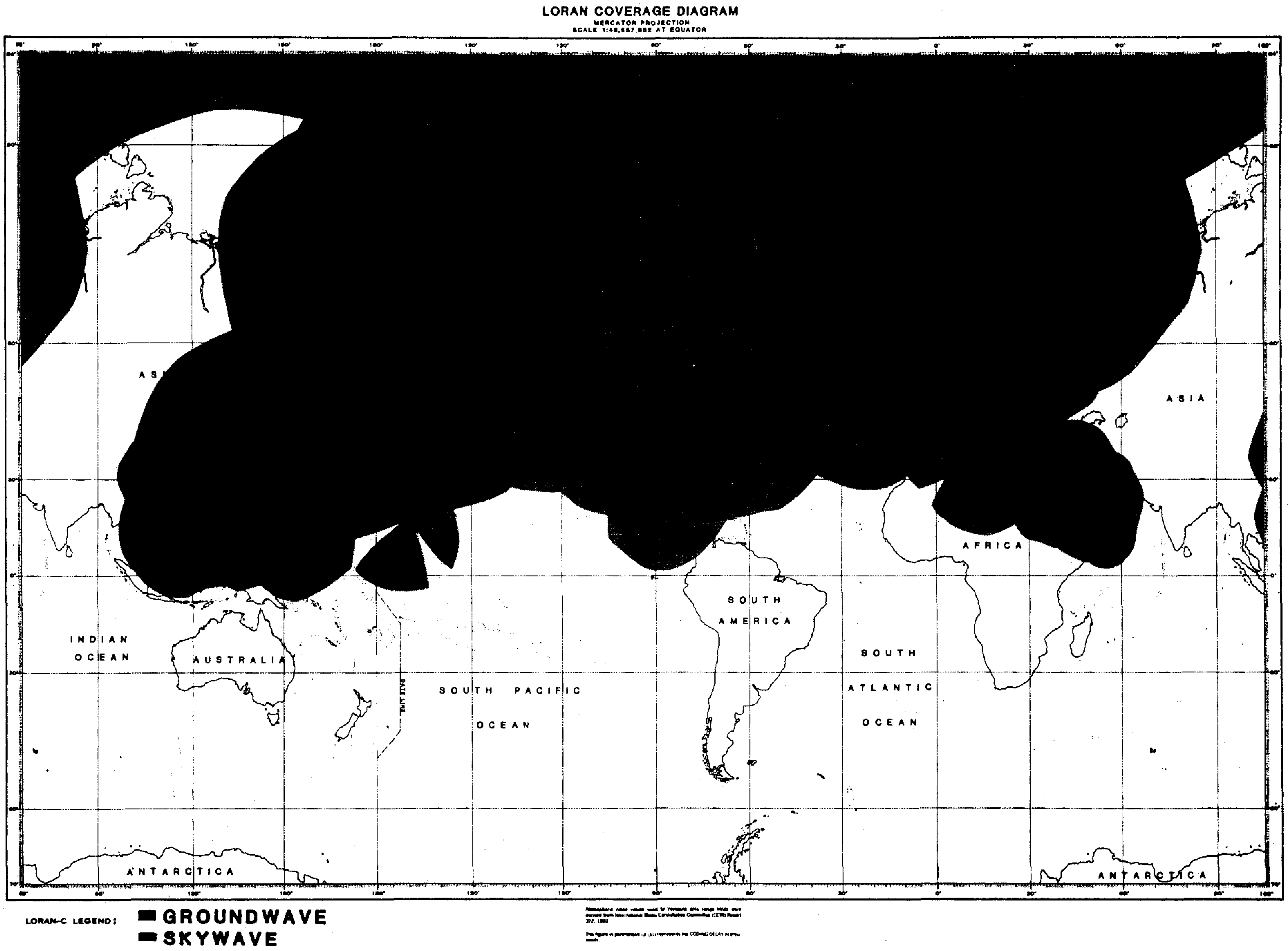


Figure 1. World-Wide Coverage

estimate of a proper decision point is the early 1990's when GPS has become operational and commercial user equipment are available for evaluation. Therefore, even given a decision in the early 1990's to phase out Loran-C, the in-country operation would still go on until the years 2005-2010. The author is not at all convinced that any decision to phase out Loran-C will be made for various reasons presented later in this article.

It might be well to note at this point that the 1984 FRP does not present an approved future mix of navigation systems for the U.S. and where applicable for the world. Rather, this FRP sets forth a proposed scenario and comments regarding it are invited from all interested parties both U.S. and international. The readers of this article may be well advised to review this FRP and to submit their comments on behalf of themselves or of the organizations which they represent.

The 1984 FRP does however reiterate a formal decision which has been taken regarding the future of overseas Loran-C and that is that the U.S. will cease funding and/or operating its overseas stations as of 1992. The host countries and others who may be affected have been advised of this decision by the U.S. government and considerations are now going on in many areas regarding the mechanisms for continuation and/or expansion of these operations after 1992. The overseas turnoff date of course assumes deployment and operational status of the GPS satellite configuration and the military user equipment sufficient to maintain essential military operations in the areas effected by the possible turnoffs.

The future of overseas Loran-C is therefore seen to depend on the decisions made by the host countries. These decisions will be forthcoming over the next three to five years. However, it is the author's projection that the current overseas coverages will not only be continued but, in fact, will be expanded.

PRESENT ACTIVITIES

There are currently a number of interesting situations involving Loran-C including:

- Federal Aviation Administration (FAA) actions in the United States to certify Loran-C for airport non-precision approaches thereby providing an instrument landing capability for 5,000-7,000 airstrips which would otherwise never have such capability. This activity will involve the emplacement of more than one hundred monitor units nationwide so as to assure continuous acceptability of the Loran-C signals in each operational region.
- FAA activities conducted with the support of the Coast Guard to to provide signal coverage over the "mid-continental gap" so that complete CONUS coverage is available for aviation applications. This activity will include coordination with Canada for possible mutual interests along the border and will also consider improved coverage of the western Gulf of Mexico using a station located in the Yucatan.

- Dual-rating of an Alaska station to improve coverage in that region.

- The Loran Working Group - Europe made up of members from the Loran-C host nations in Europe along with other interested countries has recently submitted its first report and recommendations regarding the possibilities for Loran-C in Europe after 1992. Figure 2 illustrates the present coverages and some desireable expansions.

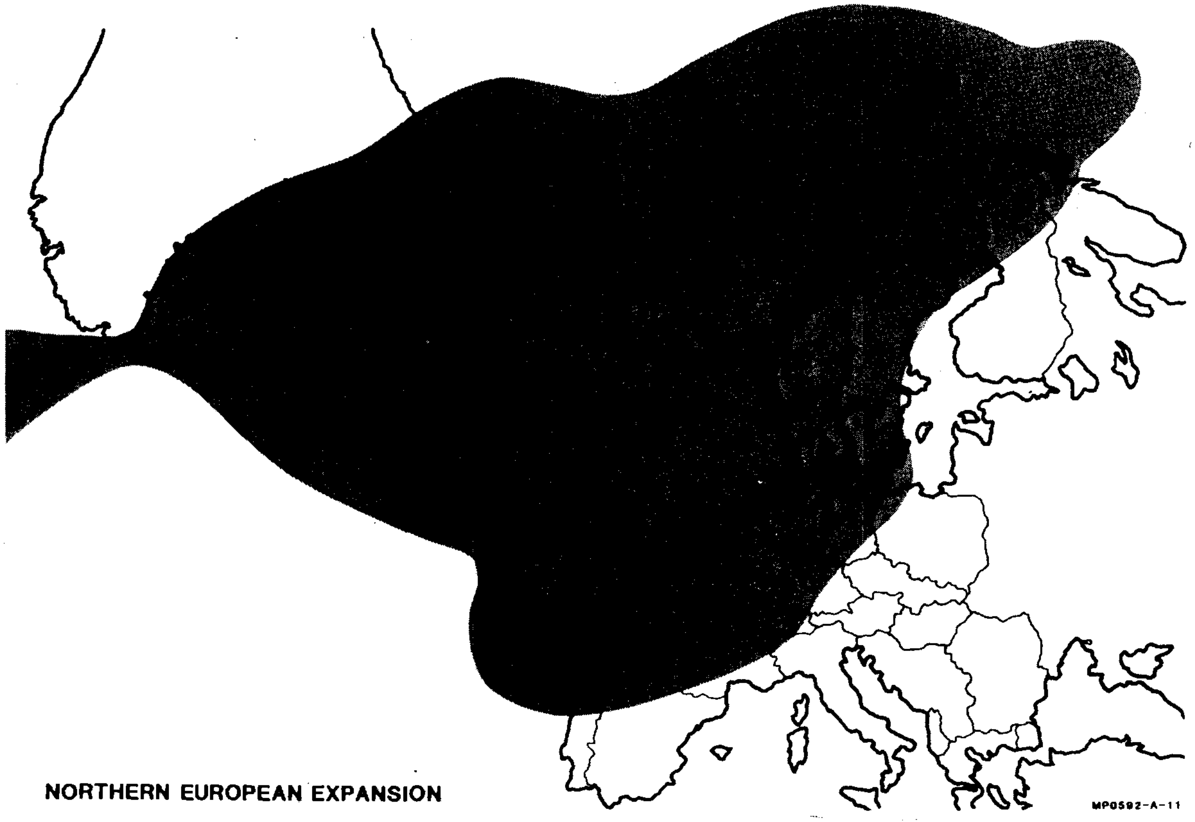


Figure 2. Present Coverages

- Iceland is planning a mandatory reporting system for all ships operating in its waters with position information derived from Loran-C and radioed ashore.

- The Peoples Republic of China is planning for the use of Loran-C as a coastal navigation aid supporting its developing ports and economic zones. Figure 3 illustrates the coverage of the initial three stations.

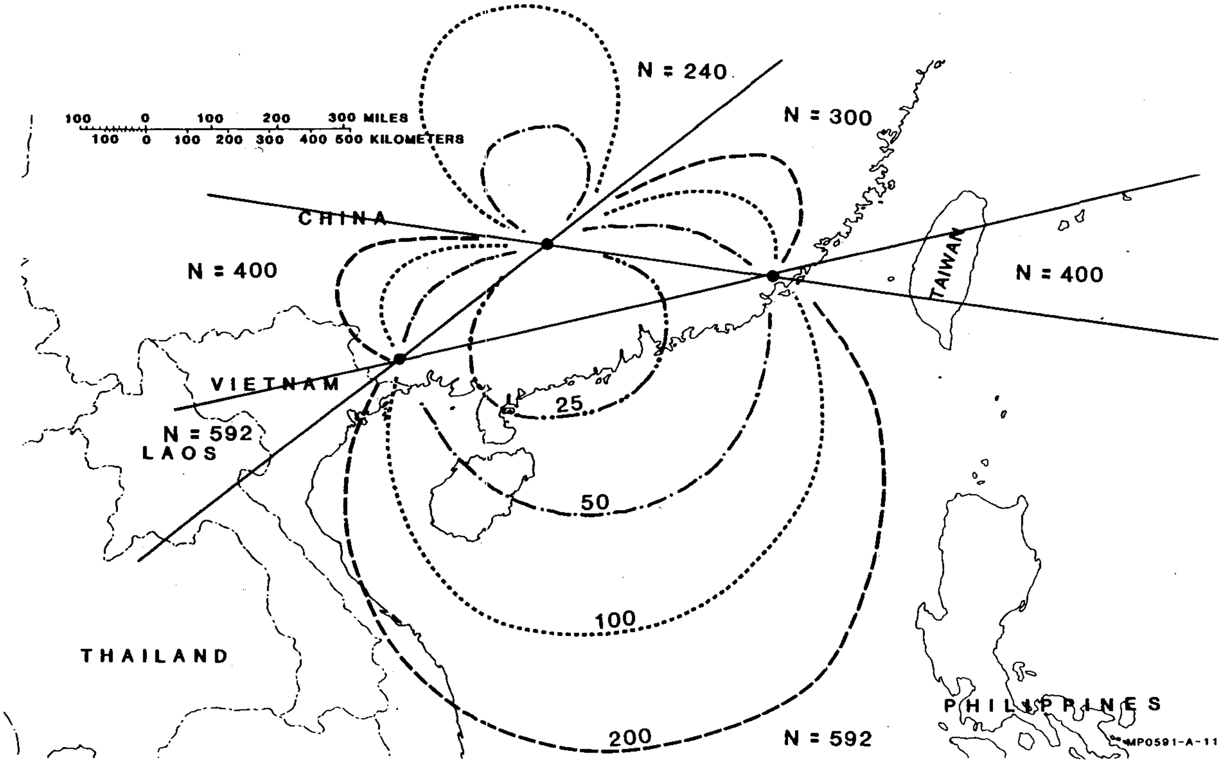


Figure 3. Three Station Coverages

- Preliminary reports indicate that Russia is adding stations to its eastern chain and perhaps establishing a new chain in the polar regions. Figure 4 illustrates the general location of those new stations and estimates the expanded coverage.

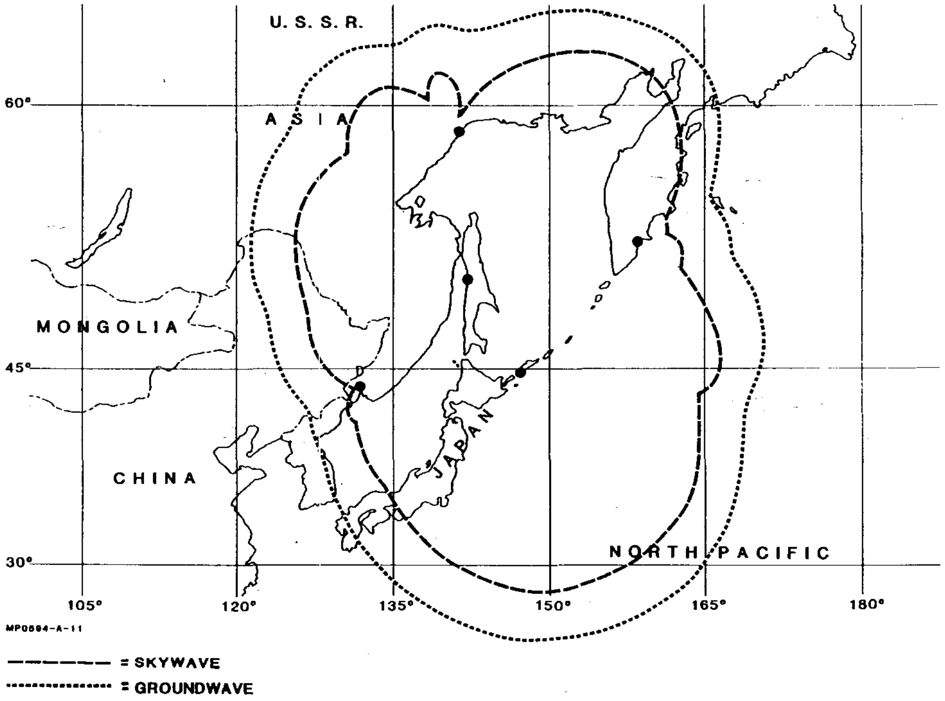


Figure 4. Eastern Russian Loran-C Coverage Area with Additional Stations

- In Egypt the second phase of the Gulf of Suez navigation and implementation program is upcoming. This phase will involve the emplacement of a radio aid and Loran-C is being strongly considered because of the presence of the complimentary coverages in the Mediterranean and all of the waters around Saudi Arabia. One possible configuration which provides coverage not only over the Gulf of Suez but also over the Gulf of Aqaiba, the Sinai, the Egyptian Mediterranean coast and much of central Egypt is shown in Figure 5.

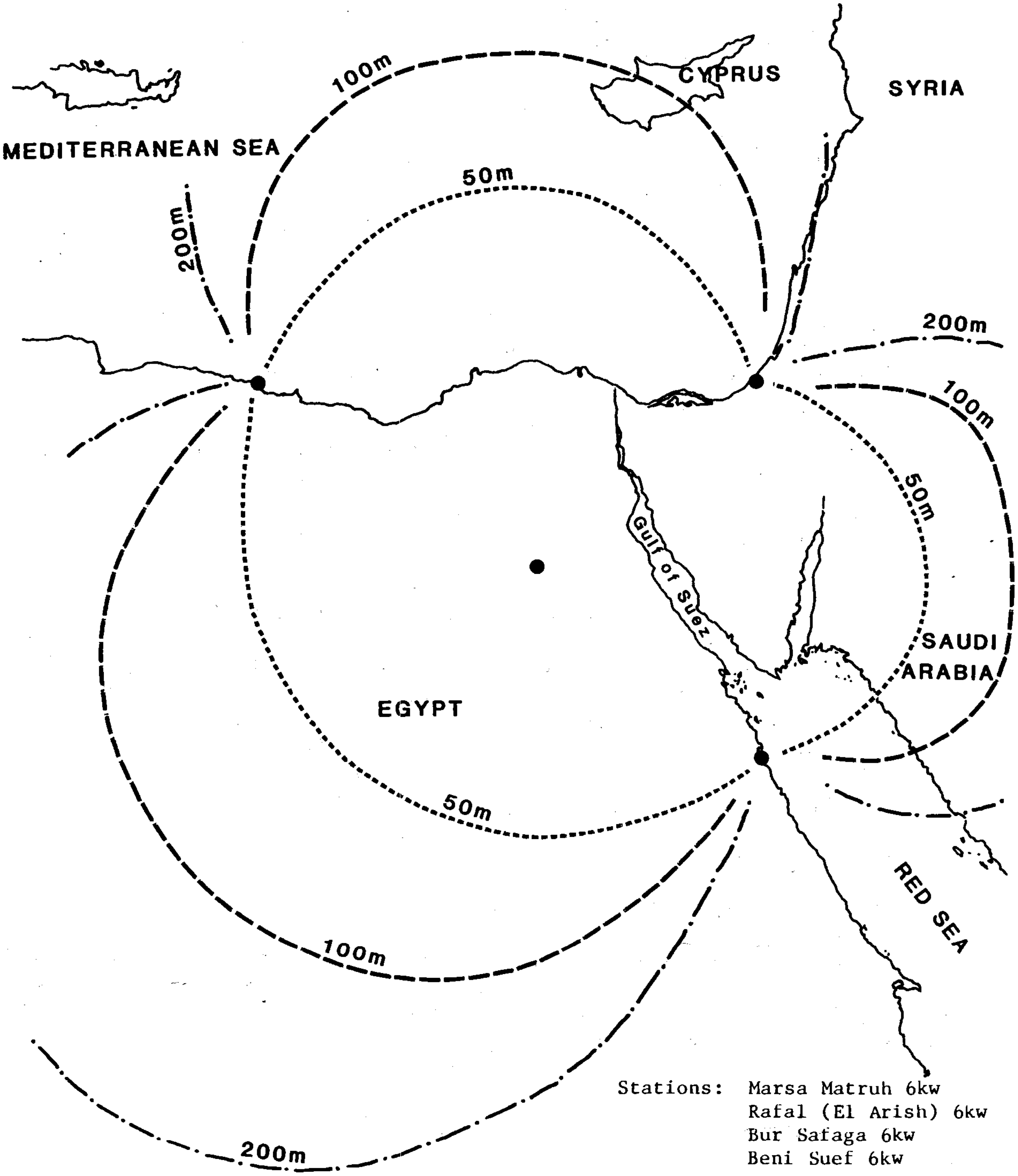
- In the Far East, it is understood that both Japan and Korea are beginning to look at the future prospects of Loran-C.

- South Africa is considering the use of Loran-C as a national system, although the present situation there may cause some delay.

- In the user equipment area, capabilities continue to increase as prices continue to drop. Effective marine receivers with latitude/longitude readouts and other navigational information are regularly selling for $600-1000 USD. Full capability area-navigation airborne sets are available from $2000-4000 USD and prices continue to decrease as this market matures. The computing power of the new Loran-C avionics units is such that they are providing many of the functions of a flight management system bringing this capability for the first time into the cockpit of small aircraft. Observers expect a new generation of equipment with Very Large Scale Integrated Circuits (VLSIC) and universal coordinate transformation programs to be available in five to ten years. This would result in receivers for $50-200 USD in mass market applications such as vehicle location and will bring down the cost in all applications.

FUTURE OF LORAN-C

It is the opinion of the author that the use of Loran-C will continue and for the foreseeable future it will be the standard and most widely used system in the world. It may lack the glamour and technical complexity of the satellite systems but has proven itself and it has a satisfied, growing number of users in many applications. The reports of the demise of Loran-C are indeed greatly exaggerated.



Stations: Marsa Matruh 6kw
Rafal (El Arish) 6kw
Bur Safaga 6kw
Beni Suef 6kw

MP0593-A-11

Figure 5. Potential Eastern Mediterranean Egyptian Loran-C Coverage

AUTHORS BIOGRAPHY

Mr. Edward L. McGann has been involved with Loran-C since the mid-1960's. He has presented a number of papers on the subject and has worked on the design of various Loran-C equipments and the implementation of Loran-C systems in many parts of the world. Expansion of Loran-C worldwide has been his continuous goal. Mr. McGann is currently Executive Vice President of Racal Megapulse, Bedford, Massachusetts, U.S.A. He is a Director and a former Vice President of the Wild Goose Association and received the Presidents award for service to Loran-C. He is a member of the Institute of Navigation and a committee member on the National Ocean Industries Association. Mr. McGann holds a Bachelors and Masters degree in Electrical Engineering from the University of Lowell in Massachusetts.

FUTURE RADIONAVIGATION SYSTEMS
FOR
CIVIL AVIATION

Jerry N. Bradley

Federal Aviation Administration

The following material summarizes the presentation made by Mr. Bradley and was extracted from the Federal Radionavigation Plan - 1984. DOD-4650.4 and DOT-TSC-RSPA-84-8.

U.S. Civil Aviation Radionavigation Systems

Today:

- VOR
- VOR/DME
- NDB
- LORAN-C (Supplement)
- OMEGA (Supplement)
- DME/DME RNAV

U.S. Civil Aviation Radionavigation Systems

Future: (Post 1995)

- FAA Preliminary Recommendation in 1984 Edition
- FAA Final Position in FY 1987

PRELIMINARY RECOMMENDATION ON THE FUTURE RADIONAVIGATION SYSTEM MIX

-- A Preliminary Recommendation on the future radionavigation systems mix has been jointly developed by DOD and DOT.

-- The Preliminary Recommendation is in the form of a policy statement.

DOD/DOT POLICY FOR THE FUTURE RADIONAVIGATION SYSTEMS MIX

PURPOSE: This statement sets forth the policy for Federally funded radionavigation systems to be supported for the remainder of this century and into the early part of the next.

BACKGROUND: Section 507 of the International Maritime Satellite Communications Act of 1978 (PL 95-564) requires the development of a plan to determine the most cost effective method of reducing proliferation and overlap of Federally funded radionavigation systems. That plan, the Federal Radionavigation Plan (FRP), was developed through the joint efforts of the Departments of Defense and Transportation. The FRP (current edition March 1982) cites key events in selecting radionavigation systems to be used in the future. One of these events is publication of a DOD/DOT policy statement that sets forth a preliminary selection of Federally funded radionavigation systems. This policy statement will provide the basis for revising the FRP. Subsequent reviews of the FRP will be undertaken, at least biennially or more frequently, if necessary.

All common user systems currently operating or planned were considered in reaching this selection for the future mix of Federally funded radionavigation systems. This policy statement addresses how and for what period each system should be a part of the Federal radionavigation system mix. When a decision is made to terminate a navigation system, an appropriate transition period will be provided.

The Department of Transportation (DOT) is responsible for ensuring safe and efficient transportation. Radionavigation systems play an important role in carrying out this responsibility. The two main elements within DOT that operate radionavigation systems are the United States Coast Guard and the Federal Aviation Administration (FAA).

The Coast Guard has the statutory responsibility to define the need for, and to provide aids to navigation and facilities needed for safe and efficient navigation. The FAA has the responsibility for development and implementation of radionavigation systems to meet the needs for safe and efficient navigation and control of all civil and military aviation, except for those needs of military agencies which are peculiar to air warfare and primarily of military concern. The FAA also has the responsibility to operate aids to air navigation required by international treaties.

The Department of Defense (DOD) is responsible for developing, testing, evaluating, implementing, operating, and maintaining aids to navigation and user equipment required for National Defense and ensuring that military vehicles operating in consonance with civil vehicles have the navigational capabilities required to operate in a safe and expeditious manner.

DEFINITIONS:

Sole Means Air Navigation System: An approved navigation system that can be used for specific phases of air navigation in controlled airspace without the need for any other navigation system.

Supplemental Air Navigation System: An approved navigation system that can be used in controlled airspace of the National Airspace System in conjunction with a sole means navigation system.

Predictable Accuracy: The accuracy of a position with respect to the geographic, or geodetic, coordinates of the earth.

Repeatable Accuracy: The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.

2 drms: The radius of a circle that contains at least 95 percent of all possible fixes that can be obtained with a system at any one place.

POLICY

RADIOBEACONS: Maritime and aeronautical radiobeacons serve the civilian user community with low cost navigation. They will remain part of the radionavigation mix well into the next century.

LORAN-C: LORAN-C provides navigation for both civil and military air and surface users. It is the Federally provided navigation system for the U.S. Coastal Confluence Zone (CCZ) and in the differential mode has been demonstrated capable of meeting the 8-20 meter 2 drms navigation accuracy requirements in harbor and harbor approach areas. LORAN-C is also approved as a supplemental air navigation system in some areas. DOD will phase out military use of overseas LORAN-C by 1992. The United States will discontinue LORAN-C transmitting stations established for military use that do not serve the North American continent, as military LORAN-C users become GPS equipped. The LORAN-C system serving the continental United States and its coastal areas will remain a part of the navigation system mix into the next century.

OMEGA: OMEGA is a global navigation system serving maritime and aeronautical users. It is a sole means of air navigation in some oceanic areas. DOD will phase out military air use of OMEGA by 1992. However, some naval receivers may continue in operation after that date. OMEGA will remain a part of the radionavigation system mix until at least 2000.

VOR/DME: VOR/DME provides users with a sole means of air navigation in the National Airspace System. DOD will phase out military support and use of VOR/DME by 1997. VOR/DME, as the international standard for civil air navigation in controlled airspace, will remain the short distance aviation navigation system well into the next century.

TACAN: TACAN is a short range navigation system used primarily by military aircraft. DOD will phase out land-based TACAN by 1997 assuming GPS, integrated with other onboard aircraft systems, proves acceptable as a sole means radionavigation system for military use in controlled airspace. Shipboard TACAN systems will continue in operation after that period.

ILS/MLS/PDME: These are precision approach systems for aircraft. MLS will replace ILS.

TRANSIT: TRANSIT is a satellite based radionavigation system operated by the DOD. It will be replaced with GPS by 1994. TRANSIT will not be operated by or transferred to a civilian agency of the U.S. Government.

GPS: GPS is a DOD developed worldwide satellite based radionavigation system that is scheduled to be operational with three dimensional coverage in 1988. The GPS Precise Positioning Service (PPS) will be restricted, due to national security considerations, primarily to the military. The GPS Standard Positioning Service (SPS) will be made continuously available to all users, worldwide, and will provide 100 meter 2 drms navigation accuracy.

AIR USE: GPS has the potential to become a sole means air navigation system for the United States. The adequate control of aircraft in national and international controlled airspace must be assured if GPS is relied upon, and those agencies with safety and operational responsibilities will determine when GPS, properly integrated with other aircraft navigation systems, is acceptable. Approval of civil navigation receivers to operate with the GPS system is initially expected to be on a supplementary system basis. Resolution of coverage and integrity issues is needed in order to certify GPS as a sole means system.

SURFACE USE: The GPS SPS, as currently proposed, provides better accuracy than the predictable accuracy of LORAN-C. It does not, however, have the capability of LORAN-C in the repeatable mode, and it cannot provide as good accuracy as LORAN-C in some locations. It is possible that some enhanced form of GPS may provide accuracy equivalent to existing systems for harbor and harbor approach areas, and for coastal and land radionavigation. Several enhancement techniques are currently being investigated.

CIVIL USER CHARGES: There should be no direct charges to civil users of GPS service. GPS costs should be underwritten through other mechanisms such as those provided for by existing statute(s).

PHASE OUT OF EXISTING SYSTEMS: It is the goal of the DOD to phase out use of TACAN, VOR/DME, OMEGA, LORAN-C and TRANSIT in military aircraft and other platforms. Civil user phase out of LORAN-C and OMEGA would be keyed to (a) resolution of GPS accuracy, coverage, integrity, and financial issues; (b) GPS meeting civil air, marine, and land needs currently met by LORAN-C and OMEGA; (c) GPS civil user equipment being available at prices that would be economically acceptable to LORAN-C and OMEGA users; (d) a transition period of 15 years; and (e) resolution of international commitments in the case of LORAN-C and OMEGA.

GPS

-- FAA actively involved since 1975

-- Full flight evaluation using Z set

-- Evaluation of coverage

24 satellite constellation
- results looked acceptable

18 satellite constellation
- inadequate for sole-means civil aviation radionavigation system

21 satellite constellation
- With certain position of satellites can provide single level coverage for contiguous U.S.A.
- Does not provide redundant coverage required for sole means

-- Evaluation of Integrity

- Not suitable for nonprecision approaches

GPS

FAA PLANS FOR GPS

- CIVIL NATIONAL AVIATION STANDARD FOR GPS
- MOPS FOR GPS
- SUPPLEMENTAL SYSTEM
- OCEANIC WITH IMU
- INTEGRITY SYSTEM
- RESOLVE COVERAGE ISSUE
- SOLE MEANS

MILITARY

- GPS WITH IMU

LORAN-C

- -- ADVISORY CIRCULAR AC 20-121 (8/23/84)
- -- RTCA SC-137 CONSIDERED LORAN-C RNAV
- -- NEW RTCA SC FOR LORAN-C
- -- FAA/USCG LORAN-C MEMORANDUM OF AGREEMENT
- -- NATIONAL AVIATION STANDARDS FOR LORAN-C
- -- LIMITED NUMBER OF LORAN-C NONPRECISION APPROACHES APPROVED FY-86
- -- GENERAL NONPRECISION APPROACH PROCEDURES APPROVAL AS REQUESTED
- -- FAA LORAN-C MONITORS FOR NONPRECISION APPROACHES
- -- COMPLETE CONTIGUOUS USA COVERAGE

U.S. CIVIL AVIATION RADIONAVIGATION SYSTEMS

My View of Future:

VOR VOR/DME NDB DME/DME	At least through life of current equipment
OMEGA	At least through 2005
LORAN-C	At least through 2010
GPS	Through 2020?

Then What?

(New CNS Satellite System?)

Expanded Use of Loran-C
for
Aviation Purposes - State Involvement

By

Paul E. Burket
Chairman, NASAO Loran-C Task Force
and
Administrator, Oregon Aeronautics Division

Abstract

Beginning with the Vermont project in 1979-81, state aviation and transportation agencies have developed an ever-increasing interest and involvement in expanding the utilization of Loran-C for aviation. Because of the perceived potential for "opening up" the national system of airports for increased accessibility by the aviation community, the states' strongest interest presently lies in two areas:

1. Accelerating the availability of Non-Precision Approach Procedures
2. Closing the "Mid-Continent Gap".

This paper reviews the present status of the NPA Implementation Program and the development of a partnership of Federal, State and Private entities that helped bring it into being.

Background

The long-range radionavigation system has been around and in use for many years, although not precisely as we know it today. Beginning in World War II, primarily as a means for maritime navigation, it saw some limited use in military aviation for overwater navigation. However, the degree of accuracy and the effective signal range in those early years left much to be desired.

Results of work done by the U. S. Coast Guard, other government agencies and equipment manufacturers, to expand and refine the system in the 1970's began to show considerable promise for aviation applications. This led to interest and activity by some manufacturers of marine receivers to develop that equipment, through miniaturization and improved design, to make it more suitable for use in aircraft. As more lightweight compact receivers became available, and more and more general aviation aircraft owners became aware of their relatively low cost and usefulness for enroute navigation, the market demand began to expand at an almost explosive rate.

Installation and use of Loran in aircraft has been estimated to involve anywhere from 20% to 35% of the active domestic general aviation fleet, depending on the area of the country.

The reasons for such rapid and enthusiastic growth in usage are relatively simple:

- The Loran system is already in existence with good coverage in most of the conterminous United States.
- The overall system is continuously broadcasting signals that are usable for air navigation.
- Equipment required in aircraft is relatively low cost.
- It works and is easy to use!

Purpose

It is not the purpose of this paper to examine the technical aspects of the system in any degree of detail but rather to review the evolving process of increasing involvement of state government in an active partnership with the Federal Aviation Administration (FAA) in working with other federal agencies and private entities toward two current major objectives:

1. To speed up the development and availability of Loran-C non-precision approaches.
2. Installation of additional transmitters to effectively close the midcontinent gap.

The principal parties involved, including a growing segment of the general aviation community, are convinced that these objectives can and should be reached over a relatively short time span. Furthermore, any terminal approach/departure procedures developed for use with Loran are seen as being readily transferable to the Department of Defense backed satellite

Global Positioning System (GPS) when it becomes available to civil aviation.

More About FAA/NASAO Partnership

The National Association of State Aviation Officials (NASAO), through its member state aviation agencies has long recognized a need, indeed a responsibility, to encourage and support the expansion of instrument approach capabilities at airports throughout the nation. The number of these procedures available at public-use general aviation airports is woefully low. In large part, this is due to the relatively high cost of the conventional facilities required and the low priority placed on their installation because of low cost effectiveness at most of the low activity airports. It is also widely recognized that many elements of the present system of electronic navigational, radio communication networks, air traffic control and instrument approach facilities are old, outdated and expensive to maintain.

We recognize that the current National Airspace System Plan (NASP) and the existing Airport and Airway Improvement Act are intended to correct these problems. However, we feel that previously stated time frames for implementation of those items under discussion might well be improved. The states believe that development of Loran approach procedures can and should be accelerated to provide expanded approach capabilities for the nation's system of airports. This would provide for increased utilization of aviation and benefit the national economic health as well. To these ends, several state aviation agencies began some time ago to work closely with the Federal Aviation Administration on this issue and to ask FAA what could be done to speed things up.

In the forefront of this cooperative effort was a two-year project in Vermont to evaluate the technical and operational suitability of Loran-C RNAV for use in areas where traditional VOR/DME coverage is marginal and at airports where it is either uneconomical or technically difficult to install Instrument Landing Systems. Teamed in this effort were the State of Vermont's Agency of Transportation and the FAA's Technical Center who were responsible for flight operations; NASA's Langley Research Center and the U. S. Department of Transportation's Transportation Systems Center, who were responsible for operation of ground monitor facilities, data reduction and evaluation, and reports. The conclusion reached was that "the Loran-C RNAV system can meet published FAA criteria for use in the National Airspace System under both VFR and IFR conditions."[1]

As Loran-C grew more popular with the general aviation community and the system's capabilities became more widely known, more individual states became involved in contacts with high FAA officials. Following in Vermont's footsteps, and citing the results of the Vermont evaluation project, Massachusetts, Ohio and Oregon began asking the FAA what they

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[1] From a paper titled "Operational and Economic Benefits Deriving from Use of Loran-C RNAV" presented by William L. Polhemus (Project consultant to the Vermont Transportation Agency) to the Institute of Navigation at Annapolis, Maryland, June 1981.

could do to speed the implementation of Loran-C instrument approach procedures. Several months of such efforts, coupled with follow-on work by key officials in the FAA and the Transportation Systems Center, culminated in formulation of a program to evaluate signal reliability and integrity of the Loran system on a broader scale but in a shorter time frame than previously proposed. With strong support from the new FAA Administrator, Admiral Donald D. Engen, a limited implementation program began to materialize this year involving seven runways in five different states which were fairly well distributed across the country. (Oregon, Texas, Ohio, Massachusetts and Vermont)

TABLE 1

Phase I Development Program - Monitor Installations

	Location	Runway
Massachusetts	Bedford (Hanscom)	11
Ohio	Mansfield	32
Ohio	Columbus (Ohio State University Airport)	09R
Oregon	Portland (Portland International)	10R
Oregon	Salem (McNary)	31
Texas	Port Arthur/Beaumont (Jefferson County)	12
Vermont	Burlington	15

Planning/Work-Group and NASAO Task Force

To assist in coordinating and executing this "Phase I Implementation Program", a coalition of the key people involved was brought together for the first time in a meeting hosted by the Ohio Division of Aeronautics at their facilities on the Ohio State University campus at Worthington, Ohio in February 1985.

> It should be noted here that the Avionics Engineering Center of Ohio University, under the able leadership of Dr. Robert Lilley, has certainly been in the vanguard of work done over the last five years to develop the use of Loran for non-precision approaches. In a joint University program with Princeton and MIT, which was sponsored by NASA and FAA, Ohio University made a major contribution by designing and flight testing a Loran receiver specifically for use in aircraft. In a follow-on project funded by the State of Ohio, Department of Development, through the Aviation Safety Institute, the Avionics Engineering Center completed a study last summer involving measurements of the availability of Loran signals at Galeon, Ohio. More recently, the State of Ohio, Department of Transportation, through its Aviation Division, has provided half of the funding for installation of a monitor that is now in operation at Galeon. The other half of the funding for this one-year study came through the U. S. Department of Transportation's Transportation Systems Center.

The "Planning/Work-Group", with its somewhat diverse but relatively small membership, functions as a coordinating body for the Non-Precision Approach

Implementation Program.[2] The Group has held a series of three meetings thus far and plans to meet three or four times each year, or as the need exists, with the next meeting set tentatively for November 19-20, 1985 at the Transportation Systems Center in Cambridge, MA. Meeting number two was held in Washington, D. C. April 9-10, 1985 and hosted by John Kern, Director of the FAA Office of Flight Operations (AFO-1), FAA Hq., and his staff at their Hangar 6 facility on Washington National Airport. It should be noted that Mr. Kern has provided especially strong leadership and support throughout the program and his efforts are appreciated by all concerned.

Group meeting number three was hosted by NASAO at its facilities in downtown Washington, D. C. This meeting took place July 24, 1985. In the writer's opinion the meetings thus far must be characterized as enthusiastic and productive work sessions. They have provided an excellent forum for questions, comments and discussion of problem areas and important issues that need to be dealt with as we move forward into the Phase I Implementation Program, and beyond. Also at this meeting, a July 22, 1985 memorandum was made public wherein FAA Administrator Engen announced the key members of the FAA project team and the roles assigned to each. (Appendix B)

As a subelement of the Work-Group, a NASAO Loran-C Task Force, presently comprised of the State Aviation Directors from eight states, was sanctioned by NASAO President Clay Wilkins (Texas) and activated by the NASAO Standards Council Chairman Arnold Stymest (Massachusetts). (See Appendix C for membership of Task Force.)

The NASAO Task Force was formed as an outgrowth of the initial Work-Group meeting in Ohio and, as half of the FAA/State partnership, fulfills an "interface" and coordinating function with all of the entities involved in the Loran Phase I Implementation Program. This includes, but is not limited to, the FAA/DOT and other federal agencies such as the U. S. Coast Guard, as well as other interested states, Congressional members and their staffs, equipment manufacturers, consultants, users and user groups in the aviation community, aviation publications and other news media.

Flight Demonstrations

As an adjunct to the July 1985 meeting of the Work-Group and guest observers, a flight demonstration program was conducted to familiarize participants with the capabilities of Loran-RNAV. The program was co-sponsored by the NASAO Loran-C Task Force and Northern Airways, Inc. of Burlington, Vermont with assistance and significant support from Advanced Navigation, Inc.; Offshore Navigation, Inc.; II Morrow, Inc.; Polhemus Associates, Inc. and RACAL-Megapulse, Inc.

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[2] Interests represented at the initial meeting: FAA (several key individuals from Washington, DC Headquarters and Flight Procedures Branch); U. S. Coast and Geodetic Survey; U. S. Coast Guard; Wild Goose Association; Ohio University; State Aviation Agencies (representing their own states and the National Association of State Aviation Officials). Please see Appendix A for detailed listing.

Using a DC-3 aircraft and crew supplied by Northern Airways, nine one-hour flights were conducted in the Washington, D. C. area on three different days during the period July 23 through July 26, 1985. A total of 105 guest passengers were carried on a circuitous route that included non-precision Loran approaches to the Manassas, Virginia and Washington National Airports. Participants included personnel from DOT/FAA and other federal agencies, state aviation agencies, Congress, various aviation organizations and publications and other interested parties. (Appendix D shows a list of guest participants and the primary flight-crew members.)

The aircraft was equipped with three ANI/ONI-7000 Loran receivers (one in the cockpit and two in the passenger compartment), as well as a II Morrow vehicle tracking system (VTS). The latter consisted of a panel-mounted 19" video display tube driven by the output from its associated Apollo II receiver. The VTS displayed Loran flight data on the left side and a variable-scale, three-color map of the Washington area on the remainder of the screen.

A symbol depicting the aircraft and leaving a visible trace on the screen provided an impressive means for passengers to track the progress of the aircraft throughout the flight. This enabled participants to observe and verify the accuracy of Loran guidance and generated numerous positive comments.

All flights operated out of FAA's Flight Operations Section in Hangar 6. Each flight group followed a tightly scheduled routine which contributed to the smooth flow of events and the overall operational success of the demonstration program. Only one flight out of ten scheduled had to be canceled and that was due to a heavy rainstorm at Washington National while the aircraft was airborne causing it to land at Manassas.

The routine for each flight began with a short pre-takeoff briefing presented by Paul Burket and Bill Polhemus in the VIP briefing room and ended with a very short debriefing at the same location. Participants were then invited to observe the manufacturers' Loran equipment on display upstairs in the hangar and visit with their representatives who were present to explain their gear and answer questions.[3]

All sponsors involved with the demonstration are highly appreciative of the outstanding support and cooperation provided by hangar manager, Bernie Batchelder, and his staff. Their efforts contributed a great deal toward making it a success.

Summary

State transportation and aviation agencies recognize the important role that individual states and the NASAO as a whole can and should play as partners of the FAA in expanding and accelerating development of the use of Loran in aviation applications. Individually and collectively, we accept that responsibility and look forward to a continuing cooperative

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[3] Companies with equipment on display were: II Morrow; ARNAV; Texas Insruments; ANI/ONI and RACAL-Megapulse.

relationship with all involved entities to achieve our mutual objectives of progress in aviation and a healthy national economy.

We are indeed encouraged by the positive and productive attitudes that have developed and prevailed among all parties involved in the Phase I Implementation Program, in government and private sectors alike.

The writer is convinced that if present approaches and efforts are continued with appropriate and adequate funding authorization by the Congress, our entire national transportation system will realize tremendous benefits that will ultimately accrue to those who use it.

APPENDIX A

INITIAL MEETING OF LORAN-C PLANNING/WORK GROUP
February 21 and 22, 1985
Worthington, Ohio

NAME	ADDRESS
Jerry Bradley	FAA/AES-310 800 Independence Avenue SW Washington, DC 20591 Tel: (202) 426-8452
Kent Brooks	Ohio University, Consultant Avionics Engineering Center % Dr. Robert Lilley Room 329, Clippinger Lab Athens, OH 45701-2979 Tel: (614) 262-8494
Paul E. Burket	Oregon Aeronautics Division 3040 25th Street SE Salem, OR 97310 Tel: (503) 378-4880
David Cencula	Ohio Department of Natural Resources Flight Operations 2829 West Dublin-Granville Road Worthington, OH 43085 Tel: (614) 265-6565
John Cornett Norm Crabtree David Dennis	Ohio Department of Transportation Division of Aviation 2829 W. Granville Road Worthington, OH 43085 Tel: (614) 466-7120
John B. Galipault	Aviation Safety Institute Box 304 Worthington, OH 43085-0304 Tel: (614) 885-4242
John S. Kern	FAA/AFO-1 800 Independence Avenue SW Washington, DC 20591 Tel: (202)426-8237
Robert W. Lilley	Avionics Engineering Center Room 329, Clippinger Lab Athens, OH 45701-2979 Tel: (614) 594-5263

Appendix A (Continued)

NAME	ADDRESS
Chick Longman	FAA/AFO-210 800 Independence Avenue SW Washington, DC 20591 Tel: (202) 426-8452
James R. McCullough	U. S. Coast & Geodetic Survey Crawford Law WHOI Woods Hole, MA 02543 Tel: (617) 548-4678
Edward L. McGann	Wild Goose Association c/o RACAL-Megapulse, Inc. 8 Preston Court Bedford, MA 01730 Tel: (617) 275-2010
William L. Polhemus	Polhemus Associates, Inc. P. O. Box 5 Cambridge, VT 05444 Tel: (802) 644-5569
George Quinn	FAA/APN-410 800 Independence Ave. SW Washington, DC 20591 Tel: (202) 426-1944
Jim C. Savage	FAA/AVN-210 Box 25082 Oklahoma City, OK 73125 Tel: (405) 686-4164
Tomas J. Thomas	Wisconsin Bureau of Aeronautics P. O. Box 7914 Madison, WI 53707 Tel: (608) 266-3351
LCDR Bill Thrall	US Coast Guard Headquarters (G-NRN-1) 2100 2nd Street SW Washington, DC 20593 Tel: (202) 755-1515
Gary Wirt	FAA/AVN-200 Box 25082 Oklahoma City, OK 73125 Tel: (405) 686-2766

APPENDIX B

Key Members of the FAA Project Team and Their Roles*

NAME	ROLE
John Kern, AFO-1	FAA/NASAO and AVS program coordination
George Quinn, APM-420	Overall FAA program coordination
Chester 'Chick' Longman, AFO-210	User certification criteria development
Don Funai, AFO-230	Instrument approach procedure policy
Gary Wirt, AVN-201	Instrument approach procedure development and flight inspection arrangements
Robert Dye, ATO-320	Air traffic coordination
Paul Burket Administrator, Oregon Aeronautics Division	NASAO task force leader
Mike Moroney, DTS-52	Loran-C monitor installation coordination

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*Extracted from a memorandum from Administrator Engen to "All Regional Directors" dated July 22, 1985.

APPENDIX C
1985 NASAO LORAN-C TASK FORCE MEMBERS

STATE	NAME AND TITLE
Massachusetts	Arnold R. Stymest, Executive Director Massachusetts Aeronautics Commission 10 Park Plaza, Room 6620 Boston, MA 02116-3966
New Mexico	Bob White, Director New Mexico Aviation Division P. O. Box 579 Santa Fe, NM 87504-0579
Ohio	Norman Crabtree, Deputy Director Ohio Division of Aviation 2829 West Granville Road Worthington, OH 43085
Oregon	Paul E. Burket, Chairman, Loran-C NASAO Task Force and Administrator Oregon Aeronautics Division 3040 25th Street SE Salem, OR 97310
South Dakota	James R. Kastner, Director of Planning South Dakota Dept. of Transportation 700 Broadway Ave. East Pierre, SD 57501-2585
Texas	C. A. (Clay) Wilkins, Executive Director Texas Aeronautics Commission P. O. Box 12607 Austin, TX 78711
Vermont	Robert L. Merchant, Director of Operations Vermont Operations Division State Administration Building 133 State Street Montpelier, VT 05602
Wisconsin	Frederick Gammon, Director Wisconsin Bureau of Aeronautics P. O. Box 7914 Madison, WI 53707
Technical Consultant	Bill Polhemus Polhemus Associates, Inc. PO Box 5 Cambridge, VT 05444
Ex-Officio Member	Robert T. Warner, Executive Vice Pres. NASAO 777 14th Street NW, Suite 717 Washington, DC 20005

APPENDIX D

LORAN-C DEMONSTRATION FLIGHT PARTICIPANTS

Flight 5

Joan Bauerline, FAA Hq, AFO-1, Office of Flight Operations
John C. Cittadino, DOD, Director, Tactical, C^3
M. Cynthia Douglas, DOT, Admin. Research & Special Programs Administration
Admiral Donald D. Engen, Administrator, FAA Hq., AOA-1
Hal Findlay, President, Northern Airways, Inc.
John Heubusch, Office of Congressman Denny Smith
Jack K. Johnson, Chief, Florida Bureau of Aviation
Jim Kelly, The Analytic Sciences Corp.
John S. Kern, FAA Hq., AFO-1, Director, Office of Flight Operations
Mike Moroney, DOT, DTS-52, Manager, Center for Navigation
Dawson Ransome, President, Ransome Airlines
Louis Roberts, DOT (RSPA/TSC), DTS-1, Director, Center for Navigation
Denny Smith, U. S. Representative, Mbr. Budget-Interior & Insular Affairs
Don Wallace, Director of Air Services, Ontario Northland (norOntair)
Robert E. Whittington, FAA, ANE-1, Director, New England Regional Office
Admiral Ted Wojnar, Chief, Navigation Branch, US Coast Guard

Other Flights

A. P. Albrecht, FAA Hq. ADL-1, Asso. Admin. Development & Logistics
Henry Alexander, FAA, Air Traffic Control Tower
Carl Andren, RACAL-Megapulse
Glenn A. Bales, Jr., FAA, AEA-530, Eastern Region, Mgr. Airspace and Procedures Branch
Neal A. Blake, FAA Hq. ADL-2A, Deputy Assoc. Administrator, Engineering
Jim Bland, Director of Airports, Virginia Dept. of Aviation
Dick Bowers, Air Transport Association
Ellen Bowie, FAA HQ., AFO-806, Accident Prevention Staff, Office of Flight Operations
Jerry Bradley, FAA HQ AES-310, Systems Studies/Advanced Concepts Division
Ed Bregstone, GTES-4, U. S. Coast Guard
Robert Bronson, Vice President, II Morrow
Kent Brooks, Ohio University, Consultant, Avionics Engineering Center
Eugene (Gene) L. Burdick, FAA, AEA-201, Eastern Region, Asst. Mgr. Flight Standards Division
Paul E. Burket, Chairman, NASAO Loran-C Task Force and Administrator, Oregon Aeronautics Division
Joseph E. Burnside, National Business Aircraft Assoc., Inc.
Jack Clifford, US Dept. of Commerce, Office of Micro Electronics
Lou Davis, Sr. Editor, AIR TRANSPORT WORLD
Walt Dean, ARNAV, Inc.
Bev Draughon, National Air Transport Association
Ralph Dukette, FAA, Air Traffic Control Tower
Phyliss Duncan, FAA, GENERAL AVIATION NEWS
Robert Erikson, FAA ACT-140, Technical Center
Tim Feinstein, Office of Congressman Judd Gregg
Perry Flint, COMMUTER/REGIONAL AIRLINE NEWS
Victor Foose, FAA Hq., ADL-5, Technical Liaison Staff

Norman T. Fujisaki, FA HQ., APM-720, Mgr. Helicopters Program Branch
Donald K. Funai, FAA Hq., AFO-230, Mgr. Flight Procedures Standards Branch
LCDR Lee Gazlay, USCG, Chief, Radio Navigation Information Branch
George A. Hendon, III, FAA, AEA-8, Eastern Region, Mgr. Aviation Consumer Affairs Staff
Dashwood Hicks, Jr., House Subcommittee on Transportation, Aviation & Materials
Dave Higdon, Commuter/Regional Editor, AIR TRANSPORT WORLD
Tim Hillard, Washington Bureau Chief, Fisher Broadcasting Company
William C. Hoffman, President, Flight Transportation Association
Gerard Holtorf, FAA ANE-223, New England Region Hq.
Walter Houghton, Director of Airports, Burlington International Airport
Kenneth S. Hunt, FAA Hq., AVS-2, Act. Dep. Assoc. Admin. for Aviation Standards
Zeke Jackson, FAA Hq., APM-420, Navigation Programs Branch
Dale Johnson, Asst. to President, II Morrow
Herb Johnson, Offshore Navigation, Inc.
Rudolph Kalafus, Transportation Systems Center, Center for Navigation
Ed Krawiec, FAA, AEA-220, Eastern Region
Cmdr Jack Lang, US Coast Guard Headquarters
Lt. Cmdr. Stan Lehman, US Coast Guard, Governor's Island
Robert Lilley, Ohio University, Assoc. Director, Avionics Engineering Ctr.
Dale Livingstone, FAA Technical Program Mgr., Technical Center
Chester Longman, FAA Hq., AFO-210, Flight Technical Programs Branch
William Lowry, FAA, ANE-462, New England Reg. Facilities Operations Br.
George Lyddane, FAA, ANM-104N, Aircraft Certification Division
Linda Mancini, FAA Hq., AVN-6, Hangar 6, Washington National Airport
Judy Marriott, Northern Airways, Inc.
Keith McDonald, FAA Hq., AES-310, Program Management Staff
Al McDonough, FAA, Programs Manager, Helicopters
Ed McGann, RACAL-Megapulse
John McKeever, U. S. Coast Guard
Robert L. Merchant, Director of Operations, Vermont Agency of Transp.
Norman Y. Mineta, US House of Representatives
Tom O'Brien, FAA Hq., APM-401, Navigation & Landing Division
John Ogden, FAA HQ., AVN-6, Hangar 6, Washington National Airport
Joseph Ortega, Systems Control Technology
Duane Orth, Texas Instruments, Inc.
Mark Patiky, Executive Editor, PROFESSIONAL PILOT
William L. Polhemus, Polhemus Associates, Inc.
John Pope, AVIATION CONVENTION NEWS
Alan Porfert, FAA, ANE-153, New England Reg. Systems & Propulsion Branch
Sid B. Poritsky, FAA Hq., ADL-30, Technical Liaison Staff
Thomas Quinlan, FAA Hq., AFO-230, Flight Procedures Standards Branch
Larry Reid, FAA Hq., APM-401, Navigation & Landing Division
Lex Reis, Cameraman, Fisher Broadcasting Company
Stanley Rivers, FAA, ANE-400, New England Region, Mgr., Airway Facilities
Kenneth A. Rowe, Director, Virginia Department of Aviation
Dave Salmon, Aircraft Owners & Pilots Association
Jimmie Savage, FAA Hq., AVN-210, Manager, Standards Development Branch
Dave Schaffer, Minority Staff, Aviation Subcom. House Public Works & Trans.
David Scull, DOT, RSPA, Program Manager, Communications and Radio Navig.
John J. Sheehan, AOPA, Sr. Vice Pres. Government & Public Affairs
William T. Sheppard, FAA Hq., Office of Aviation Medicine

Harriet Smith, Minority Staff, Science & Technology Committee
William J. Southerland, Jr., FAA Hq., AAS-300, Safety & Compliance Division
Steven D. Thompson, ARINC Research Corp.
Bob Thurber, Aviation Subcomm. House Public Works & Transportation Comm.
Matt Thurber, Asst. Editor, FLYING MAGAZINE
Rober Till, FAA, ACT-140, Technical Center
Jimmie Toms, President, Advanced Navigation, Inc.
Gary Travis, FAA Hq., Air Traffic
David Underwood, Contributing Editor-Avionics, CANADIAN AVIATION MAGAZINE
Tirey Vickers, Editor, JOURNAL OF AIR TRAFFIC CONTROL
Robert T. Warner,, Executive Vice President, NASAO
Robert W. Wedan, FAA Hq., ADL-20, Manager, Evaluation Staff
William Weeks, FAA Hq., APM-420, Navigation Program Branch
Bill Whittle, FAA, Washington, DC Airports District Office
William H. Williams, FAA, ANE-200, New England Reg. Flight Standards Div.

Flight Crew

Norris Leclair, Northern Airways, Inc.
Chuck Polhemus, Northern Airways, Inc.
Ralph Prescott, Director of Operations, Northern Airways, Inc.

BIOGRAPHICAL INFORMATION

PAUL E. BURKET - ADMINISTRATOR
AERONAUTICS DIVISION
OREGON DEPARTMENT OF TRANSPORTATION
AND
CHAIRMAN, NASAO LORAN-C TASK FORCE

Appointed by Oregon State Board of Aeronautics October 1, 1972, and reappointed by Director of Department of Transportation July 10, 1973.

Held office of President, National Association of State Aviation Officials for 1977 and is a fully accredited Executive member of American Association of Airport Executives.

Prior to coming to Oregon was Director of Nebraska Department of Aeronautics for two years - and for 4 years prior to that was Assistant Director of Lincoln, Nebraska Airport Authority.

Before joining Lincoln Airport Authority completed 22 years active duty U. S. Air Force as pilot and staff officer. Presently holds a commercial pilot's license, with single and multi-engine, instrument and helicopter ratings, and has over 5,000 hours flying time as a pilot.

Completed undergraduate work and received degree as Bachelor of General Education from University of Omaha in January, 1966.

LORAN C FOR NONPRECISION APPROACHES

Chick Longman
FAA Office of Flight Operations
800 Independence Ave. SW
Washington, DC 20591

ABSTRACT

The FAA has initiated a limited implementation program to permit nonprecision instrument approaches using LORAN C navigation. The procedures, controls and limitations of this program are described with a plan to issue standard criteria for general implementation in the future.

Background information about the use of earth referenced navigation for general instrument operations in the National Airspace System and about the design of instrument approaches are included.

INTRODUCTION

LORAN C is far and away the fastest growing radionavigation system in aviation. Since 1980, in spite of FAA reluctance to accept the system, nearly 50,000 aircraft have entered the LORAN C user community. Rotorcraft and general aviation operators have been pressing the FAA and Congress to further expand the role of LORAN for aviation.

For most aviation operations LORAN is limited to Visual Flight Rules(VFR). During the past three years Instrument Flight Rules(IFR) enroute operations have been conducted by an increasing number of users. A very small number of rotorcraft have also been approved for instrument approaches to oil rigs in the Gulf of Mexico using LORAN and an airborne mapping radar.

Effective this month the FAA, working closely with the National Association of State Aviation Officials(NASAO), has initiated a limited implementation of LORAN C nonprecision approaches. It is my purpose today to tell you about this program and our general concerns about the use of LORAN as a primary navigation system for all phases of aircraft operations.

EARTH REFERENCED COORDINATE SYSTEMS IN THE NAS

The first issue I want to discuss is the use of earth referenced coodinates such as latitude and longitude as opposed to the traditional station referenced position descriptors.

Our experience with earth referenced systems has been good. OMEGA and Inertial Navigation Systems(INS) are used for most long distance over water and some high altitude domestic operations. They are normally flown with specially trained flight crews in low density airspace. Accidents still happen.

Latitude and Longitude are a poor language at the man/machine interface. Both pilots and air traffic controllers are exposed to extra error opportunities when such a language is used. We are working in several arenas to develop high integrity procedures to overcome the limitations of this language.

Among these arenas are:

RTCA	SC-155	-	Future Air Navigation Systems(FANS)
	SC-157	-	User Selectable Databases
	SC-158	-	LORAN C MOPS

- GPS Phase-in Steering Committee
- FAA National Airspace Systems Planning Groups
- ICAO FANS Committee

In addition to the human factors of the language we are also concerned about the accuracy of geodetic surveys and the datum system used. A chart or map with coordinates based on North American Datum 1927(NAD-27) may not be compatible with a navigation system which uses World Geodetic Survey 1984(WGS-84). To be safe and effective all elements of the system must use a common reference.

The role of LORAN in the next decade and the next century will become clearer as the various study groups complete their efforts. It does seem clear that earth referenced systems will become more common and perhaps dominate navigation in the future. How best to enhance the NAS to safely accommodate such systems in one of our major challenges.

INSTRUMENT APPROACH PROCEDURE DESIGN

There are several steps required to issue an Instrument Approach Procedure. Many of these steps are independent of the navigation system used to support the approach.

The first step is allocating airspace. Partitioning the airspace can be described in many ways. Controlled versus uncontrolled; VFR versus IFR; Enroute, Terminal and Approach. For the purposes of discussing instrument approaches it is sufficient to recognize that aircraft must be able to descend safely below the height of geographic and manmade obstacles near the airport along a path that will be clear of other aircraft. A Standard Instrument Approach Procedures(SIAP) describes such a flight path.

Allocating airspace for a SIAP is, therefore, defining the boundaries of controlled airspace needed for the procedure. This may require elimination of some uncontrolled airspace or may merely involve the restructuring of existing controlled airspace. In either case rulemaking action is required. This involves the preparation of environmental impact statements and other supporting documents and a public comment opportunity.

The second step, usually accomplished concurrent with the first, is a comprehensive survey of the airport and nearby obstacles.

The third step is defining the desired flight path from one or more Initial Points to a Final Approach Fix(FAF) to a Missed Approach Point(MAP). The bible for this step is the Terminal Procedures Handbook(TERPS). The criteria in TERPS assure that the average pilot flying on instruments using the poorest approved navigation system is protected from obstacles and placed in a position from which a normal landing can be made. The dimensions of the protected airspace are based on the quality of the navigation and the Flight Technical Error(FTE)

Figure 1 illustrates how several aircraft actually track over the ground when the navigation quality is essentially perfect. This dispersion is the FTE and is often the controlling factor on the amount of airspace required.

With this limited background and the illustration it should be clear why a SIAP may not be possible when an airport is surrounded by obstacles.

The fourth step in the SIAP process is charting and publication. For public use approaches the charting and publication are done by the National Oceanographic Survey(NOS). For special approaches the user arranges for the charting through commercial companies such as Jeppesen Sanderson.

Finally there is the quality control process. This begins in step one and continues for the life of the procedure. Included in this process are commissioning and periodic flight inspection.

FAA/NASAO IMPLEMENTATION PROGRAM

In February official of FAA and NASAO met in Columbus, OH and defined a limited program to implement LORAN C nonprecision approaches at eight airports. Two additional meetings were held this summer to refine the original plan and to assess progress. The next meeting is scheduled in December at the Transportation Systems Center in Cambridge, MA.

The sites selected for the program are in six states which have been pressing hard for LORAN C. They will involve four different LORAN C chains, have differing signal to noise characteristics and widely varying GDOP. Each runway used in the limited program already has a conventional instrument approach which will be used as a reference for the operation.

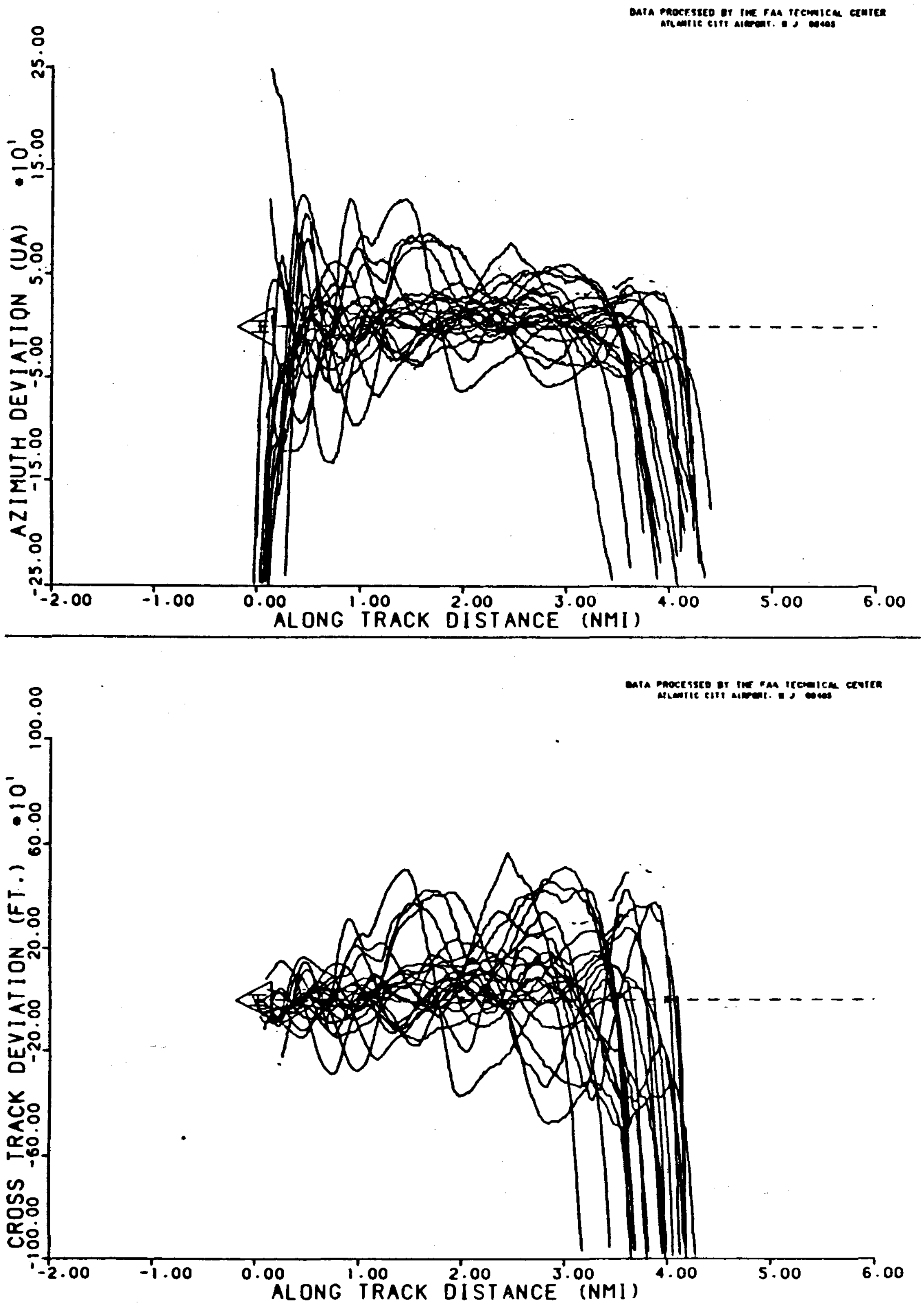
The selected sites are:

Bedford, MA, Hanscom	Runway 11
Burlington, VT	15
Mansfield, OH	32
Columbus, OH, OSU	9R
Portland, OR	10R
Salem, OR, McNary	31
Orlando, FL, Executive	07
Port Arthur, TX - to be replaced due to poor GDOP	

Special LORAN C signal monitors with remote status indicators are being established at each of the selected airports. A remote status indicator is located at the ATC clearance delivery point for each approach. Details about this monitor and the database we hope to attain during the program will be described in other papers being presented at this meeting. Six of the eight monitors are installed and operating. The other two will be installed by the end of the year.

The initial criteria for user participation include some limitations. Two pilots are required. This permits a cross check between the LORAN and the reference approach aid at two points during the approach. A special receiver test is required. The FAA Technical Center will validate that each receiver type approved for approach operations has 10 second flag-alarm integrity. They will also verify that manual station selection and time difference calibration is possible from the control panel.

Potential participants have been identified for each of the sites. Qualification testing is in progress for several of these users and we expect to have several flying before the end of the year.



FLIGHT TECHNICAL ERROR SAMPLE

FIGURE 1

October 27, 1985 should be a never forgotten date in the history of the Wild Goose Association. The first LORAN C instrument approach became effective on that day. Figure 2 is the approach plate for this historic achievement. Similar approaches for Burlington, VT and Columbus, OH have also been issued.

On November 4 the FAA Administrator, aviation officials from Massachusetts and Vermont and many other dignitaries will inagurate this instrument approach at Bedford, MA. A Beech Kingair owned by the Sprague Electric Co. will receive airworthiness and operational approval to conduct LORAN C instrument approaches. The FAA Administrator will participate in the first approach in the Sprague aircraft.

We believe this program illustrates how federal, state and industry cooperation can produce results. A February meeting results in approved approaches in November.

On behalf of FAA, I want to offer a special thanks to Mr. Paul Burkett, Chairman of the NASAO LORAN C nonprecision approach Committee, and Bill Polhemus for their support during this effort. As they have noted during this meeting, the FAA Administrator and Mr. John Kern, Director, Office of Flight Operations, have led the FAA effort. Among the many contributors to the effort are Ohio University, Transportation Systems Center, FAA Technical Center, FAA Aviation Standards National Field Office, Megapulse, George Quinn, and numerous FAA, State and local officials.

FUTURE OPTIONS

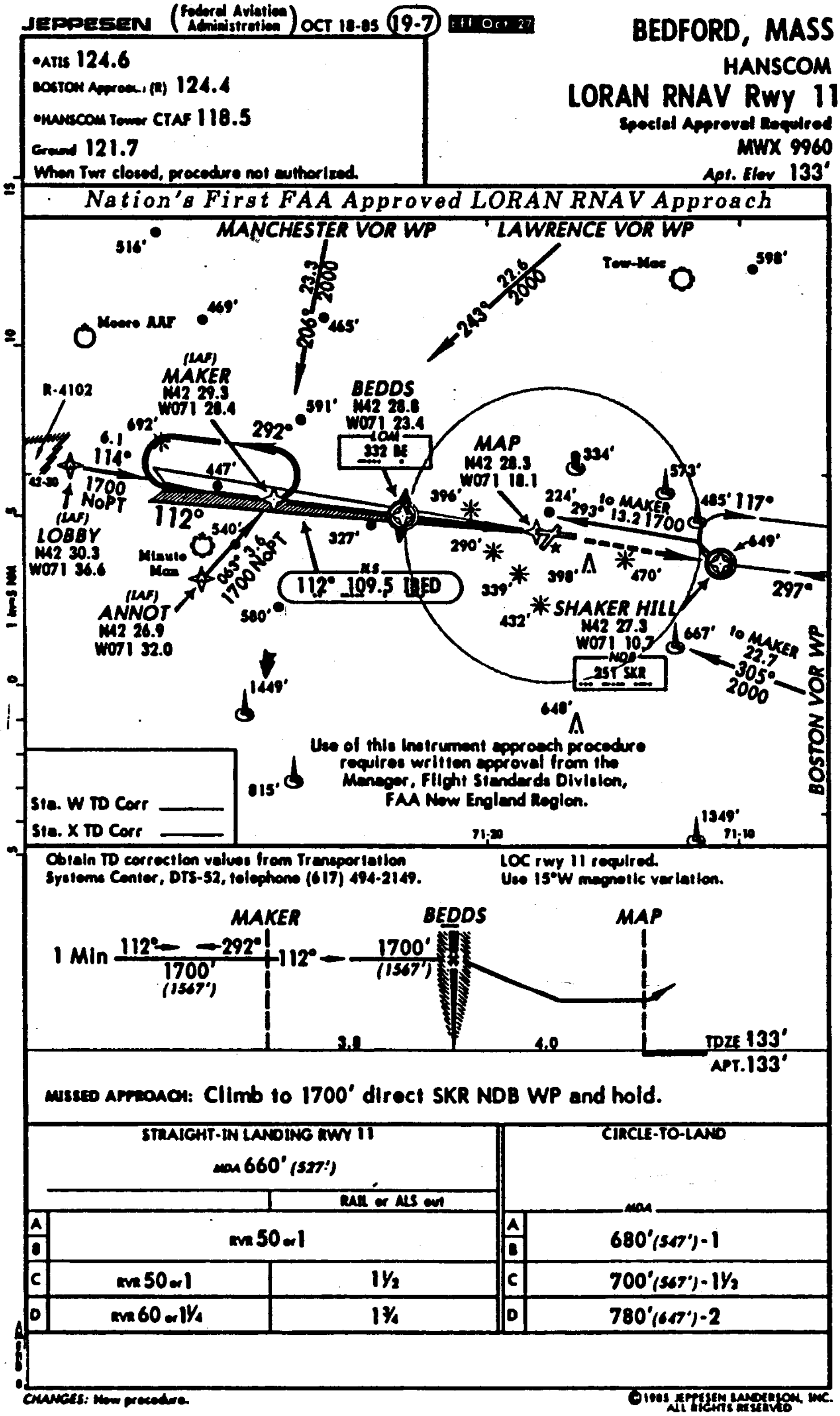
The next big hurdle is how to proceed with general implementation in 1987. The FAA is already committed to the Microwave Landing System(MLS). Where we have had an average of 10 to 12 new starts each year with the Instrument Landing System, we are faced with 100-150 new starts with MLS. We didn't get an increase in the number of procedures specialists for this. Adding 150-300 new starts for LORAN C is, therefore, impossible.

Discussions are being held about establishing a new type of delegated option. Our success with Designated Engineering Representatives, Certified Flight Instructors, etc. leads us to believe that a Designated Procedures Specialist may be possible. This would provide states, airport operators, and aviators a source of expertise which they could hire to accomplish most of the work to establish instrument approaches. From a Federal sense it would significantly reduce the cost of LORAN C approaches and thus raise their benefit/cost ratio.

This type of solution will be a subject during our 1986 meetings with NASAO and other industry groups.

At the same time we must maintain an awareness of other efforts in the radionavigation world. In the United States the implementation of GPS is expected. Internationally, ICAO is studying the whole of future communications, navigation and surveillance.

One thing is clear. Earth referenced navigations systems are growing in number and importance. We must learn to use them safely and effectively. LORAN is a chance to practice with these systems. When GPS is in common useage we'll be in a real game.



JEPPESEN (Federal Aviation Administration) OCT 18-85 (19-7) Eff Oct 27

BEDFORD, MASS

HANSCOM

LORAN RNAV Rwy 11

Special Approval Required

MWX 9960

Apt. Elev 133'

•ATIS 124.6

BOSTON Approach (R) 124.4

•HANSCOM Tower CTAF 118.5

Ground 121.7

When Twr closed, procedure not authorized.

Nation's First FAA Approved LORAN RNAV Approach

Use of this instrument approach procedure requires written approval from the Manager, Flight Standards Division, FAA New England Region.

Sta. W TD Corr ______

Sta. X TD Corr ______

Obtain TD correction values from Transportation Systems Center, DTS-52, telephone (617) 494-2149.

LOC rwy 11 required.
Use 15°W magnetic variation.

MISSED APPROACH: Climb to 1700' direct SKR NDB WP and hold.

	STRAIGHT-IN LANDING RWY 11 MDA 660' (527')			CIRCLE-TO-LAND MDA
		RAIL or ALS out		
A B	RVR 50 or 1		A B	680'(547')-1
C	RVR 50 or 1	1½	C	700'(567')-1½
D	RVR 60 or 1¼	1¾	D	780'(647')-2

CHANGES: New procedure.

FIRST LORAN C APPROACH CHART

FIGURE 2

BIOGRAPHICAL INFORMATION

Chick Longman
Navigation Systems Specialist
For
Flight Operations
FAA - Washington, D.C.

Radio Engineering graduate from Valpariso Technical Institute. Advanced studies in physics and math at Oklahoma City University.

Twentynine years experience with FAA directly associated with avionics instrumentation of FAA flight inspection aircraft including ten years as the Manager, Avionics Engineering.

Five years staff association with FAA Office of Flight Operations including past two and one-half years in present position where he actively deals with MLS, Loran-C and GPS.

LORAN-C RNAV In The Ontario Airspace Plan

William L. Polhemus
Polhemus Associates, Inc.
Cambridge, Vermont

and

Gordon B. Hamilton
Sypher Consultants, Inc.
Ottawa, Ontario

Abstract

This paper reports the results of a study undertaken by SYPHER Consultants, Inc. of Ottawa, Ontario on behalf of the Ministry of Transportation and Communications of Ontario, to determine the appropriate solution to the Province's perceived needs in Enroute, Terminal and Approach navigation.

The study reviewed the results of four successful flight evaluations of LORAN-C RNAV conducted in northwestern Ontario by the Ontario Northland Transportation Commission and norOntair Airline, during 1981,82,83, and 84.

It included results of a survey of Ontario aircraft owners and operators completed by the Air Office of MTC and extensive research into User needs by Mr. Wm. Law, Senior Aviation Planner of that office.

The authors are indebted to the Ontario MTC and other members of the SYPHER team for permission to utilize portions of the MTC report.

Introduction and Summary

A review of the Canadian Airspace Plan by the Air Office of the Ontario Ministry of Transportation and communications (MTC) lead to the conclusion that if there were no redirection of plans, that the focus of Canadian airspace development would be on serving the enroute navigation needs of high altitude jet aircraft and the enhancement of instrument approach services at high density airports. In Ontario alone there are over 200 small carriers and 6,000 private operators who operate at lower altitudes and into less populated areas, operating areas not to be beneficiaries of the new capabilities.

The MTC approached the problem in two phases: firstly, a survey of Ontario-based carriers was undertaken to identify the characteristics of their current and future operations; secondly, a study of options to provide an appropriate air navigation system was undertaken.

The survey of carriers indicated that:

- 55% of all movements within Ontario are presently at or below 5,000 ft. altitude
- 58% of all movements are VFR, in large part because there are no suitable navigation aids.

The expectations of these carriers were that in the period 1985-2000:

- many operators would be flying the same types of aircraft they presently own.
- 68% of operations will remain below 10,000 feet.
- 17% of operations will still be VFR, because of lack of aids.
- 26% of operators plan to fly using area navigation (RNAV) equipment.
- 47% indicated that by the year 2000, RNAV would be their preference for operations (specifically cited LORAN-C as the preferred system, in many cases).

The SYPHER/MTC study followed the survey by characterizing the operational requirements of an adequate air navigation and airfield IFR approach system for Ontario operators and the options available to meet the defined requirements. The requirements were defined as:

- a reliable ground level-to-altitude navigation aid providing contiguous coverage for all areas and routes in both Northern and Southern Ontario
- an area navigation capability that permits precise location of position and accurate determination of course, distance and ETA
- airborne equipment affordable to operators flying piston aircraft and light turbo-prop aircraft
- sufficient accuracy to limit total system cross-track error to 0.25-0.33 nm at 1 nm distance form the runway threshold

- the potential to meet the performance requirements of the U.S. FAA Advisory Circular 90-45A governing RNAV systems
- sufficient accuracy to provide non-precision approach capability at as many airports as possible

For full implementation of LORAN-C in Canada from 60°N latitude South to the US border, up to 7 additional transmitters would be required. If Ontario is considered in isolation, two additional transmitters are needed at a capital cost of approximately $13.4 million ($6.7 million each.....Canadian Dollars).

A comparison of the costs and benefits of LORAN-C with extension of the conventional VOR/DME/NDB system to provide similar coverage at 5000' altitude for enroute and similar approach capabilities showed:

- LORAN-C would be significantly more cost-effective on a 15 year life-cycle cost basis, particularly in providing for non-precision approaches
- Considering only operating cost savings through the use of RNAV and accident reduction savings, benefits of LORAN-C RNAV and non-precision approach would exceed costs by approximately $167 million over a 15 year period
- LORAN-C provides additional unquantified benefits in terms of improved track and location information for search and rescue, forest firefighting, forest and agricultural spraying, aerial survey, and for non-aviation users such as police, taxis and road transport.

Discusssion of Requirements

The air navigation and airfield approach systems exist to serve the User Community which includes activities of vast social benefit such as medical evacuation, resources management, forest fire detection and suppression, etc. Through these systems aviation is enabled to provide more efficient, more reliable, safer and less costly operations.

As a general pattern, the more sophisticated the user group, the more extensive and expensive are the aids and services provided. The high level airways serving jet operators in Southern Canada and the major airports are served by a complete enroute and approach system, including aids, communications and surveillance.

There are, however, other system users which include more than 20,000 private aircraft in Canada, commercial operators and numerous Provincial and Federal government operators. In Ontario alone there are 202 small commercial operators who own more than 1000 aircraft. These users also require navigation and approach systems. Although the passengers and goods they move are less than those that utilize the jet operators, the services they provide to smaller and more isolated areas are, relatively, very important.

The requirement for navigation and approach aids to serve users in Onatario or elsewhere in Canada will be identified by determining the needs of all users; large and small. Through ATAC and direct consultations, the larger users often have an opportunity to express their needs. There is some concern, however, that the large group of users not operating jet equipment could be overlooked.

The Survey conducted by the Air Office of the Ontario Ministry of Transportation and Communications, was sent to 252 operators. A 28% response rate was achieved, and the responses were determined to be geographically well distributed and representative in terms of types of licenses. The questionnaire focussed on current operations (types of operation, altitudes, etc.), a forecast of characteristics of operations by the year 2000 and report of specific problems being experienced with the current system for air navigation, communications and airports.

The responses describing current operations may come as a surprise to those unfamiliar with the geography of Ontario (nearly as large as Alaska in square miles) and the distribution of radionavigations, airports and services in the northern half of the Provinces.

- Provincially 37% of the areas reported that lack of suitable aids forces them to operate VFR;
- In the North-East of the province VFR areas make up 53% of the total reported;
- 65% of the areas reporting, indicated that <u>less than 5% of their movements are IFR</u>. In the North-West this figure reaches 87% reporting inability to operate IFR.
- a major complaint was the lack of reliable, accurate low altitude navigation aids.

Forecast, Ontario Year 2000

Changes in operating characteristics between 1985 and 2000 are not anticipated to be dramatic. Carriers expect their operations to be basically similar. The significant points identified by the survey were:

- 68% of carriers expect to continue to operate below 10,000 feet;
- 40% of operators will operate at or below 5,000 feet;
- 17% of routes are expected to remain VFR Only;
- 26% of operators plan to be operating RNAV systems;
- 47% of operators responding indicated that RNAV (specifically LORAN C RNAV) would be their preference for operations by 2000.

The continued pattern of low level, relatively unsophisticated operations is a variance with some assumptions inherent in the Canadian Airspace Plan to the effect that the fleet will relatively rapidly evolve to pressurized, more sophisticated aircraft.

The survey is absolutely consistent with previous financial studies undertaken which indicate that, in general, the smaller operations are in a precarious financial situation and are likely to be flying the same aircraft in 15 years as they are today.[1]

The small size of many of these operators, the marginal returns and the low residual value of the average aircraft suggest that any navigation or airfield approach system which is intended to be used by these operators should be supported by inexpensive airborne equipment. (An operator with an aircraft of only $30,000-$60,000 resale value and only 300 annual revenue hours is unlikely to willingly install a $20,000 navigational receiver).

FACTORS AFFECTING SELECTION OF EQUIPMENT

A. Coverage and Availability of VOR/DME

The Ontario airspace system presently relies upon 31 VORs. (including VOR/DMEs and VORTACs), and 84 NDBs to facilitate en-route and terminal area navigation to service a geographic area of approximately 413,000 square miles. There are more that 230 airports in the Province offering runways 2500 feet in length or greater.

With respect to airfield approach aids, the Province is equipped with:

11 ILSs
2 Localizer-only facilities
8 of the ILSs offer Back Course approaches
33 airports offer NPAs

Nominal Signal Service Area for VOR/DME at Various Heights Above Ground, and Numbers of VOR/DME Required to Provide Province Wide Coverage

HEIGHT ABOVE GROUND (ft)	RADIUS OF COVERAGE (nm)	SIGNAL SERVICE AREA (nm^2)	NUMBER OF VOR/DMEs REQUIRED	PRESENT SHORTFALL
2000	53.66	9,048	43	
3000	65.73	13,572	28	
5000	84.85	22,620	17	111
8000	107.33	36,191	11	
10000	120.00	45,239		

TABLE 1

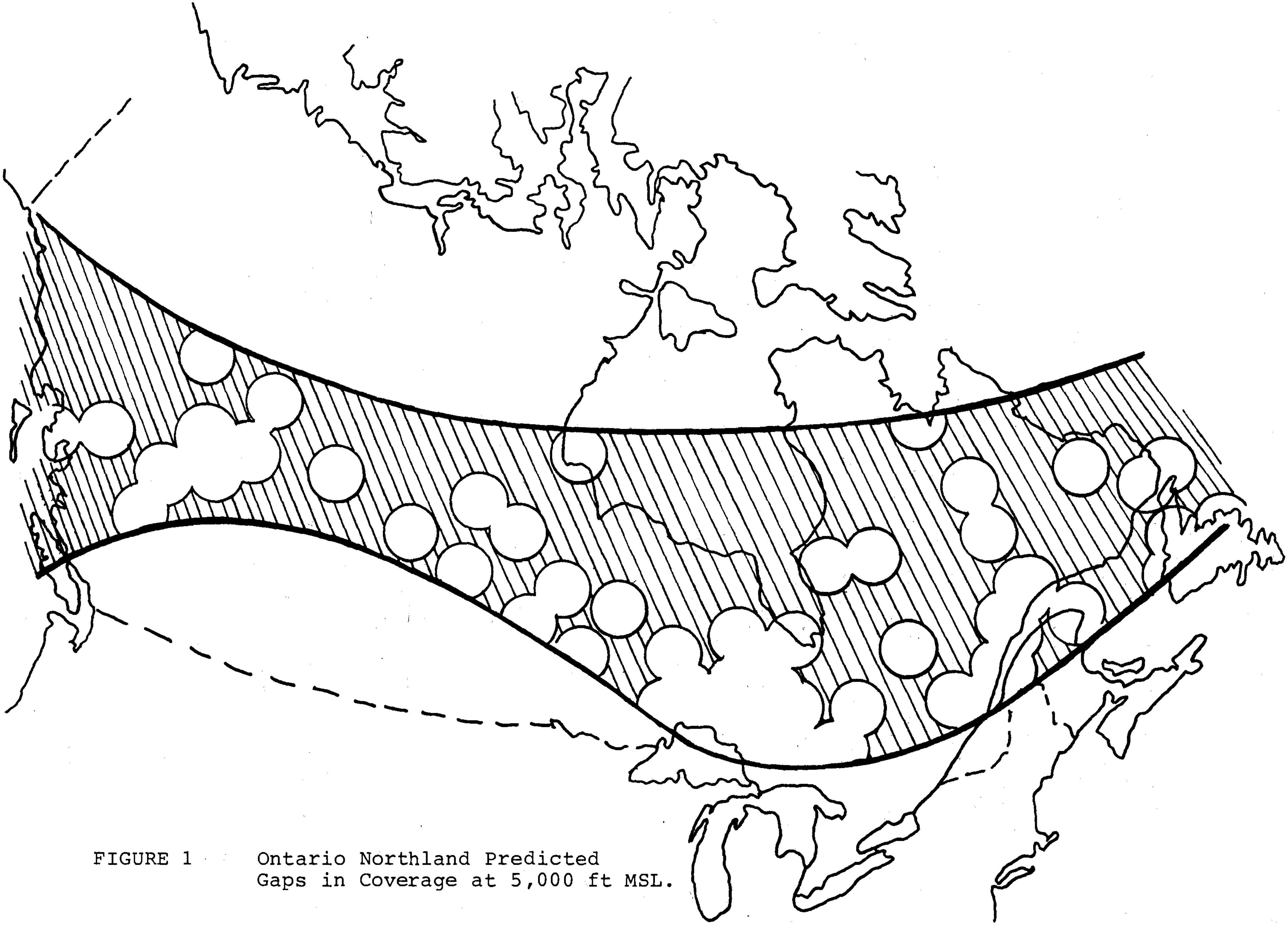


FIGURE 1 Ontario Northland Predicted Gaps in Coverage at 5,000 ft MSL.

Airfield Approach Accuracy Criteria

The majority of Ontario aircraft utilized for commercial and air transport purposes are Category A or B aircraft, i.e. approach speed below 120 KT. Thus the target Cross-Track Distance Accuracy criteria suggested as appropriate for non precision approach is 0.25 nm at 1.0 nm from runway threshold, based on utilizing minima of 400 ft DH and 1 nm RVR. The pilot of the approaching aircraft is assumed to obtain visual contact with the runway at this distance from threshold.

Review of NPA criteria listed in the U.S. Federal Radio Navigation Plan describes expected performance of a VOR/DME approach predicated on siting the facility of runway threshold, which limits the number of runways offering a Straight-In procedure, or requires use of Circling Approach procedures and requires that every airport be equipped with a VOR/DME, i.e., 230 facilities in Ontario.

Only 10 aerodromes in Ontario offer VOR/DME approaches and meet the 0.25 nm accuracy at 1.0 nm distance criteria stated above.

Observed LORAN-C Performance in Ontario

The LORAN-C system is stated to be a "better-than-quarter-nautical-mile" system and where an appropriate ground-truth reference system is available to verify performance, it is shown to produce that accuracy.

NorOntair's evaluation of LORAN-C RNAV during 1982 and 1983, provides evidence of LORAN-C RNAV performance within Central Ontario. Fifty-three measurements of position were completed at 15 locations within this region. The mean error for these measurements was 0.222 nm (1,350 feet); standard deviation was 0.175 nm (1,064 feet). All destinations located within the USCG 1:3 SNR contour, except Chapleau (.29), Timmins (.28) and Hearst (.36), displayed uncalibrated, 2-dimensional absolute accuracies of less than one quarter nautical mile.

Beyond, or north of, the upper SNR contour of the "8970" LORAN-C chain (set by limits of ground-wave coverage from the Master station at Dana, Indiana) and or the western SNR contour (the limits of the ground-wave from Seneca, New York), LORAN-C signals are not presently of sufficient strength to provide dependable, useful service: i.e, in the Armstron, Pickle Lake, Red Lake region. The communities of Kenora, Ft. Frances, and Sioux Narrows lie within the region of the baseline extension of the Dana-Baudette pair of transmitters, or within the region of marginal geometry.

The USCG intends to modernize and to increase peak radiated power of the Baudette transmitter from 500 KW to 900 KW beginning in June or early July, 1985. The improved system is to be operational by mid-summer, in time for the start of the Transport Canada/FAA Flight Test Program. This change will increase signal strength along the Timmins, Kirkland Lake, North Bay arc by at least + 3 dB.

USCG PREDICTED POSITION ACCURACY

	SYM	AID	REF	USCG PREDICTED				
				XING ANGLES	ACCURACY GRI	2drms	GRADIENT FT/0.1 s	
1		2	3	4	5	6	8	9
KIRKLAND LAKE	KL	NDB	PHOTO	60.5°	8970 9960,	317' 320'	MX-100' MW- 96'	MY- 95' M2-100'
EARLTON	E	NDB	PHOTO	63°	8970 9960	302' 298'	MX- 95' MW- 93'	MY- 94' MZ- 95'
TIMMINS	–	VOR/DME	"	63°	8970	302'	MX- 99'	MY- 90'
KAPUSKASING	KAP	NDB	"	61°	"	320'	MX-107'	MY- 90'
HEARST	–	NDB	"	–	–	–	–	–
HORNE PAYNE	H	NDB	–	66°	8970	288'	MX-104'	MY- 78'
GERALDTON	G	NDB	PHOTO	64°	"	308'	MX-114'	MY- 79'
ARMSTRONG	A	NDB	–	–	–	–	–	–
SIOUX LOOKOUT	–	–	–	–	–	–	–	–
DRYDEN	D	NDB		54°	8970	413'	MX-141'	MY- 89'
RED LAKE	RL	VOR/DME	—	36°	"	759'	MX-155'	MY-161'
KENORA	K	NDB		36°	"	757'	MX-152'	MY-164'
SIOUX NARROWS	–	VOR/DME		36°	"	757'	MX-152'	MY-164'
ATKOKAN	A	NDB		76°	"	292'	MX-128'	MY- 61'
THUNDER BAY	TB	VOR	RWY INT-SECT	79°	"	260'	MX-128'	MY- 61'
ANGUS ISLAND	–	–	PHOTO	–	–	–	–	–
TERRACE BAY	X	NDB		72°	8970	267'	MX-106'	MY- 70'
MARATHON	–	VOR/DME	–	–	–	–	–	–
WAWA	W	VOR/DME	–	74°	8970	244'	MX- 92'	MY- 73'
CHAPLEAU	–	NDB		72°	8970	249	MX- 90	MY- 78
ELLIOT LAKE	EL	NDB		80°	"	219	MX- 76	MY- 77
SUDBURY	S	VOR/DME		72°	"	248	MX- 80	MY- 87
NORTH BAY	NB	VOR/DME		68°	"	270	MX- 83	MY- 94
KILLALOE	–	VOR/DME		79°	9960	230	MX- 68	MY- 90
OTTAWA	–	VOR/DME		84°	"	274	MX- 56	MY-124
SAULT STE MARIE			RUNWY THLD	84°	8970	209	MX- 79	MY- 68

TABLE 2

The transmitter located at Dana, Indiana, presently a 400 KW installation, is not to be uprated, thus limiting effective coverage in northern Ontario to that which is indicated by the contour shown, an arc located approximately 650 nm from the transmitter. The transmitter located at Seneca, NY produces 800 KW peak radiated power and can be received reliably at 1:3 SNR in western Ontario to a distance of approximately 750 nm.

The installation of two new transmitters at Ft. Severn or Ft. Churchill, and at Moosonee will therefore be necessary to provide reliable coverage of northern and western Ontario.

Repeatable Accuracy

The data from the norOntair flight tests provided an opportunity to evaluate repeatability of position measurements at Kirkland Lake, Sault Ste. Marie, Thunder Bay and Timmins. The two test periods were approximately one year apart (Table 3).

Repeatability of LORAN-C Accuracy in Mid-Ontario

Difference Quantities - Arc Minutes

	1982		1983		Apparent Change	
	Lat.	Long.	Lat.	Long.	Lat.	Long.
Kirkland Lake	.11'	.13'	.18'	.45'	.07' (420',	.32* 1301')
Sault Ste. Marie	.09'	.07'	.09'	.06'	0.0' (0' ,	.01' 42')
Thunder Bay	.08'	.04'	.12'	.03'	.04' (240',	.01' 42')
Timmins	.17'	.06'	.24'	.24'	.07' (420',	.18' (746')

* Attributable to DND transmitter operating at 113.2 kHz?

TABLE 3
REPEATABLE ACCURACY

The year-to-year differences at the four locations should all be similar in magnitude to those observed at Sault Ste. Marie and Thunder Bay. However the Kirkland Lake and Timmins data were taken while the aircraft was airborne wheras the Thunder Bay and Sault Ste. Marie measurements were made while the aircraft was sitting on the ground.

Present Availability and Coverage of LORAN-C Signals

Coverage is supplied to central and southern Ontario by three transmitters in the Great Lakes chain (GRI 8970) and to eastern and southern Ontario by four transmitters in the Northeastern U.S. chain (GRI 9960).

Approximately sixty percent of the Province of Ontario is currently provided with a minimum of two LORAN-C Lines of position at a Signal to Noise Ratio (SNR) of 1:3, theoretically yielding two-dimensional (latitude and longitude) fixes accurate to one quarter mile or less on a 95% Probability basis.

With respect to attenuation of signal, the USCG 1:3 SNR contours protrayed on Figure 2, is a true representation of the regions of useful navigation performance for GRIs 9960 and 8970. The shaded area presented on Figure 2, falls beyond the regions within which the U.S. Coast Guard states that the LORAN signals will demonstrate a Signal-To-Noise Ratio of at least 1:3, and the geometry of fix is such tat uncalibrated accuracy will be ¼ nm or better. The norOntair tests show this to be true.

Fully eighty percent of the 230 airports identified in this study fall within the quarter-mile accuracy coverage thus permitting consideration of NPAs to more than 180 aerodromes. All water/ice landing surfaces within this region automatically become candidates for approaches.

Incremental Benefits

The anture of LORAN-C system is such that the coverage provided is different from that porvided by the conventional navaid system. The LORAN-C signal is contiguous over the entire area where the signal is provided. For example, if LORAN-C coverage is provided for the routes in Northern Ontario, then all of Northern Ontario will have coverage.

The LORAN-C signal is also receivable at ground level so that aviation operating at low altitude, even on the airport surface, can use the signal.

From these basic characteristics, there are a number of benefits provided by LORAN-C that are in addition to conventional navigation and airfield approach benefits:

(1) Time and Fuel Savings

Any area navigation system provides the potential for significant reduction in aircraft direct operating costs by:

- o permitting direct point-to-point navigation;

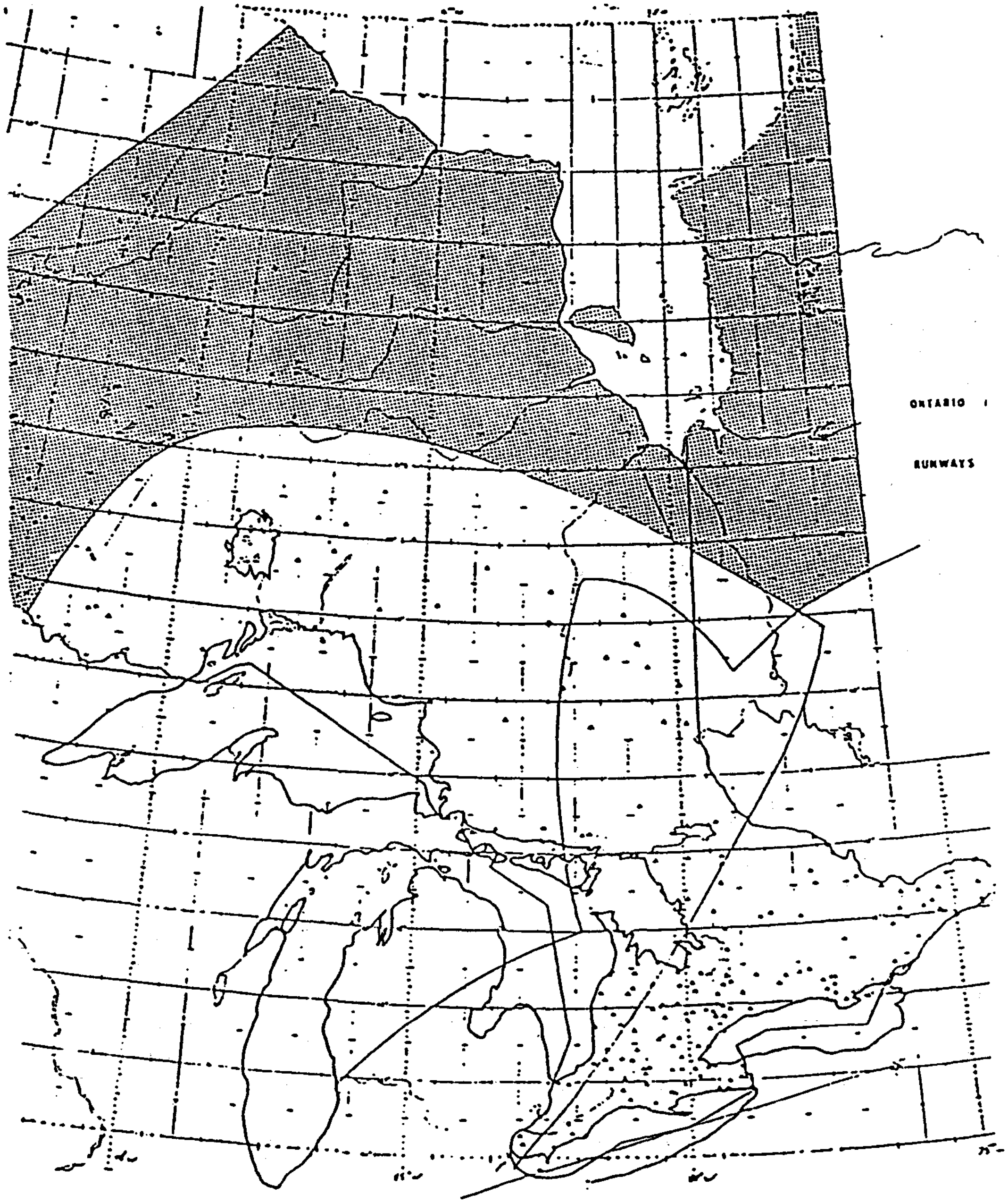


Figure 2 Current LORAN-C In Ontario at 1:3 SNR

TABLE 5

Life Cycle Cost Comprison Over 15 Years - LORAN-C RNAV and Monitored RNAV NPA Compared to VOR/DME/NDB to Provide Province Wide Coverage

	VOR/DME/NDB	LORAN-C
ENROUTE		
Ground Station Capital		
Number	11	2 transmitters
Cost (1985 $)	$10.0 million	$13.4 million
Ground Station Annual O&M ($/year)	$183,000	$350,000
Present Value 15 Years of O&M	$1.39 million	$2.66 million
Airborne Equipment Capital	-	$10.8 million
% of Users Served	100%	51%
15 Year Life Cycle Cost-Enroute (1985 $ Discounted to 1985)	$11.4 million	$26.9 million[1]
APPROACH		
Number	173[3]	173
Cost ($)	$21.6 million	0
Ground Station O&M ($/year)	$199,260	0
Present Value of 15 year O&M	$1.51 million	0
Approach Preparation		
Number	173	173
Capital Cost	$3.5 million	$2.1 million[2]
Monitoring & Calibration		
Capital Cost	-	$0.22 million
Annual O&M		$0.02 million
Present Value of 15 Years of O&M		$0.17 million
15 Year Life Cycle Cost-Approach	$26.6 million	$2.3 million
15 Year Life Cycle Cost Total	$38.0 million	$29.2 million
15 Year Cost to Transport Canada	$38.0 million	$18.4 million

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[1] Of which $10.8 million would be borne by aircraft operators.

[2] Salvage value of LORAN-C RNAV approaches at the end of 15 years for GPS use reduces effective cost by 40%

[3] NDB approaches only. Not comparable to RNAV approaches in that limits would be higher for NDB and general safety level lower. Also with NDB cannot establish SIDS and STAR.

TABLE 4
Estimated Extent of Coverage of VOR/DME, NDB/ADF, LORAN-C and Omega for Enroute, Terminal Approach in Ontario

ENROUTE OPERATONS			
	SOUTHERN	CENTRAL	NORTHERN
VOR/DME	100%	65-70%	10%
NDB/ADF	85%	70%	35%
LORAN-C (present coverage)	100%	80-85%	5%
Omega	100%	100%	100%
TERMINAL AREA & CIRCLE TO LAND CRITERIA (facility 15 nm from aerodrome)			
	SOUTHERN	CENTRAL	NORTHERN
Number of airfields	157	50	23
VOR/DME	24%	10%	9%
NDB/ADF	54%	48%	78%
LORAN-C	100%	66%	0%
Omega	NA	NA	NA
NON PRECISION APPROACH			
	SOUTHERN	CENTRAL	NORTHERN
Number of airfields	157	50	23
ILS/LOC Approaches*	6.4% (10)	6% (3)	0%
VOR/DME (within 4.13 nm of airfield)	1.3%	8%	8.7%
NDB/ADF (within 3.75 nm of airfield)	17%	32%	70%
LORAN-C ("on-airport criteria")	100%	66%	0%

* VOR or NDB approaches duplicating an ILS or LOC approach have been eliminated from data.

- reducing track "wander" and consequent increase to distance and time;
- improving traffic managment capabilities;
- permitting straight-in approaches and on-course departures;
- improving flexibility to re-route around weather.

The benefits have been quantified by a number of studies. The "White Paper Justifying LORAN-C for the NAS" estimates that fuel and direct operating cost savings to U.S. users form LORAN-C RNAV direct and NPA could be as high as $314 million/year. Specifically the estimates of reduced annual operating costs in this document are shown in Table 5.

TABLE 5

Estimated Percentage Reduction in Annual Time and Fuel Costs as a Result of LORAN-C RNAV and NPA-Source FAA "White Paper Justifying LORAN-C for the NAS"

TYPE OF USER	PHASE OF FLIGHT			
	Enroute	Terminal	Approach	Total
Personal G.A.	4-6%	1-2%	2-4%	7-12%
Charter	4-6%	1-4%	1-6%	7-14%
Regional	1-2%	1-6%	2-4%	7-12%

* Use 6% in rural areas.

TABLE 6

Payback Period for RNAV and RNAV-NPA Using LORAN-C for Selected Aircraft Types

Aircraft	Annual Operating Hours	Loran C Receiver Cost Assumed	Payback Period @ 6% Reduction in DOC	Payback Period @ 10% Reduction in DOC
HS 748	2000	$28,000	2 months	1 month
DHC 6	995	$ 8,000	2½ months	1½ month
PA 31	585	$ 4,000	3½ months	2 months
C172	410	$ 2,000	7 months	4½ months

Conclusions

(1) A review of the commercial aviation fleet basid in Ontario showed that it is composed primarily of unpressurized piston driven aircraft operating at low altitudes. The private aircraft fleet is similar.

(2) A survey of Ontario commercial operators indicated that:
- 55% of movements of these operators are at or below 5,000 ft altitude;
- 58% of movements are VFR.

(3) Responses by commercial operators on their expectations with respect to the year 2000 yielded:
- many operators will be operating the same types of aircraft
- 68% of routes are expected to be below 10,000 ft;
- 40% of routes will be below 5000 ft;
- 17% of routes will still be VFR;
- 26% of operators plan to be operating RNAV;
- 47% indicated that RNAV (specifically LORAN-C RNAV in many cases) would be their preference for operations by 2000.

(4) Analysis of operational requirements for RNAV systems indicates that any future navigation system should be capable of meeting the requirements of AC90-45A, the U.S. FAA circular on RNAV systems. In additon, ensuring that Total System Cross-Track Error on approach is limited to 0.25 nm at 1 nm from the runway threshold will enhance safety and facilitate airport access.

(5) The present Canadian Airspace Plan will not address the needs identified by Ontario commercial operators for:
- a reliable ground level to altitude navigational system providing contiguous coverage in Southern and Northern Ontario;
- an area navigation capability;
- affordable airborne equipment.

(6) A number of navigations slystems are capable of providing for bw altitude navigation and are compatible with RNAV requirements, but all except for Loran-C RNAV, fail in some significant way.
- VOR/DME will provide a LOS signal to ground level which limits coverage and a ficility is required at virtually every airport.
- Omega and differential Omega currently require expensive airborne equipmetn. The update rate is not suitable for approach. Because the U.S. will not be encouraging Omega, it is unlikely that less costly equipment will ever be produced;
- Inertial navigation systems are prohibitively expensive and require sophisticated maintenance facilities.
- GPS will probably not be fully available in certified

form for 10 years, and in its civil form may require additional ground-based systems to assure accuracy.

(7) Of the candidate navigation systems, only "monitored" LORAN-C provides the potential for the combination of:

- o RNAV to ground level;
- o non-precision approach capability at any airport in the area of coverage that is within 100 nm of a monitoring station and which has an RNAV approach plate;
- o low cost airborne receivers;
- o full capabilities including non-precision approach available in the 1986-1988 period.

(8) Recent FAA activity in investigating and promoting LORAN-C for RNAV and for non-precision approaches indicate that the U.S. will be placing more emphasis on LORAN-C than previously identified. Estimates in the U.S. are that 14% of the total U.S. fleet of GA aircraft is currently equipped with LORAN-C receivers and that this figure will climb to 60% in the next 2-3 years.

(9) There are significant gaps in LORAN-C coverage in Ontario and elsewhere in Canada. Two additional transmitters would, when combined with existing transmitters, provide coverage over almost all Ontario. Canada-wide, 7 additional transmitters would be required.

(10) A comparison of the costs and benefits fo LORAN-C with extension of the existing system of VOR/DME/NDB capable of providing similar coverage at 5000' altitude showed a net present value over 15 years of $167 million (e.g. benefits exceed costs by $167 million) including only operating cost savings and accident reduction savings. Additonal incremental benefits of LORAN-C not quantified include:

- o non-precision approach to any location in the province;
- o improved air transport service reliability'
- o improved search andrescue and medical evacuation;
- o improved capabilities for forest firefighting, forest spraying, mapping, aerial survey and agricultural spraying;
- o use by non-aviation users including police, taxi, road transport, etc.

(11) From an aircraft operators perspective, LORAN-C RNAV is extremely attractive. Operating cost savings can payback receiver capital costs for most commercial operators in 2-3 months. Even for a single engine operator, the payback period is less than six months.

(12) Current U.S. thinking is that LORAN-C air navigation may not be displaced by GPS but may complement it throught the use of an integrated GPS/LORAN-C receiver.

(13) The potential for Ontario manufacturers to become involved in the production of LORAN-C receivers is limited because the U.S. market and manufacturers are leading by several years.

There are, however, market areas where the potential for Ontario production is more promising:

- o the development and manufacturing of improved antennas for LORAN-C receivers;
- o the development of the next generation of equipment; an integrated flight management specifically targeted to smaller operator and designed to be adaptable to receive any RNAV signal.

Recommendations

It is recommended that:

(1) The Ontario aviation community be made aware of the potential for LORAN-C RNAV and LORAN-C non-precision approach.

(2) The Ministry of Transportation and Communications, through the process of the Canadian Airspace Review, ensure that LORAN-C is given adequate consideration in light of the needs of small commercial and private operators and recent U.S. actions in this area.

(3) Representation be made to CATA to modify the FAA/CATA 1985 LORAN-C flight tests so that the results can be tied to the extensive tests already taken by norOntair in past years.

BIOGRAPHICAL INFORMATION

William L. Polhemus
Polhemus Associates

Professional Navigator and Senior Partner Polhemus Associates, Inc of Cambridge, Vermont. Experience includes twentytwo years in military service; nine years in the U.S. Navy as a radio/radar operator assigned to aircraft carriers; and thirteen years in the USAF as a navigator-bombardier. USAF assignments included MATS, TAC and SAC.

Since 1962, he has completed a 'tour' with a commercial airline and twentyone years of successful operation of a small research, test and evaluation company.

Since 1968, his company has been involved in study, evaluation and documentation of Loran-C position, location and navigation capabilities in a variety of maritime, terrestrial and airborne applications.

His present work involves demonstration of the feasibility and desirability of using Loran-C RNAV within the National Airspace System.

LORAN C COORDINATE CONVERSION

By

Mortimer Rogoff

Chairman of the Board
Navigation Sciences, Inc.
Bethesda, MD 20016

Prepared for Delivery at the Wild Goose Convention
Santa Barbara, California

October 23, 1985

This paper covers the subject of Loran Coordinate Converters, and is essentially a follow-on of the work done by RTCM Special Committee 75 who published a set of Minimum Performance Standards for Loran Coordinate Converters in 1982. (The author was chairman of that committee). Since that time thousands of Loran receivers that include Coordinate Conversion as an integral feature have been placed into operation. There is general acceptance of these devices, but there have also been some complaints about the accuracy of the displayed results. What follows is a discussion of some of the factors involved in these complaints, and some suggestions as to possible improvements.

When SC-75 did its work we were told that the Defense Mapping Agency was about to publish a set of Correction Tables that would provide ASF corrections to Loran Time Differences, with the entering arguments in Time Differences, and the results also in Time Differences. Such tables had existed previous to this publication, but were reserved for DOD users. Since they were already prepared in TD format, they were issued to the general public in the same format. When SC-75 published its report, manufacturers of Loran receivers were given this information, along with encouragement to incorporate the data in the coordinate conversion equipment. Or, failing that, to make the use of the tables easy for their customers.

By doing so, the user of the coordinate converter would obtain results equivalent to those resulting from the use of Nautical Charts overprinted with Loran Lines of Position. (The tables were, in fact, the same data as used in preparing the Lines of Position for overprinting on the NOS charts). But notice that use of the tables did nothing for the user inside harbors or inland waters where no charts or corrections exist. These tables (and the charts as well) cover the Coastal Confluence Zone, with no data inside or outside the limits of this zone. No corrections are really required outside the Zone, for the errors in these areas are very small. Corrections are required, however, inside the limits, because this is the region of harbors, bays, rivers, etc., where ASF corrections tend to be large.

This was the scene as of 1982. Manufacturers proceeded with the design and sale of integral Coordinate Converters. Writing in Motor Boating and Sailing for Feb. 1985, Bill Mooney published data concerning the performance and features of 13 sets. Of the 13, five incorporated automatic provision for inserting ASF corrections, and eight did not. Of the eight manual sets, only half permit entry with Time Differences, the other half limited to entry of corrections in the form of Latitude and Longitude.

The fact that so many sets use Latitude and Longitude as entering arguments for ASF correction may explain the source of irritation and displeasure with coordinate converters being heard. The fact that no corrections at all are available for waters within harbors and inland waters surely accounts for another part of the dissatisfaction.

Latitude and Longitude is a difficult quantity for the lay user because he must, in effect, make up his own tables of correction in these units. That inevitably means subtracting Latitudes and Longitudes from each other which can be a source of anguish if not error. If this user is to make such tables within a harbor by reading positions of piers, lights, buoys, etc., then he is involved in chartwork of significant detail - again a source of irritation and error.

Any way out of this taken by the manufacturer is going to add to the cost of the Loran receiver.

It is important to understand the economic background relating to this product in order to appreciate the factors which have dictated this situation. First of all, it is evident that building into electronic memory the data needed to make automatic corrections is an expensive proposition in terms of relative cost. This probably explains why only five of the thirteen sets do incorporate these features, and why four of those five were all higher than the average cost of that group of sets.

Secondly the period of time between 1982 and 1985 has seen a dramatic compression in the cost and size of the microelectronic components that go into today's Loran receivers. These cost reductions have been applied to selling prices with the consequent rise in market penetration to extremely high levels. Hundreds of thousands of Loran receivers are in use today largely as a result of these low prices.

There is another factor at work that is going to keep Loran prices low, and that is the looming figure of Global Positioning System that threatens the very existence of Loran. One strategy that is sure to be employed is the use of the low Loran price as a weapon against GPS to be used as reason to keep Loran in operation as long as possible.

With these factors in mind, it is easy to see that there will be little incentive on the part of Loran receiver manufacturers to add features and complexity since that would result in cost and price increases - counter to the trend already established.

Thus the dilemma: at a time of rising power and capability coupled with lower cost of microelectronic devices, we are not likely to see improvements in performance of the Loran receiver. We are probably not going to see investment in new VLSI devices nor in programming systems simply because it is going to be necessary to keep costs and prices down.

The question is: "Where is the relief?". Are we going to have 'Loran Assisted Groundings' as more and more sets are acquired by the lay public? Coordinate Converters, that display position in terms of Latitude and Longitude - an understandable quantity when compared to microseconds of time difference - are going to be believed by this group of users, even as they penetrate the CCZ and enter uncorrected harbors.

There are some suggestions that can be made which can lead to improvements in this situation. They are as follows:

1. Improve the "friendliness" of the Latitude and Longitude inputs of correction in those sets limited to this form of data. Accept input in the form of the Latitude and Longitude of a known position, and let the set itself calculate the difference to create an offset. This will relieve the user of a bothersome, error-prone chore.

2. Display the amount of the ASF correction presently in use. This will serve in the first place as an alarm if no correction has been installed, and a reminder to change it if it no longer applies.

3. Display position in such a way that the user can make an immediate, visual comparison as to the Loran position versus his actual position. If the display is in the form of an electronic chart he can move the symbol representing his own vessel to a correct place on the chart, and thereby introduce an offsetting correction.

4. Add radar to the display listed above so as to make the position determination and correction an all-weather, day-night possibility. Shifting the radar map of land and objects relative to the same features shown on an electronic chart until they all line up and match will eliminate the Loran position error.

   (The suggestions in 3. and 4. above will add cost and increase price, counter to the trends noted earlier), but they may be acceptable to those purchasers who perceive the added value of the improved displays.

There are two other possibilities, both not involving equipment or purchases by the user which should be mentioned. They are:

1. The Coast Guard can broadcast Loran ASF corrections within pilotage waters and in harbors. These are as valuable as weather, tide, traffic, and Local Notices to Mariners. Either VHF channels, or Radiobeacon frequencies could be used for this purpose. This would even make possible the correction for seasonal, or local weather induced errors that would add considerable accuracy to Loran.

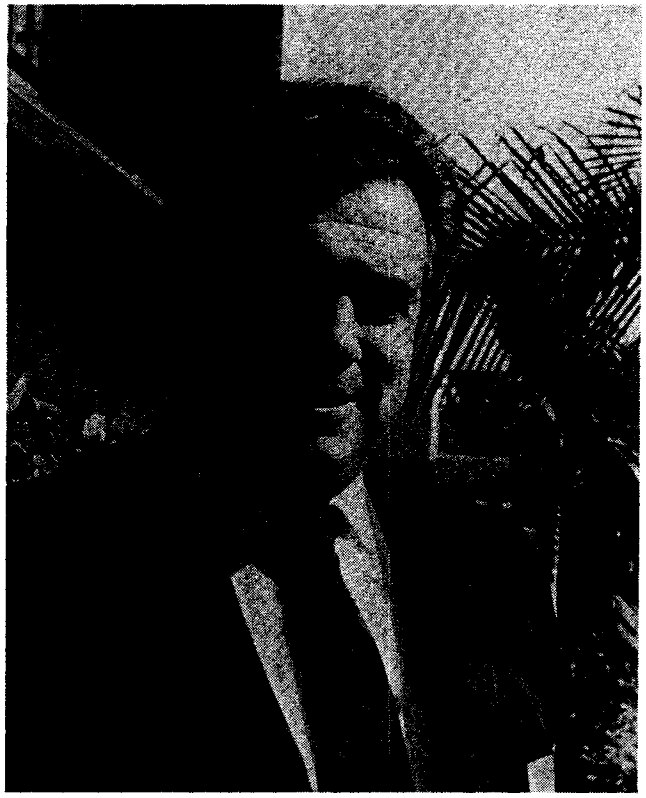
2. Local Marine Electronics dealers might find it in their own interest to publish tables of ASF corrections for their own harbors and localities. It would be a way to improve customer relations and add to their own luster in the harbor. They might be persuaded to invest in this form of marketing.

The availability of these additional sources of error correction, combined with the improved ways to utilize and display the data should result in significant improvement in user results.

TECHNICAL SESSION No. 2 - LORAN TECHNOLOGY

Session Chairman - Ronald S. Warren
The Analytic Sciences Corporation

SESSION CHAIRMAN



Mr. Ron Warren

SPEAKERS

(l to r) Bill Mooney, Issac Ginsberg, Martin Poppe (for Goddard) (back) Ron Warren, CW03 Dan Slagle, Vin Lally, Kolbjoern Saether. Einar Vestmo

LORAN-C SIGNAL STABILITY STUDY IN NORTH-NORWAY

KOLBJOERN SAETHER
EINAR VESTMO

NORWEGIAN DEFENCE COMMUNICATIONS ADMINISTRATION
OSLO MIL/AKERSHUS
N-0015 OSLO 1
NORWAY

ABSTRACT

Since July 1984, the Norwegian Defence Communications Administration (NODECA) has been conducting studies of phase and amplitude stability of a LORAN-C signal propagating over poorly conducting ground in North-Norway. The data material from these observations contain TD (Time Difference), TOA (Time of Arrival), signal strength and signal to noise ratio (SNR) measurements. A very interesting experience was the TOA measurements, and the great care that has to be taken doing such measurements. Of vital importance for success with the analysis of these data is the ability to collect data about local phase adjustments (LPA) during the whole program.
Then it is of great significance to find a proper method to estimate the oscillators drift.

The temporal phase variations were found to be much less than predicted using mathematical models of the propagation path. While the predictions gave several thousand nanoseconds in seasonal change, our findins lead to the conclusion that this variation is less than 300 nanoseconds (Peak-to-Peak).
The collected data for signal strength and SNR also indicate great stability.

LORAN-C SIGNAL STABILITY STUDY IN NORTH-NORWAY

1. Background

Norway is operating two transmitter stations in the Norwegian sea chain (7979). Since 1981 there has been plans to increase the coverage by establishing two or three new stations. The sites for the new stations are Vardoe, Bergen and Bear Island.

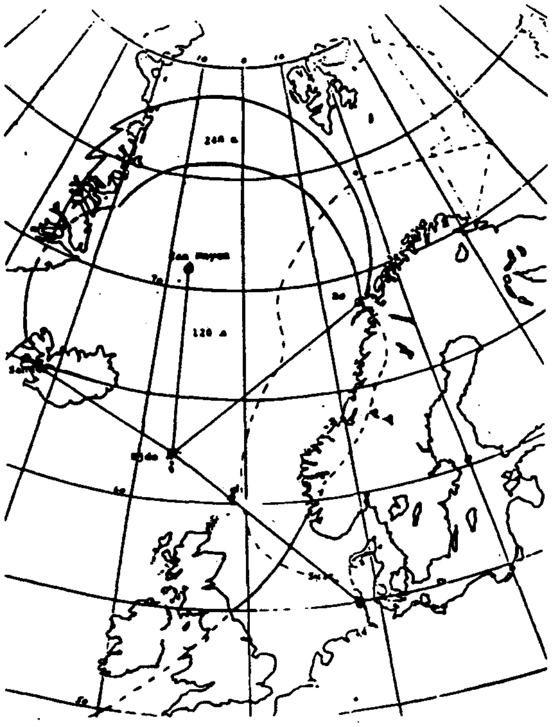


Fig 1 Present coverage in the Norwegian sea. sea

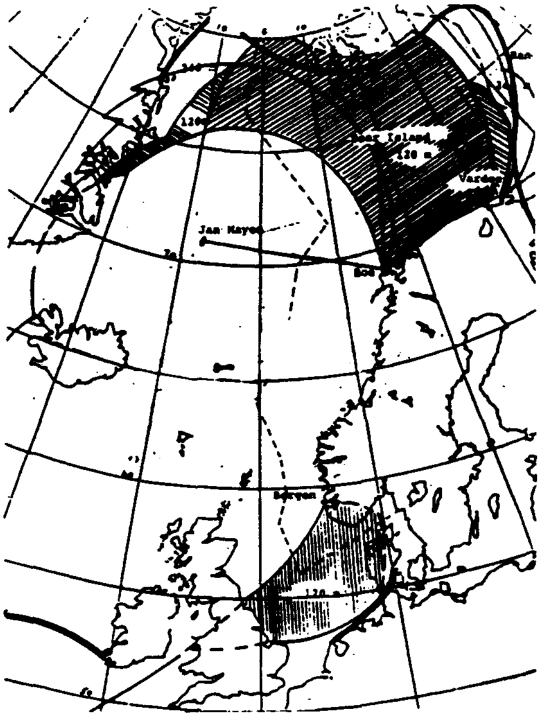


Fig 2 Addtional coverage as a result of the proposed new chain.

A consequence of this plan is that Boe and Jan Mayen must be dual rated. A new chain will then consist of:

Boe	(master)	
Jan Mayen	(secondary)	
Vardoe	(secondary)	
Bear Island	(secondary)	Providing additional coverage in the Barent sea.

The Bergen station would operate as a fifth secondary in the Norwegian sea chain (7970) - thus providing improved coverage in the southern part of the north sea.

In an area northeast of Norway the signal from Boe has to propagate over 600 km of poorly conductin ground. The propagation time is dependent upon the ground conductivity, and since the conductivity might vary with the climate we had to investigate if the climate-changes causes variations in the signal received from Boe. Theoretical studies on the subject gave different conclusions. CRPLi report 81-2 by J R Johler concluded that changes in the ground conductivity from σ = 0,0002 MHO/M to 0,0006 MHO/M would cause several thousand nanosecond seasonal change, while Per Enge from Megapulse predicted a peak-to-peak phase change of less than 1 microsecond (± 500 nanoseconds). However, experimental investigations were recommended by measuring the phase variations of the current Boe (X) signal at Vardoe.

The measurement program started in July 1984 and went on for a whole year.

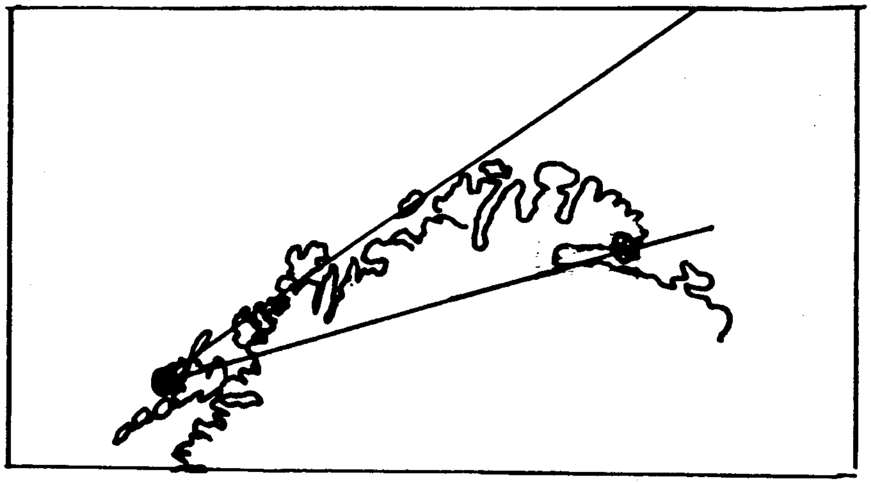


Fig 3 Propagation path of interest in North-Norway.

2. Data collection set

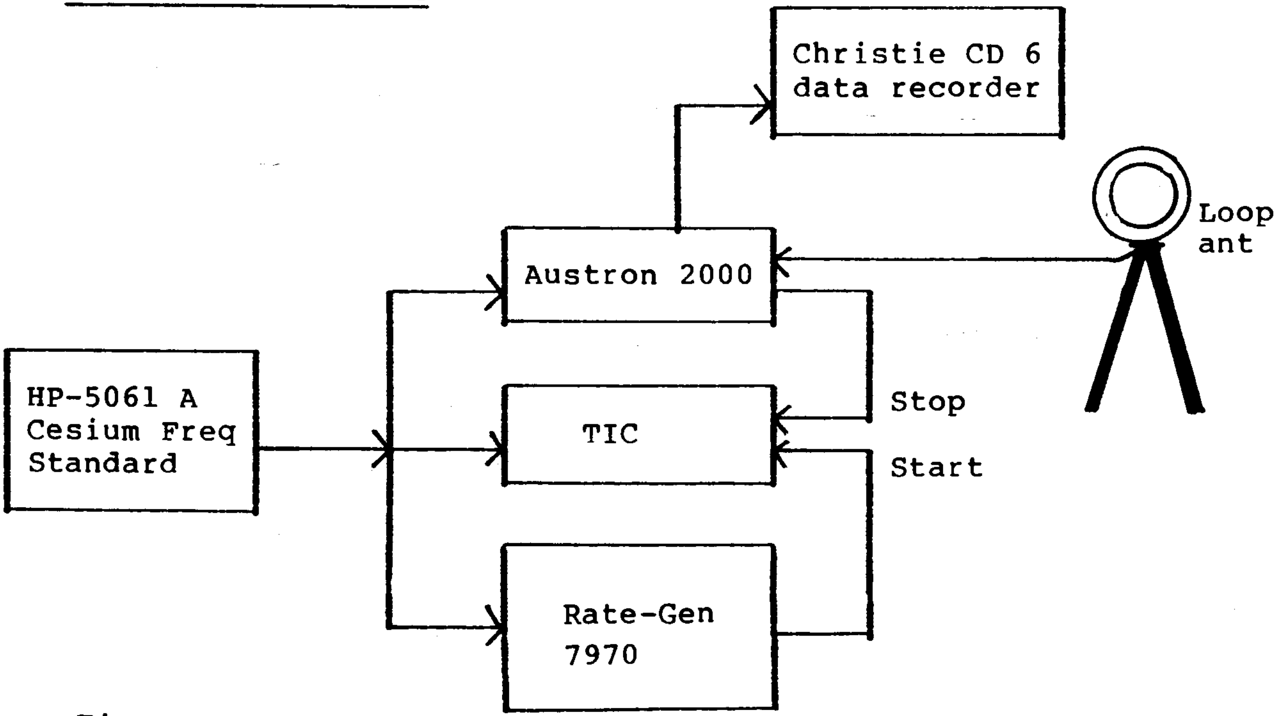


Fig 4 Data collection set block diagram.

The data recorded from the Austron 2000 is TOA-data. The reason for using a TOA-receiver is that the measurement site at Vardoe is located beyond the range of master (Ejde) of the Norwegian sea chain. Therefore, it is very difficult to montior the TD-MX at this site. On the other hand the Accufix 500 receiver made it possible to monitor the TD-XZ (Z is Jan Mayen), but the problem with this TD is that it is not a controlled TD, and therefore one would not know what really causes the variations in this TD. Anyway, we found it interesting to collect data from this TD, because this is an actual TD in the new chain.

3. TOA-measurements

During the first months of the program we experienced that great care has to be taken doing TOA-measurements. Our main goal was to investigate the seasonal change in phase of the signal propagating from Boe to Vadsoe. The change in phase is corresponding to the change in TOA. But there are some important problems associated with TOA-measurements:

(i) Oscillator drift.
(ii) Transmitter phase adjustments.
(iii) Changes in the receiver system.

The oscillator (clock) drift is the most serious problem, and is caused by the drift in the oscillator at the receiver site relative to the oscillator in the timer at the transmitting station. To reduce the effect of the drift it was necessary to calibrate the receiver site oscillator as often as possible. The calibration was made by bringing the time from the transmitter timer to the receiver site by means of a third oscillator. The 600 km distance between the two sites made it necessary to use an airplane for transportation.

The transmitter phase adjustments mainly consists of LPAs (Local Phase Adjustments), and it turned out to be absolutely necessary to collect information about the LPAs. We found that cumulative LPA could be more than 300 nanosecond in one day and this resulted in a corresponding change in TOA at Vadsoe (fig 5).

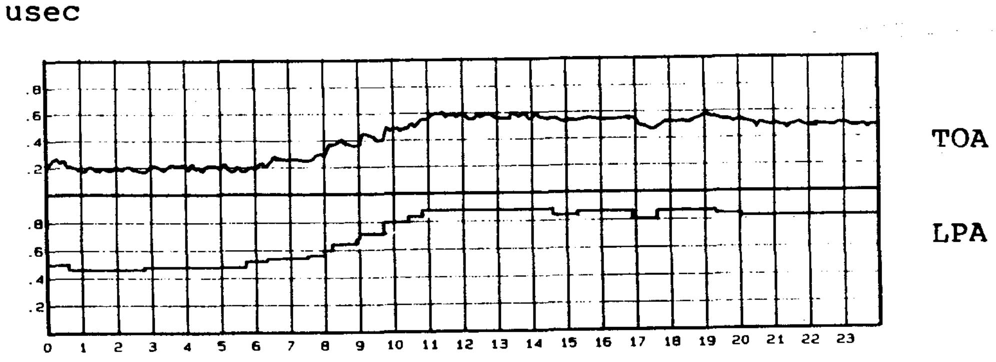


Fig 5 TOA curve (raw-data) for 6 Dec 85 and LPA curve for the same day.

4. Results

The data analysis was done at the NODECA Headquarters in Oslo, and since this is NODECAs first program of this type it required a lot of effort with programming computers. In the following the results are presented in form of curves and some tables.

Fig 5 shows the timeseries for the Austron 2000 raw data. As you can see there is a phase change of about 6,5 usec from Aug 84 to May 85. (For some periods the data is missing, and this is caused by different problems like antenna damage, Austron 2000 failure and loss of power to the cesium oscillator).

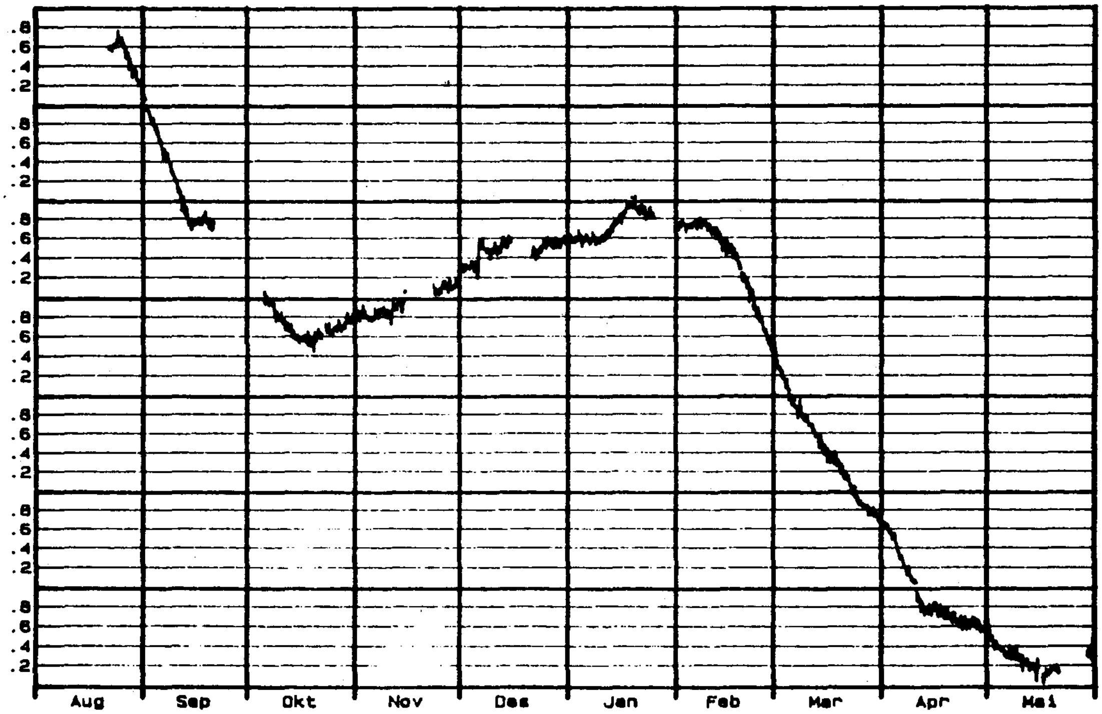


Fig 5 Uncorrected TOA-data. (Austron 2000 raw-data).

It was very surprising to find out that the cumulative LPA was in the order of a microsecond for each month, clearly demonstrating the need for keeping a LPA-log in connection with TOA measurements. Fig 6 shows the cumulative LPA-curve from Aug 84 to June 85.

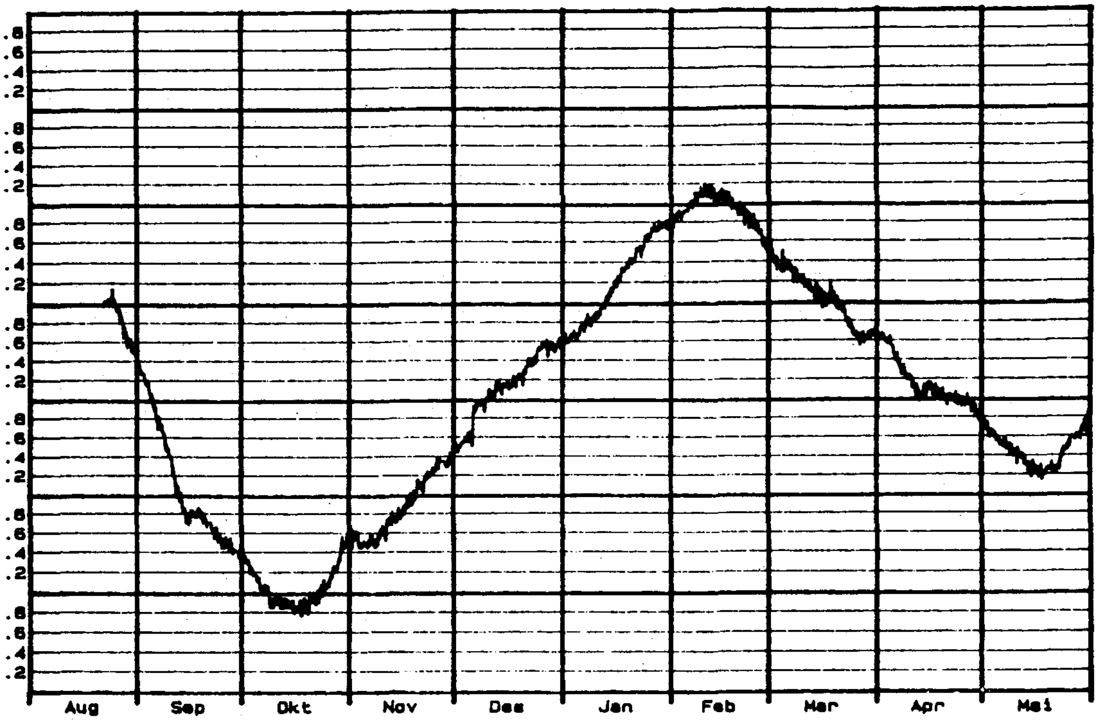


Fig 6 Cumulative LPA-curve

When applying the LPA-curve as a correction to the Austron raw-data curve we get a new TOA-curve (fig 7).

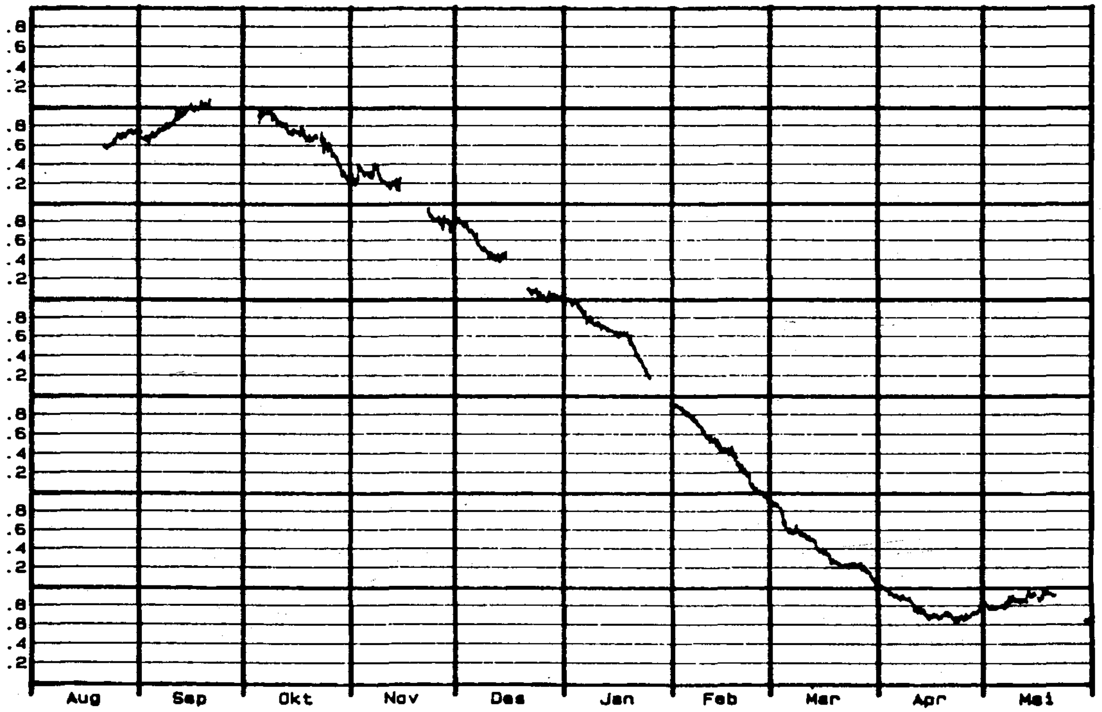


Fig 7 LPA-corrected TOA-curve.

The curve in fig 7 also indicates a large seasonal change in TOA (about 5 usec). However, bear in mind that this curve includes the oscillator drift. The drift has been estimated for each calibration period, and on the basis of this drift rates we get to the final TOA-curve shown in fig 8.

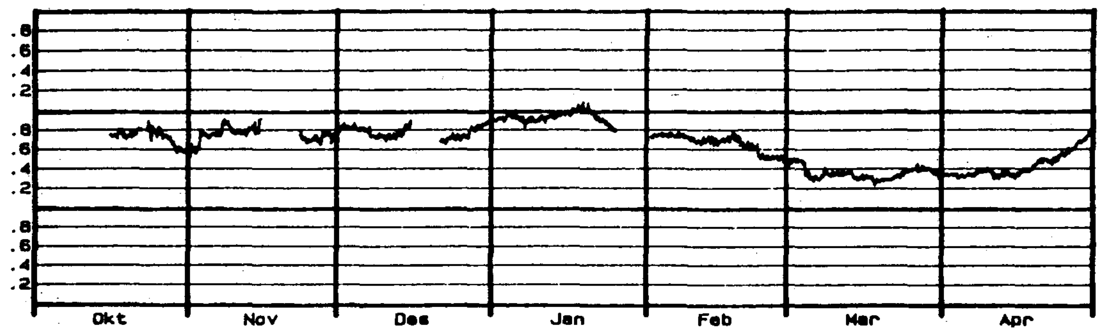


Fig 8 TOA-curve corrected for LPA and drift.

As you can see from the curve in fig 8 the peak to peak variation is about 0,8 usec. One important error source might be that we have considered the drift to be linear in the calibration periods. It must be quite clear that this assumption is not correct, but it still is the only possible solution. However, if we use the TOA measured at the time of calibration we only get a peak to peak variation of 250 nanosecond (fig 9).

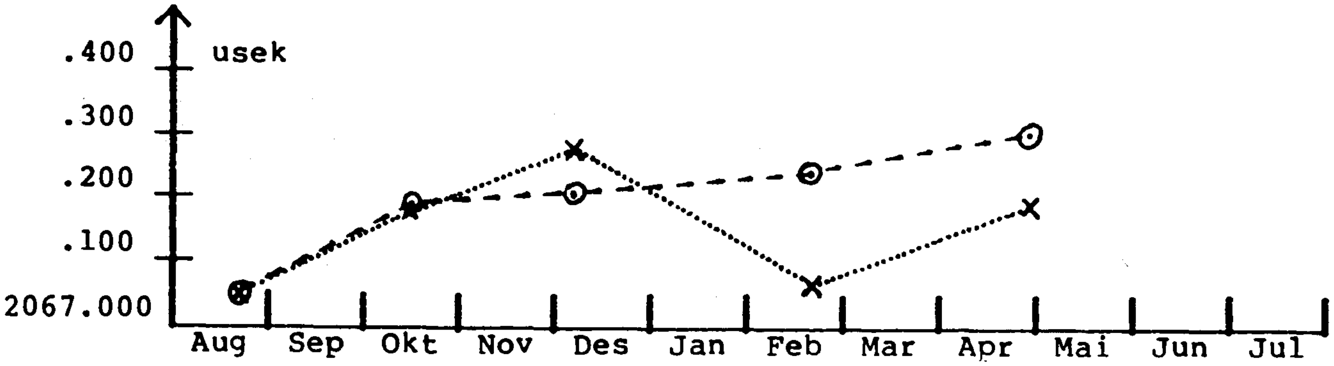


Fig 9 TOA at the time of calibration for mobil receiver (---) and stationary receiver (---).

The results of the TD-XZ data analysis is not presented in this paper, but they seem to confirm that the change in TOA-X is less than 0,5 microsecond.

5. Statistics

The standard deviation of the timeseries in fig 8 is calculated to 0,212 microsecond. As mentioned earlier this timeseries is influenced by the oscillator drift problems. For shorter timeseries the oscillator drift will influence the standard deviation less, and therefore we calculated the SD for periods of one month (table 1).

MONTH	NO OF SAMPLES	STANDARD DEVIATION
16-31 OCT	3472	0,083
NOV 84	5015	0,073
DES 84	5849	0,059
JAN 85	5820	0.053
FEB 85	6493	0,090
MAR 85	7115	0,062
1-29 APR	6916	0,119
	$\overline{SD}$	0,077

Table 1 Standard deviation for each month (microsec). $\overline{SD}$ is the average SD.

For even shorter periods like week, day and hour the calculated values of SD are presented as curves (fig 10).

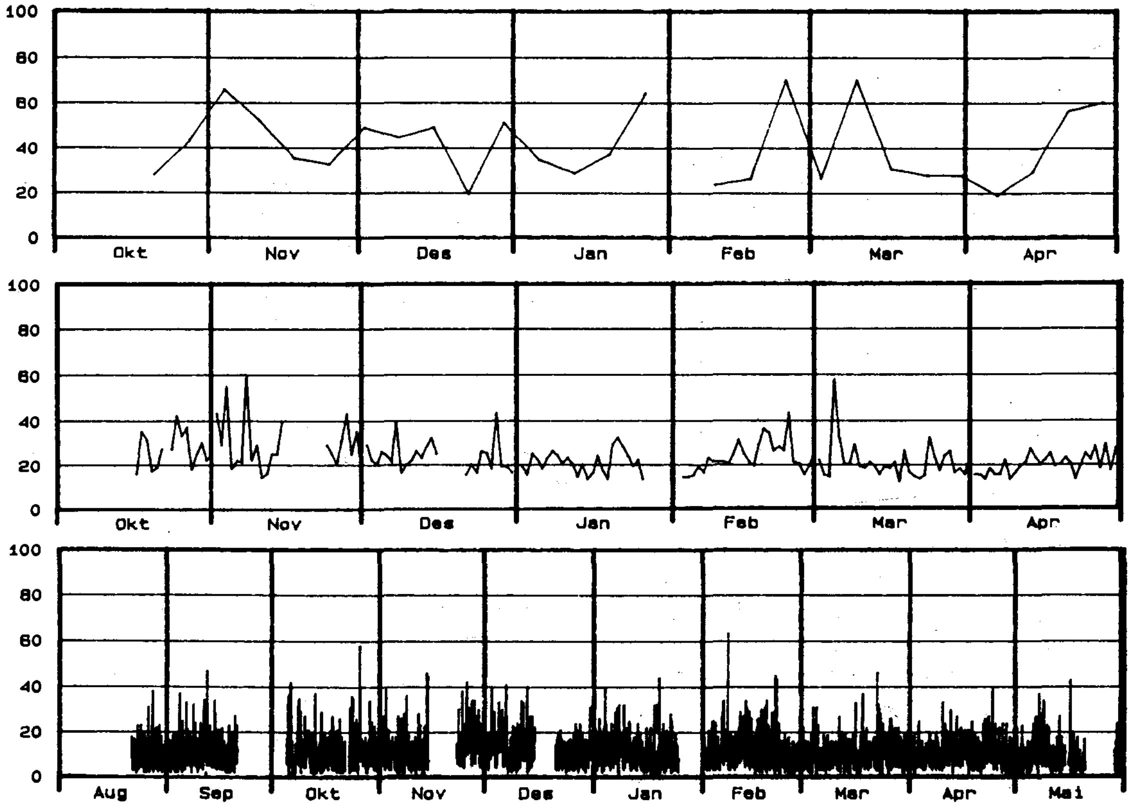


Fig 10 Standard deviation each week (a), day (b) and hour (c).

6. ASF

The predicted value of TOA-X at Vadsoe was calculated after the Millingtons methods:

$$\hat{TOA} = t_{PF} + t_{SF} + t_{ASF}$$

$\hat{TOA}$ = Predicted TOA

PF = Primary phase factor

SF = Secondary phase factor

ASF = Additional secondary phase factor

Distance from transmitter to receiver = 618029 meter

t_{PF} = 2062,220 uS

$t_{SF} + t_{ASF}$ = 5,678 uS [Millingtons method]

$\hat{TOA}$ = 2067,898 uS (Predicted TOA)

$\overline{TOA}$ = 2067,149 uS [$\overline{TOA}$ = Average measured TOA]

Estimated $t_{SF} + t_{ASF}$ = 4,929 uS

7. Amplitude

The Austron 2000 also gives us the amplitude of the LORAN-C signal. In fig 11 you can see the amplitude at the receiver site as function of time.

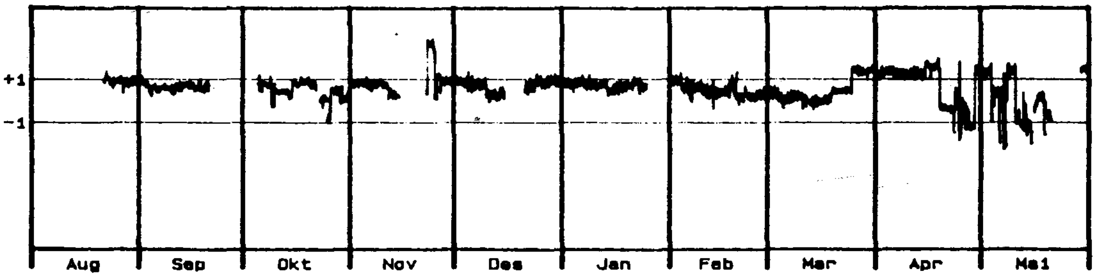


Fig 11 Amplitude (signal fieldstrength) of the X-signal in Vadsoe from Aug 84 to May 85.

The variation in the amplitude is very small, and the deviations that exists in this curve can be explained from other reasons than reasonal change in propagation conditions.

8. Conslusion

The total measured change in TOA is about 800 nanoseconds, but the five calibration measurements indicate a total change of 200-250 nanoseconds. The results of the TD-measurements seems to confirm that the variation in TOA is less than 500 nanoseconds (this data is not discussed in the paper).

On this basis it is concluded that the effect of seasonal changes in climate and weather is in the order of 200-400 nanoseconds. It is reason to believe that it is possible to keep the baseline Boe - Vardoe stable within and accuracy of 0,1 microsecond (1σ), taken into account a proper chain control system.

BIOGRAPHICAL SKETCH

Kolbjoern Saether is a project engineer at the Norwegian Defence Communications Administration (NODECA) in Oslo, Norway. He graduated from the Norwegian Institute of Technology in Trondheim in 1982. He is a former officer from the Royal Norwegian Navyø, and is now working at NODECAs navigation office.

Wind Measurements Using All Available LORAN Stations

Vincent E. Lally
Claude Morel

National Center for Atmospheric Research
Boulder, Colorado

Abstract

The Cross-chain Loran Atmospheric Sounding System (CLASS) is a technique to determine the wind field from movement of a balloon or parachute using a least-squares solution of the differences of times-of-arrival of the signals from all detectable LORAN stations. Tests of the system have been made in all areas of the country, and a survey performed to estimate the accuracy of the system throughout the region of the "mid-continent" gap. The error charts are presented based on the survey and test results. These charts are extrapolated to show improvements with one additional LORAN station located in the western plains. The technique is expanded to demonstrate the measurement of the altitude of a balloon using direct and translated LORAN time-of-arrival readings. A corollary technique is described in which winds are determined using only two LORAN stations and an independent measure of altitude.

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* The National Center for Atmospheric Research is sponsored by the National Science Foundation

The Need

For many years there has been a need for a new rawinsonde system to meet the requirements of the research community. The standard AN/GMD-1 (military) and WBRT (National Weather Service) systems have been in use for 25 years. These vacuum-tube technology systems are being rehabilitated for operational use, but this upgrade is costly. The systems cannot provide the fine scale wind structure in the boundary-layer needed for mesoscale research and accuracy is degraded at low-elevation angles and long ranges. Radar tracking systems are used in many countries for wind-soundings, but equipment costs are high and maximum range is limited.

For shipboard soundings and aircraft dropwindsondes, the OMEGA navigation system has been used to obtain wind data for synoptic analyses. The averaging times (typically 3 minutes) required to smooth the noisy data preclude the use of OMEGA sondes for mesoscale programs. In addition, the central U.S. has the worst coverage in the world for OMEGA signals. John Beukers pioneered the use of LORAN-C for radiosonde wind measurements but LORAN-C has not been accepted for general radiosonde use since coverage does not extend over the central states. Fig. 1 illustrates the accuracy of winds obtainable over the U.S. using the existing LORAN chains as individual chains. The mid-continent gap is clearly indicated. The algorithm used for determining accuracy is based on survey results for nighttime (worst case) conditions. The simple empirically-derived algorithm used for determining the standard deviation of the TOA as a function of distance is:

$$\sigma_{TOA} = -\ .0061D + .000013\ D^2$$

where σ is in meters and D in kilometers.

If D < 900 KM, $\sigma = 5$ meters
If D > 1600 KM, then the station is not used.

The Survey

The ANI-7000 LORAN-C navigator has been developed for aircraft use which permits coverage across the U.S. by combining data from all chains from which at least two stations could be detected. At NCAR we made an extensive survey in September 1984 throughout the mid-west using the ANI-7000 navigator to determine the RMS deviation of the TOA data for all received stations. These data were used to derive the algorithm given above. Wind error charts were then produced for the U.S. and surrounding regions using a least-squares solution in which all detectable stations are used and weighted according to signal strength. (Passi, 1973)

Fig. 2 illustrates the expected accuracy of wind computation using a cross-chain configuration. Note that acceptable coverage is available now

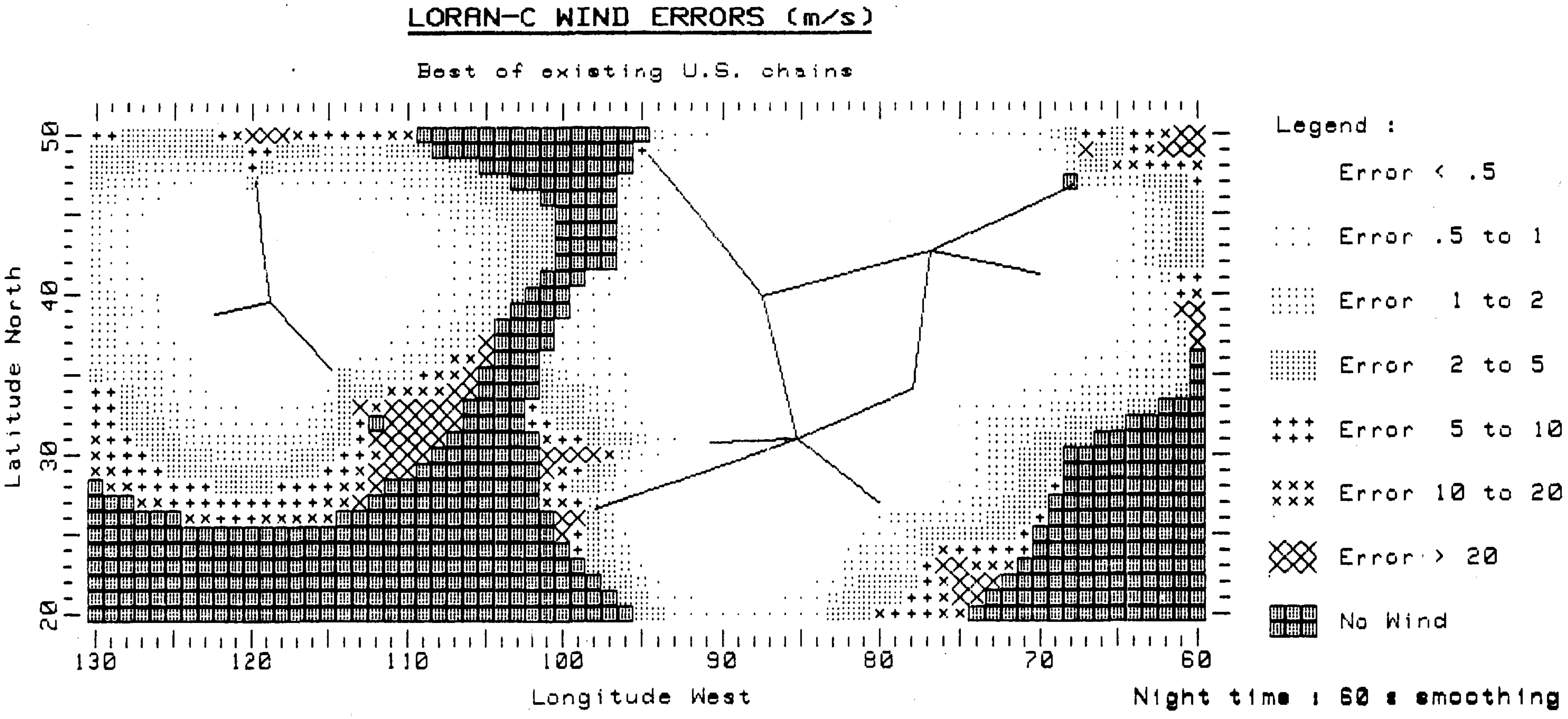
LORAN-C WIND ERRORS (m/s)
Best of existing U.S. chains
Latitude North
20
30
40
50
Longitude West
130
120
110
100
90
80
70
60
Legend :
Error < .5
Error .5 to 1
Error 1 to 2
Error 2 to 5
Error 5 to 10
Error 10 to 20
Error > 20
No Wind
Night time : 60 s smoothing

Figure 1

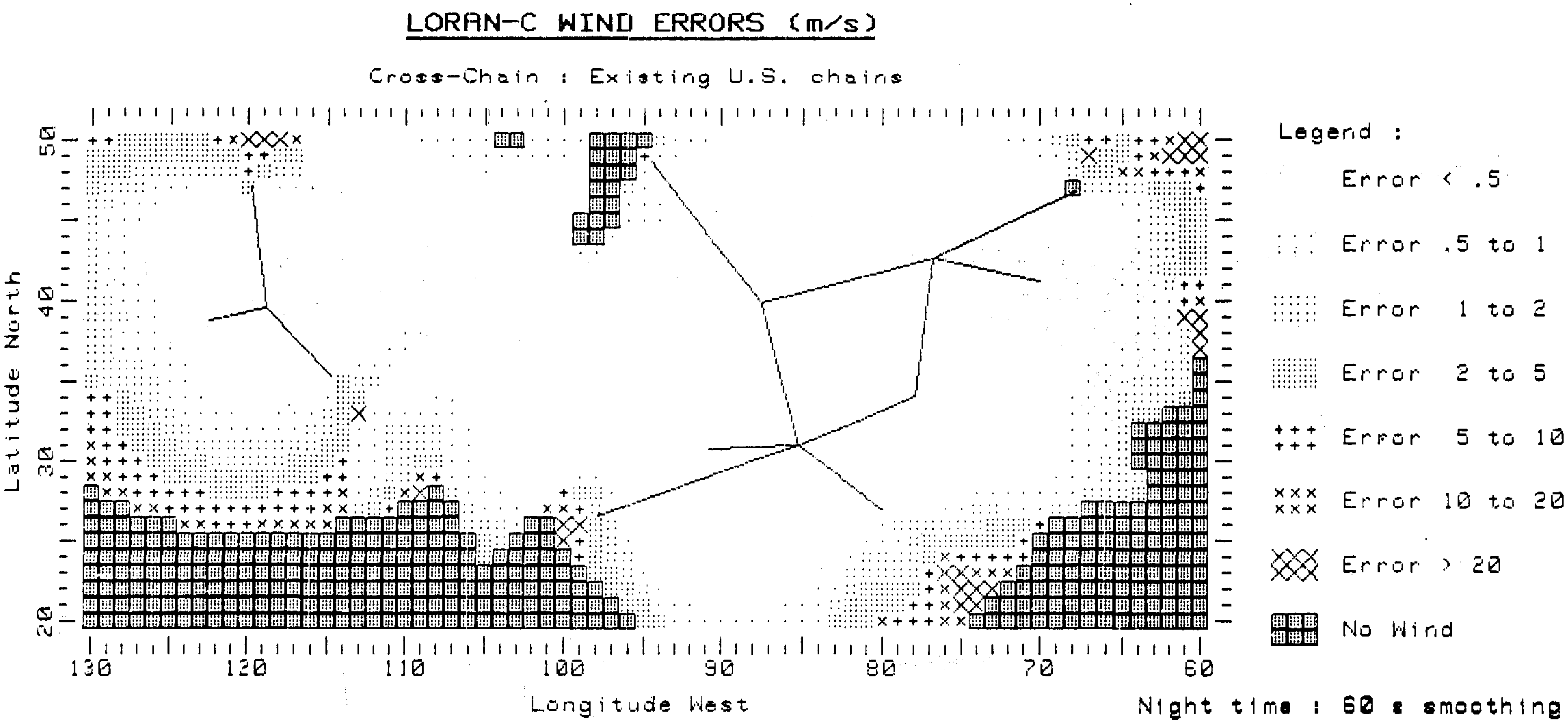
LORAN-C WIND ERRORS (m/s)
Cross-Chain : Existing U.S. chains
Legend :
Error < .5
Error .5 to 1
Error 1 to 2
Error 2 to 5
Error 5 to 10
Error 10 to 20
Error > 20
No Wind
Latitude North
50
40
30
20
130
120
110
100
90
80
70
60
Longitude West
Night time : 60 s smoothing

Figure 2

with the existing chains except for a swath through the central Dakotas. With the addition of a single station located in Colorado (40°N, 105°W) the gap is eliminated. (Fig. 3)

With assurances from the Department of Transportation that a new LORAN chain will be installed in the central U.S., we confidently abandoned our on-going radiosonde development program and devoted our efforts to the development of a Cross-chain Loran Atmospheric Sounding System (CLASS).

System Tests

The CLASS system consists of an automatic balloon launcher and electronics hardware housed in a 12-foot trailer. The balloon launcher has been successfully tested in gale-force winds (Fig. 4). The hardware includes a 400 MHz antenna, preamplifier, and receiver; elements of the ANI-7000 LORAN-C aircraft navigator; a meteorological data digitizer; an HP 9816 computer; and a smart modem to transmit data via satellite or telephone link.

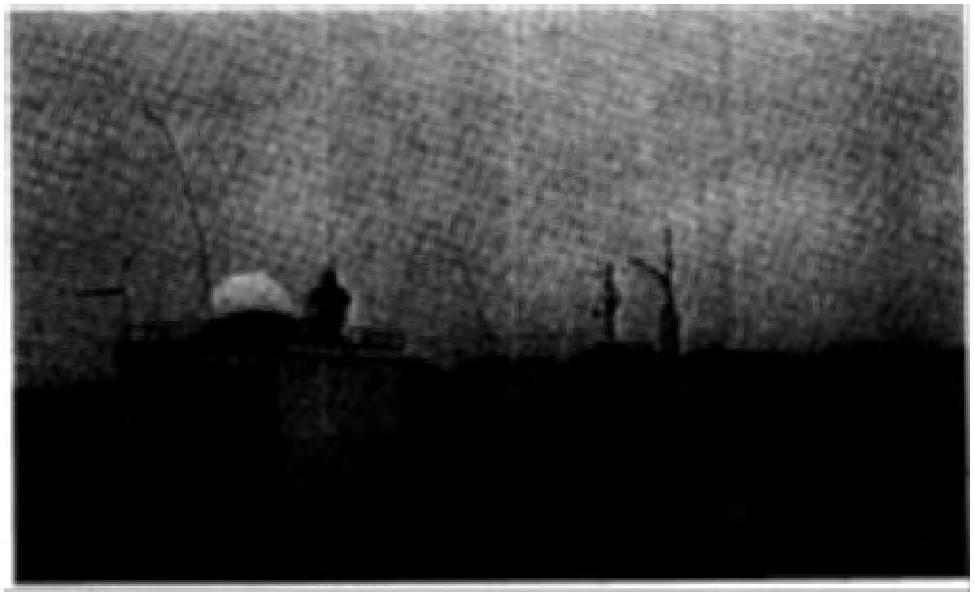

Figure 4. CLASS Balloon Launch--Heavy Winds

The system was first tested at White Sands Missile Range in January 1985. Fig. 5 is a comparison of the CLASS winds versus those determined by a precision radar. The correlation is excellent. Note that it would not be possible to obtain useful position or wind data at White Sands using a single LORAN chain. (cf Fig. 1)

A series of additional tests were made at Hatteras, North Carolina in February 1985 to test the system in severe weather conditions. Wind data were excellent as expected and the system performed well at ranges up to 200 km. The generalized least-squares solution provides, as a by-product, an estimate of the standard error of the winds which is used as a quality index. Typical computed errors were 0.5 m/s for 30 second averages.

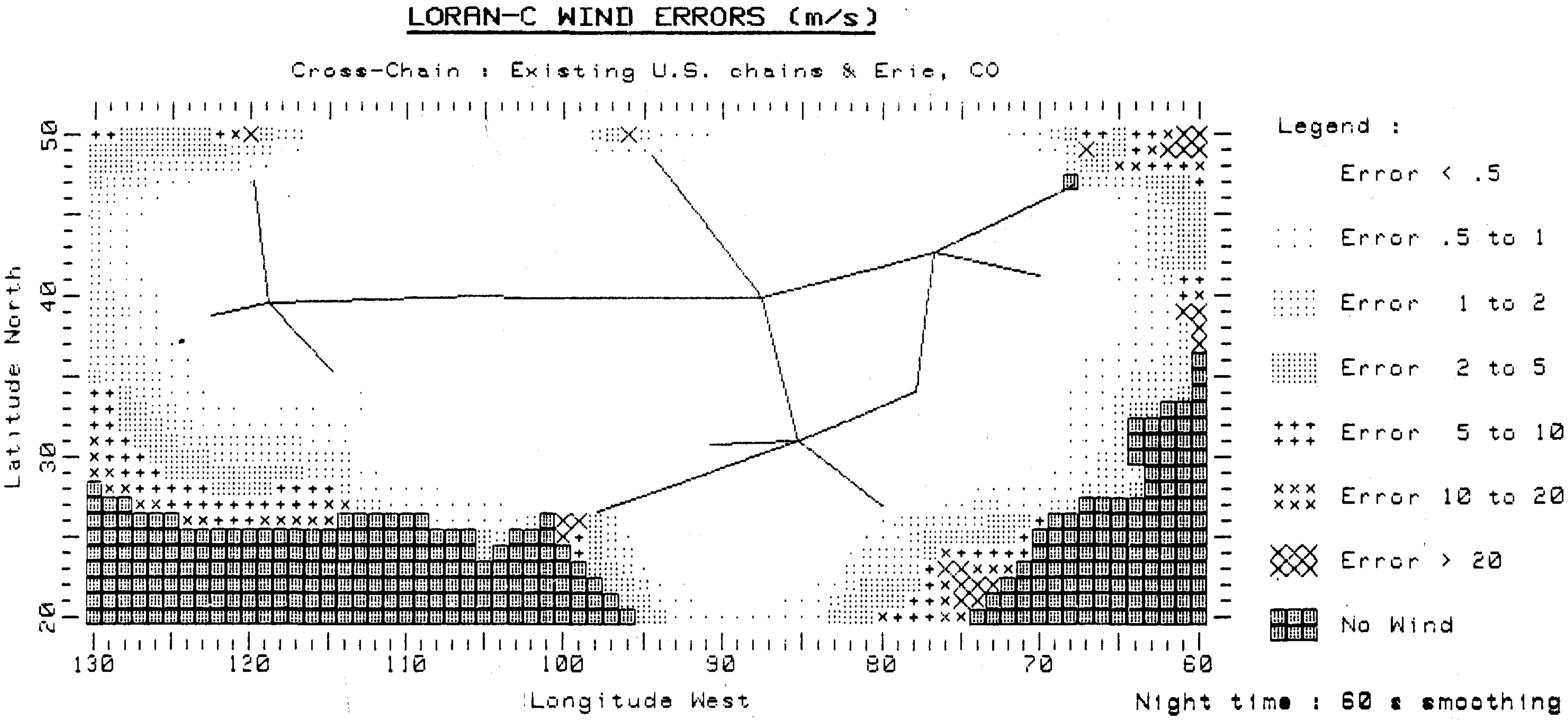
LORAN-C WIND ERRORS (m/s)
Cross-Chain : Existing U.S. chains & Erie, CO
Latitude North
20
30
40
50
130
120
110
100
90
80
70
60
Longitude West
Legend :
Error < .5
Error .5 to 1
Error 1 to 2
Error 2 to 5
Error 5 to 10
Error 10 to 20
Error > 20
No Wind
Night time : 60 s smoothing

Figure 3

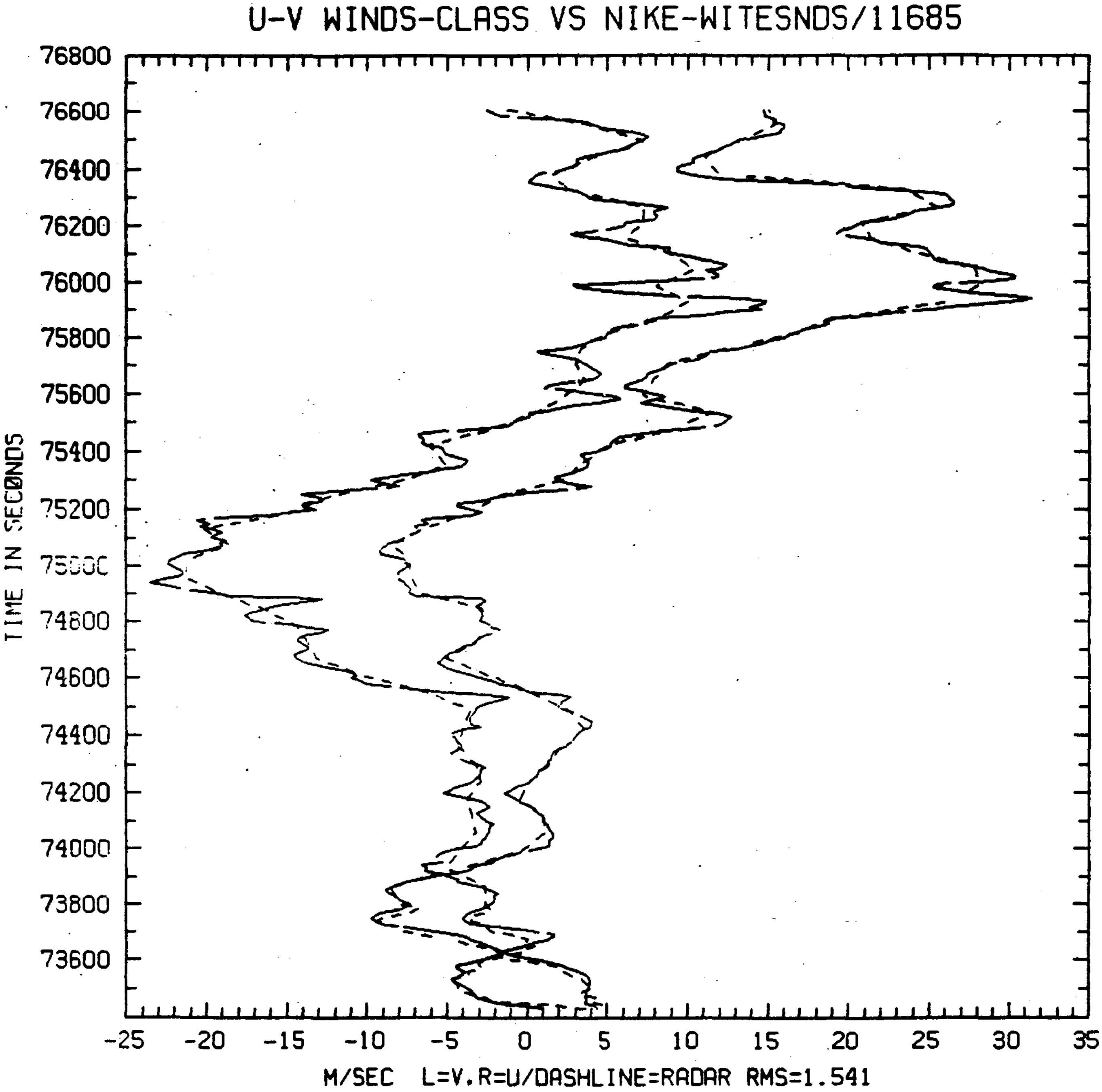
U-V WINDS-CLASS VS NIKE-WITESNDS/11685
TIME IN SECONDS
76800
76600
76400
76200
76000
75800
75600
75400
75200
75000
74800
74600
74400
74200
74000
73800
73600
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
M/SEC L=V.R=U/DASHLINE=RADAR RMS=1.541

Figure 5

Nine CLASS systems are now being assembled for use in early 1986 in the Genesis of Atlantic Lows Experiment (GALE). Three of the trailers will be built for shipboard operation.

Altitude Measurements

The radiosonde used with the CLASS system consists of a simple LORAN receiver, pressure, temperature, and humidity sensors, a modulator which mixes the LORAN signals and the meteorological data signals, and a 400 MHz transmitter. The signals, delayed in transit from sonde to ground, are demodulated and the LORAN signals introduced to the ANI-7000 navigator. Since all computations are made with respect to difference of TOA's, the common delays through sonde, sonde-to-ground, and ground receiver are all cancelled. The navigator operates as if it were on the balloon.

Consider an alternate system which includes a very stable oscillator, permitting direct measurement of arrival time of the LORAN signals rather than time differences. (Note that a second LORAN receiver can substitute for the stable oscillator if it is used to make differential measurements with a common oscillator.) The time-of-arrival, T_A, of the LORAN signal from station A, can be expressed as:

$$T_A = \frac{1}{c} (D_{AS} + D_{SR}) + t_c + \tau \qquad (1)$$

where D_{AS} is the distance from station A to the sonde, D_{SR} is the distance from sonde to ground receiver, t_c is the secondary time correction, τ is the internal electrical delay in sonde and ground receiver, and c is the vacuum velocity of light. Prior to launch of the balloon with sonde close to receiver, we can measure T_A. Since D_{AS} and D_{SR} are known, we can solve for $t_c + \tau$. Assuming that changes in T_c and τ are predictable, there are three unknowns--latitude, longitude, and altitude--to be determined. With time-of-arrival data from three stations we can solve for the three unknowns.

Our first test was to determine the variation in time delay, τ, for LORAN signals through a radiosonde as a function of temperature. The radiosonde used was a Vaisala RS-80L sonde. The average change in TOA was 13 nanoseconds per degree Celsius. During flight we assumed a temperature drop from 30°C to 0°C, corresponding to a change of about 400 nanoseconds (approximately 120 meters). Since the sonde flown was not the sonde tested, there is uncertainty in this estimate.

The secondary time correction, t_c, serves as a catch-all to describe changes in TOA due to changes in the terrain between radiosonde and LORAN station and changes in altitude. These changes can be as much as 3 or 4 microseconds as a function of altitude and varying terrain. Theory indicates that the changes can be almost completely corrected. (Johler, 1971)

On June 13, 1985 we made a test flight using the CLASS electronics systems and substituting a rubidium oscillator for the oscillator normally used in the ANI-7000 LORAN receiver. The flight was made from Boulder on a day with strong down-slope winds and turbulent cells. The difference between altitude measured by the sonde's pressure element and by the LORAN computation is given in Fig. 6. These computations were made using eight stations to compute both position and altitude. A series of computations were made using all possible three station combinations. The results were similar in all cases, indicating that differences in propagation effects from the stations to the sonde were not as significant as other error sources.

The second and third graphs in Fig. 6 plot the difference in TOA computed from position, altitude and the measured values of TOA. Graphs are presented for Searchlight, Nevada and Grangeville, Louisiana. All West Coast stations provide similar graphs to Searchlight and all of the Great Lakes and Southeast stations produce graphs similar to Grangeville. Our findings:

a) Immediately after launch there is a jump of 0.4 μsecond in TOA for all stations.

b) The errors in TOA produce errors in altitude which are amplified by a factor proportional to 1/sin α where α is the elevation angle between ground receiver and sonde. At the end of the flight this is a factor of 5x for the 11° elevation angle.

c) Phase shifts as a function of terrain are not a major contributor. If terrain effects were dominant, there should be large differences in the TOA errors for the individual stations.

d) With the documentation available on this flight we cannot distinguish among phase shifts as a function of altitude, as a function of temperature changes in the sonde receiver, or as a function of signal strength changes in the ground receiver.

The test flight demonstrated the feasibility of altitude measurement using LORAN-C. It also revealed a number of serious problems which must be solved if the technique is to be used operationally. Future tests will be made with a sonde calibrated for time delays, a precision radar for altitude measurements, and with flight over more uniform terrain where altitude and ground effects are more easily predicted.

Two-station Solutions

We have demonstrated (with reservations) that the LORAN navigation system can be used to determine altitude of a balloon if the signals from three or more LORAN stations can be translated through the radiosonde to a ground system which includes either a local LORAN receiver or a very stable oscillator. Can we locate a balloon if only two LORAN stations are in range and we have a local LORAN or a very stable oscillator on the ground as well as a measurement of altitude telemetered from the balloon

The time-of-arrival of the LORAN signal was described in Eq. 1 as a function of (D_{AS} + D_{SR}) where D_{AS} is the distance from station A to the

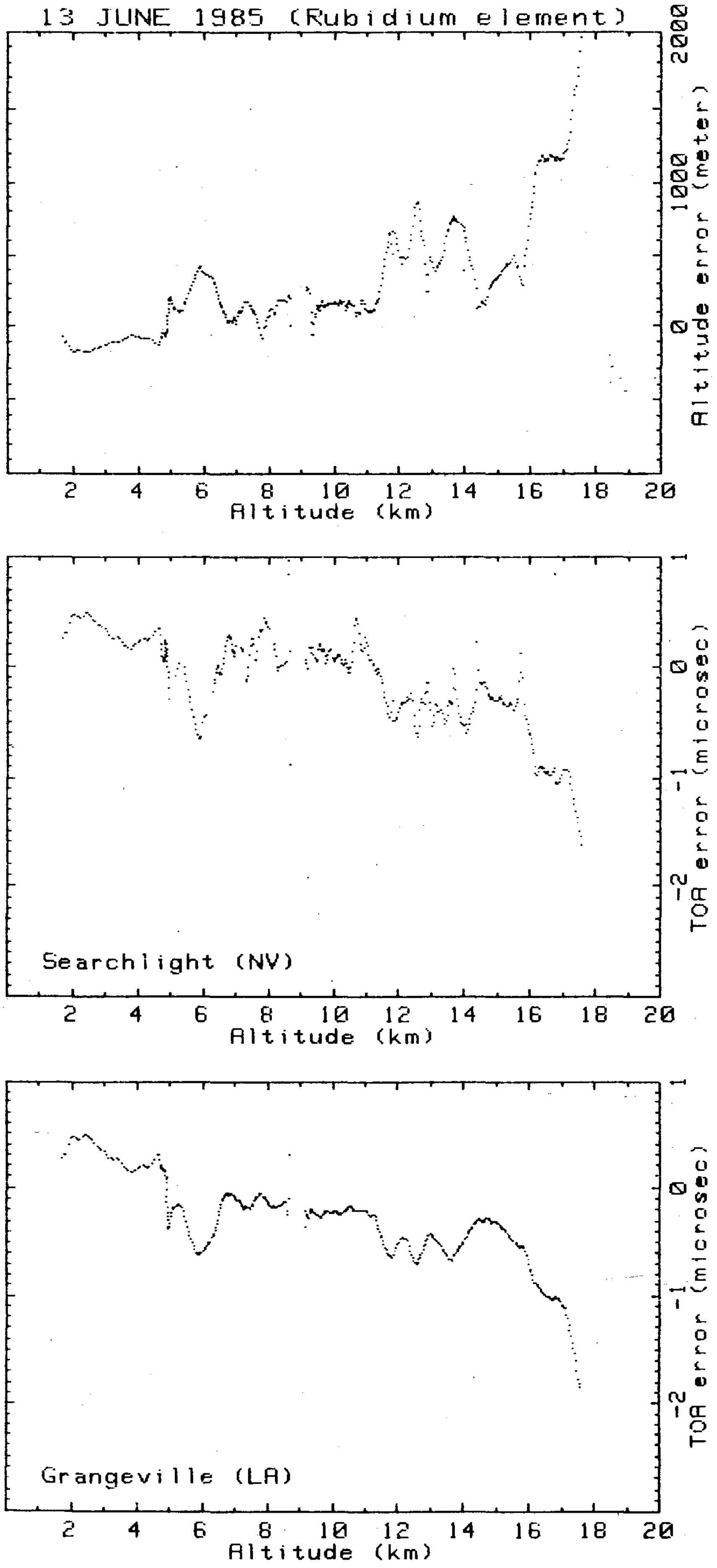
13 JUNE 1985 (Rubidium element)
Altitude error (meter)
2000
1000
0
Altitude (km)
2
4
6
8
10
12
14
16
18
20
TOA error (microsec)
1
0
-1
-2
Searchlight (NV)
Grangeville (LA)

Figure 6

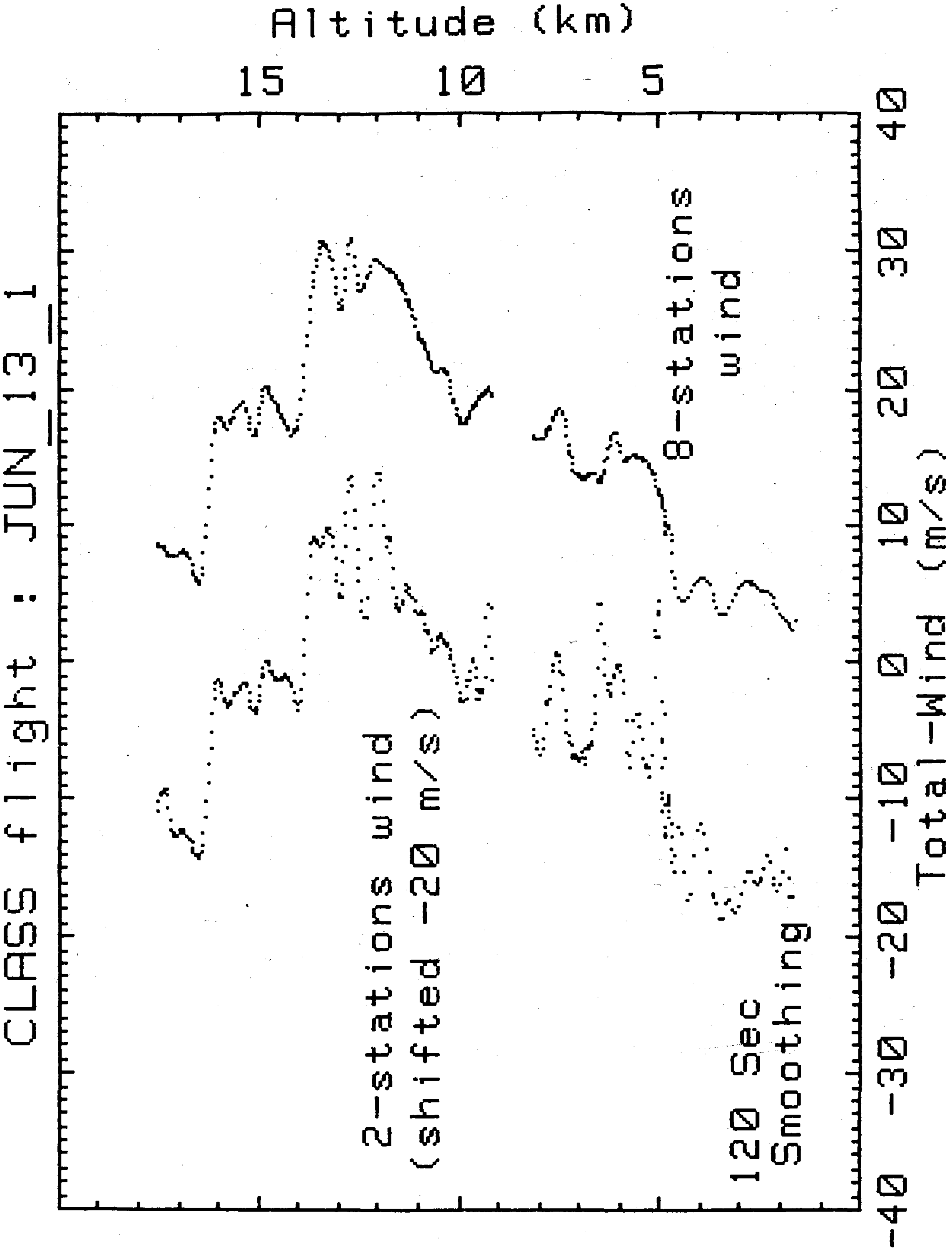
CLASS flight : JUN 13 1
Altitude (km)
15
10
5
Total-Wind (m/s)
-40
-30
-20
-10
0
10
20
30
40
8-stations wind
2-stations wind (shifted -20 m/s)
120 Sec Smoothing

Figure 7

sonde and D_{SR} is the slant range from sonde to the ground receiver. D_{AS} is a function of latitude and longitude, and D_{SR} is a function of latitude, longitude and altitude. If altitude is known, then we can solve for latitude and longitude with two stations. In this case there is no geometric dilution of accuracy at low elevation angles. Fig. 7 illustrates the total wind measurement on the 13 June flight using all eight stations in a classical least-squares solution versus a two-station solution in which altitude is obtained from pressure measurements.

Results indicate the feasibility of this approach which will allow the use of a CLASS system in areas with poor coverage. The two-station solution will permit wind computations, for example, through those areas in the Dakotas where only the Baudette, Minnesota and the Dana, Indiana stations are within range. Much theoretical work on error sources and careful tests must be made before the two-station solution can be considered for operational use. Extensive studies and tests are planned for 1986.

Summary

The CLASS system provides a means of obtaining accurate, research-quality wind data using all available LORAN stations. Its accuracy will be greatly enhanced with the addition of a single additional LORAN station east of the Rockies. The quality of the data available from the system and its programming flexibility may produce altitude measurements of sufficient accuracy to obviate the need for a pressure element. As a corollary, use of the altitude data derived from the pressure element permits computation of winds with only two available stations.

Acknowledgements

We acknowledge our debt to John Beukers who in 1967 demonstrated the measurement of winds from a balloon using translated LORAN signals. We also owe much to Jimmie Toms of ANI, Inc. who provided the cross-chain LORAN receivers and graciously modified these to meet our needs for balloon tracking. Dean Lauritsen produced the CLASS system in record time from decision to build in October 1984 to successful flight demonstration in January 1985. Ranjit Passi has provided the mathematical insight and the algorithms for our over-specified systems; Zohreh Malekmadani produced the operational software under the tightest time constraints; and Bob McBeth conducted the critical survey and acted as skillful field manager. Aubrey Schumann provided the analysis of White Sands data.

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Passi, R.M., 1973: Errors in wind measurements derived from Omega signals. NCAR Tech Note, TN/STR-88, 35 pp.

Johler, R.J., 1971: LORAN Radio Navigation over irregular inhomogeneous ground with effective ground impedance maps. Telecommunications Research and Engineering Report 22, OT/TRER22, U.S. Department of Commerce.

Biographical Sketch

Vincnet E. Lally

Vincent E. Lally is a Senior Scientist at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. He holds degrees from the University of Chicago and the Massachusetts Institute of Technology.

After service in World War II as a Meteorologist and Radar Officer in the Army Air Corps, Mr. Lally was in charge of meteorological systems development for the U.S. Air Force in the 1950's. Since 1961 he has been on the NCAR staff with responsibility for scientific balloon systems development. He is a Fellow of the American Meteorological Society.

LORAN-C SIGNALS IN THE CONTERMINOUS UNITED STATES

FRANCIS W. MOONEY

U.S. Department of Transportation
Transportation Systems Center
Cambridge, MA 01945

ABSTRACT

From 1982 through 1985, engineering test teams from the Transportation Systems Center (TSC), under sponsorship of the Radionavigation Division (G-NRN), U.S.Coast Guard, visited all LORAN-C stations (LORSTAs) in the Conterminous United States (CONUS). Using a special suite of test equipment, emissions from each station were measured in the frequency and time domain. Measured data were compared with the "Specification of the Transmitted Loran-C Signal," U.S. Coast Guard Commandant Instruction M16562.4. This paper describes the test program and presents a summary of results. On the whole, LORSTAs demonstrated that they could meet frequency and time domain standards. The AN/FPN-42 transmitters, soon to be replaced, had difficulty meeting in-band energy requirements when interfaced with antennas other than the 625 foot top loaded monopole.

INTRODUCTION

In 1981, the Coast Guard commissioned TSC to assemble a suite of test equipment which could be used to document emissions of LORSTAs in the frequency domain. The equipment suite had to be installed in a mobile test facility (MTF) so that a number of measurements could be made at various locations in the vicinity of a station. Successful tests were conducted at LORSTA Seneca in 1982. The capability to measure time domain emissions was added in 1983 and TSC conducted measurements at all CONUS LORSTAs during the period of August 1983 through May 1985.

Individual station reports were prepared after visits to provide the Coast Guard with easily referenced data. Station emissions were compared to the U.S. Coast Guard "Specification of the Transmitted LORAN-C Signal," contained in COMDT INST. M16562.4. A composite report addressing the entire program is being prepared and will be distributed by the National Technical Information Service (NTIS). This paper presents a summary of information which will be contained in the composite report.

FREQUENCY DOMAIN

EQUIPMENT DEVELOPMENT

Basic procedures for establishing in-band energy levels from LORSTAs were developed by the Coast Guard many years ago. Energy samples were obtained at discrete frequencies throughout the band 76 to 124 kHz and the energy in-band was calculated using Simpson's rule. Data required considerable time to gather and on-station harmonic measurements were suspect due to the high RF energy levels.

Introduction of the microcomputer controllable, via standard interface bus, Hewlett Packard (HP) 3585A Spectrum analyzer made it possible to conduct off-station, in-band power measurements in minutes, rather than hours. The spectrum analyzer was "steered" by a controlling scientific microcomputer which recorded data and calculated in-band energy levels. By observing the IF output of the spectrum analyzer, it was also possible to unambiguously identify and measure harmonic transmissions from stations with dynamic resolution in excess of 120 dB. In addition, special scanning techniques were developed which permitted identification of interfering frequencies throughout the mobile maritime band. The suite of equipment was successfully tested at LORSTA Seneca in 1982.

Two different controlling microcomputers were used during the program. A Tektronix 4052 graphics computer was used from 1982 through 1984. Limitations in memory size restricted data analysis and continuing problems with mass storage functions led to its replacement with a Hewlett Packard HP86 computer. Diagrams of the instrumentation suites are shown in Figures 1 and 2.

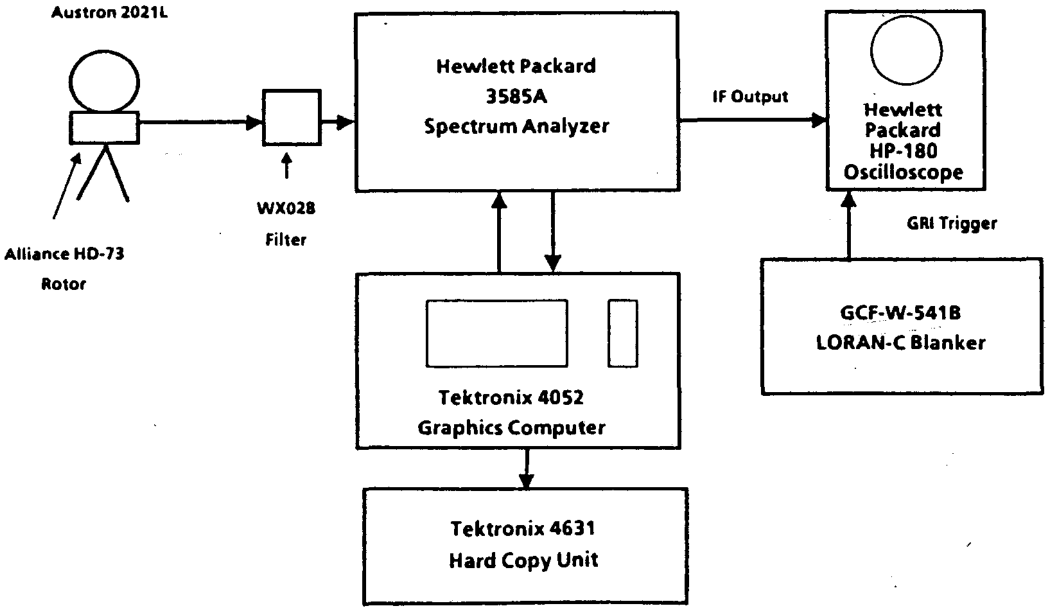


FIGURE 1. EQUIPMENT CONFIGURATION FOR MEASUREMENT OF FREQUENCY DOMAIN DATA USING TEKTRONIX 4052

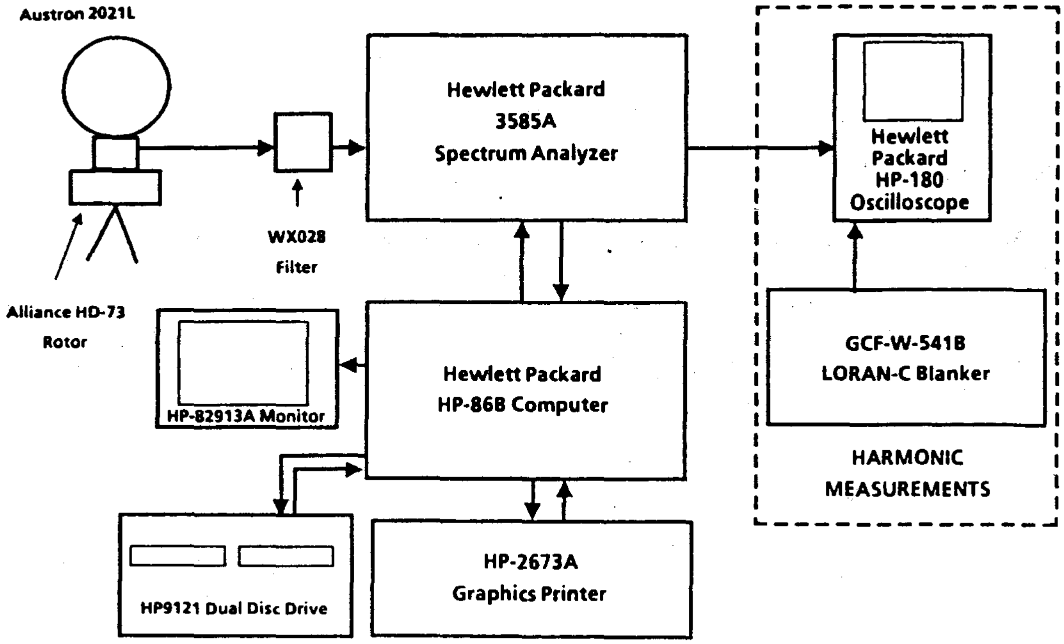


FIGURE 2. EQUIPMENT CONFIGURATION FOR MEASUREMENT OF FREQUENCY DOMAIN DATA USING HP-86

MEASUREMENT PROCEDURES

Frequency domain data were taken on station, at a near station site (typically 0.5 mi. from the station) and at least 3 sites remote from the station (1 to 4 mi.). In-band energy was measured at all sites. Harmonic data was taken at the near station site.

MEASUREMENT RESULTS

There are three generic types of transmitters used in CONUS; the AN/FPN-42, the AN/FPN-44/45 and the AN/FPN-64. Each type proved to have unique characteristics and the results are summarized by transmitter type. The transmitters are interfaced with several types of antennas. A listing is provided in Table 1.

AN/FPN-42 Stations

AN/FPN-42 transmitters operated into 625 foot top loaded monopole (TLM) antennas met in-band energy requirements of 99 percent (+/-0.1 percent), with some skewing of out-of-band components. When operated into wider band antennas, such as the sectionalized LORAN-C Transmitting (SLT) antenna at Caribou ME, and the top loaded, inverted pyramid (TIP) antenna at Carolina Beach, NC, the transmitters failed to meet the 99% in-band requirement. LORSTA Baudette, MN, with its 730 foot TLM, also did not meet requirements.

Harmonics were measured from 200 through 1200 kHz. No specifications regarding performance is currently included in M16562.4. There were significant variation in harmonics between stations. Figure 3 shows representative curves of energy levels for transmitter performance into different antennas. Table 2 summarizes performance results.

TABLE 1. CONUS LORAN-C STATIONS

NAME	*TRANSMITTER*	*ANTENNA*
NANTUCKET	AN/FPN-42	625' TLM (1)
JUPITER	AN/FPN-42	625' TLM
BAUDETTE	AN/FPN-42	730' TLM
CARIBOU	AN/FPN-42	SLT (2)
CAROLINA BEACH	AN/FPN-42	TIP (3)
DANA	AN/FPN-44A	625' TLM
MIDDLETOWN	AN/FPN-44A	625' TLM
FALLON	AN/FPN-44A	625' TLM
SEARCHLIGHT	AN/FPN-44A	SLT
GEORGE	AN/FPN-45A	SLT
SENECA	AN/FPN-64(56 HCG)	700' TLM
MALONE	AN/FPN-64(56 HCG)	700' TLM
GRANGEVILLE	AN/FPN-64(56 HCG)	700' TLM
RAYMONDVILLE	AN/FPN-64(32 HCG)	700' TLM

(1) Top Loaded Monopole

(2) Sectionalized Loran Transmitting Antenna

(3) Top Loaded Inverted Pyramid

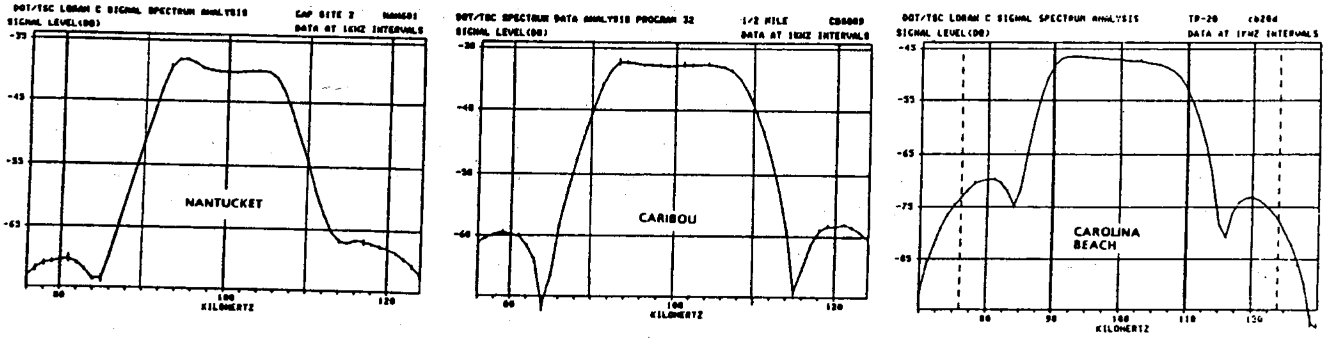


FIGURE 3. REPRESENTATIVE AN/FPN-42 SPECTRUM ENERGY ENVELOPES

TABLE 2. FREQUENCY DOMAIN PERFORMANCE OF AN/FPN-42 TRANSMITTERS

SPECIFICATION	POWER DISTRIBUTION (in %)			HARMONICS (in dB, referenced to pulse peak)										
	IN BAND	BELOW 90 KHZ	ABOVE 110 KHZ	200	300	400	500	600	700	800	900	1000	1100	1200
NANTUCKET(1)	98.6	0.8	0.5	-39	-50	-49	-50	-47	-50	-53	-51	-49	-49	-49
JUPITER	99.4	0.4	0.2	-60	-56	-79	-74	-83	-81	-82	-73	-71	I.N. (3)	I.N.
BAUDETTE	98.4	1.0	0.6	-71	-78	I.N.	I.N.	I.N.	I.N.	I.N.	-74	-72	-74	I.N.
CARIBOU	96.6	1.9	1.4	-68	-78	-76	-84	(2)	-77	-81	-82	-75	-87	I.N.
CAROLINA BEACH	93.5	2.4	4.1	-53	-61	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.

(1) ONE TRANSMITTER AT 98.9%
(2) LOCAL RADIO STATION MASKED HARMONICS
(3) I.N.- IN NOISE; HARMONIC OBSCURED IN BACKGROUND NOISE LEVEL

AN/FPN-44/45

These transmitters are located at West Coast stations and at LORSTA Dana. During the period when measurements were conducted, the West Coast transmitters were being upgraded with a feedback modification. Among other features, this modification makes it easier to control the shape of the pulse tail. This, in turn, makes it easier to control performance in the frequency domain. All transmitter/antenna combinations proved capable of meeting in-band energy requirements of 99 percent (+/-0.1 percent), but all stations did not meet requirements. LORSTA Fallon outperformed all other stations by demonstrating in-band energy of 99.34 percent.

Harmonics from these transmitters were lower than those of the AN/FPN-42. Figure 4 shows the spectrum envelopes of LORSTA Fallon (feedback equipped) and LORSTA Middletown (prior to feedback). Table 3 summarizes station performance.

AN/FPN-64

The AN/FPN-64 is the newest generation of LORAN-C transmitters and proved to have consistent in-band energy performance at the required 99 percent (+/-0.1 percent) level. There was little variation between stations. Harmonics proved to be considerably lower than either the AN/FPN-42 or AN/FPN-44/45 transmitters. A representative energy spectrum is shown in Figure 5. Table 4 summarizes station performance.

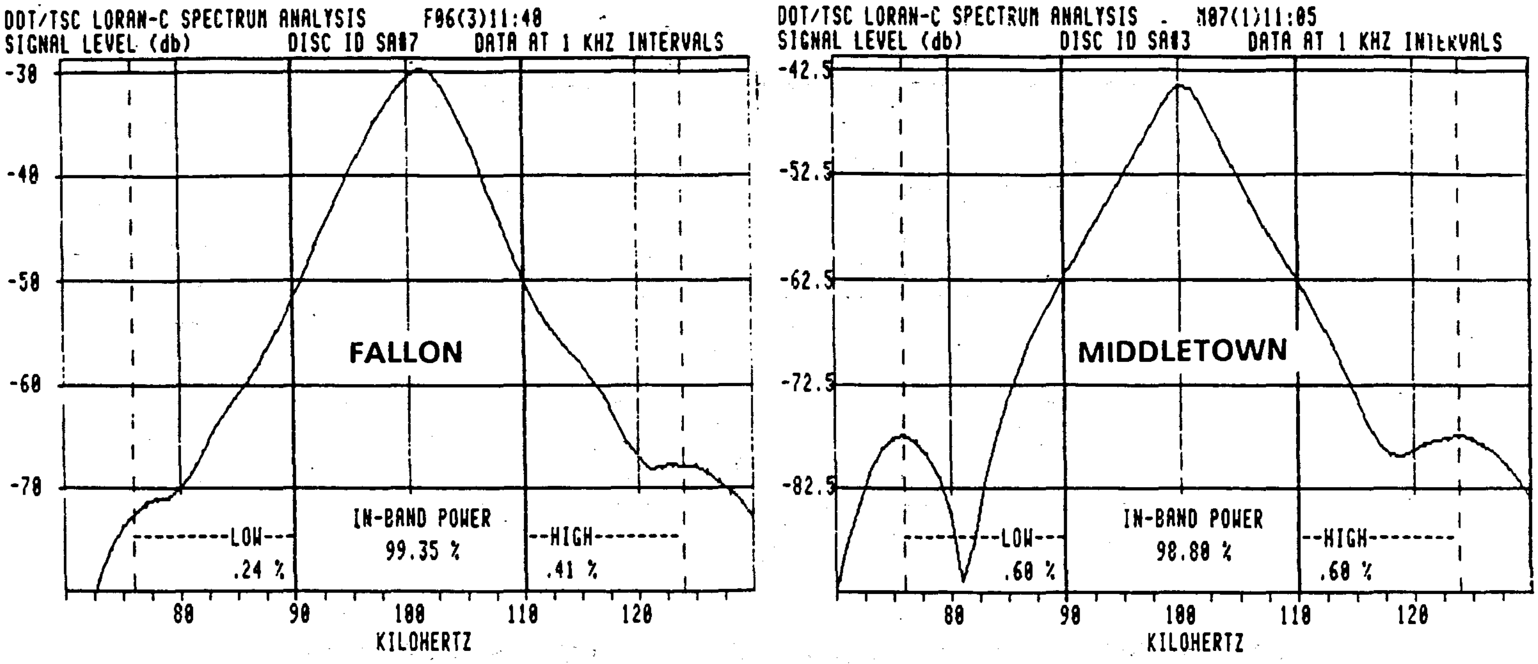


FIGURE 4. SPECTRUM ENERGY ENVELOPES FOR LORSTAS FALLON AND MIDDLETOWN

TABLE 3. FREQUENCY DOMAIN PERFORMANCE OF AN/FPN-44/45 TRANSMITTERS

SPECIFICATION	POWER DISTRIBUTION (in %)			HARMONICS (in dB, referenced to pulse peak)										
	IN BAND	BELOW 90 KHZ	ABOVE 110 KHZ	200	300	400	500	600	700	800	900	1000	1100	1200
DANA	98.2	1.2	0.7	-71	-76	I.N.*	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.
MIDDLETOWN	98.9	0.6	0.6	-69	-76	-83	-85	-84	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.
FALLON	99.4	0.3	0.4	-65	-85	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.
SEARCHLIGHT	99.0	0.2	0.8	-65	-78	-80	-80	-85	-85	-95	-98	-93	-100	-100
GEORGE	99.1	0.3	0.6	-70	-79	I.N.	I.N.	I.N.	-76	I.N.	I.N.	I.N.	I.N.	I.N.

* I.N.- IN NOISE;HARMONIC OBSCURED IN BACKGROUND NOISE LEVEL

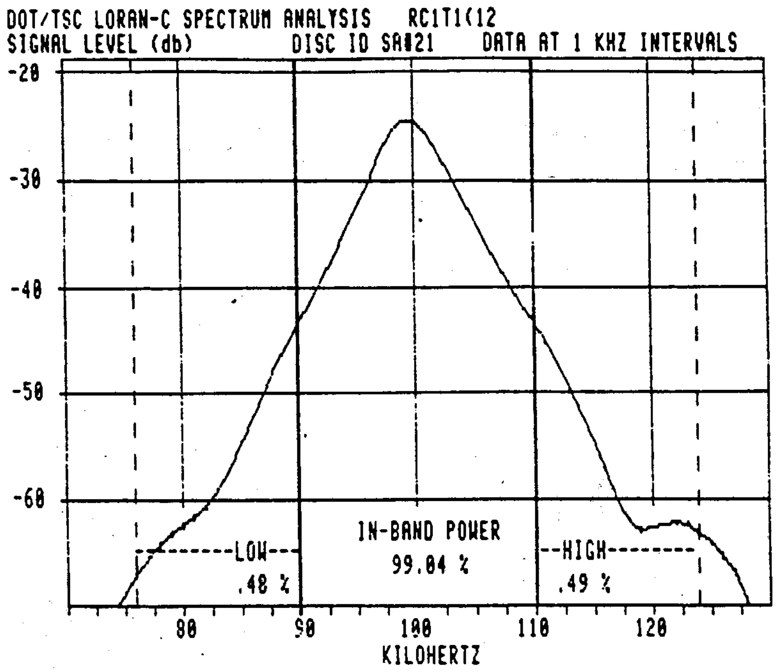


FIGURE 5. SPECTRUM ENERGY ENVELOPE FOR LORSTA RAYMONDVILLE

TABLE 4. FREQUENCY DOMAIN PERFORMANCE OF AN/FPN-64 TRANSMITTERS

SPECIFICATION	POWER DISTRIBUTION (in %)			HARMONICS (in dB, referenced to pulse peak)										
	IN BAND	BELOW 90 KHZ	ABOVE 110 KHZ	200	300	400	500	600	700	800	900	1000	1100	1200
SENECA	98.9	0.5	0.6	I.N.*	-109	I.N.	-115	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.	I.N.
MALONE	99.1	0.4	0.5	101	86	109	81	113	103	117	113	117	I.N.	I.N.
GRANGEVILLE	98.9	0.7	0.5	-84	-64	-92	-83	-91	-91	-93	-93	-89	I.N.	I.N.
RAYMONDVILLE	99.0	0.4	0.6	-70	-57.5	-85	-80	-91	-94	-94	-87	-88	I.N.	I.N.

*I.N.- IN NOISE;HARMONIC OBSCURED IN BACKGROUND NOISE LEVEL

TIME DOMAIN

EQUIPMENT DEVELOPMENT

All chain and Regional Managers routinely measure time domain performance using a LORAN-C Data Acquisition (LORDAC) system. The LORDAC measures pulses by taking multiple samples, through many pulses, over many GRI. A composite representation for each pulse in the train is developed through analysis of the data samples.

In 1982, Hewlett Packard introduced the HP5180A waveform recorder, a microprocessor based, 20 mHz bandwidth, A/D converter with memory. The HP5180A presented the opportunity to scan individual pulses, effectively making high resolution snapshots. Examination of the HP5180A characteristics showed that all pulse parameters could be directly measured except pulse tail energy at 500 microseconds (the pulse tail requires over 60 dB dynamic range and the HP5180A had only 54dB). A HP5180A was purchased for testing at a LORSTA.

Identification of zero crossings proved to be the most sensitive measurement because of the reduced signal slope to noise ratio at the beginning of the LORAN pulse. The tolerances for zero crossings varies from +/- 50 nanoseconds(nsec) at the sampling point (Category 1, Single Rate Transmitter) to +/- 2000 nsec at the zero crossing at 5 microseconds(usec) (Category 2, Dual Rate transmitter). Tests using LORAN-C simulators and continuous wave (CW) signals established uncertainty bounds for individual zero crossing determinations that were less than 10 percent of the specification requirement. This is shown in Figure 6. Satisfactory field tests were conducted at LORSTA Nantucket in August 1983. Use of the 5180A added a new capability to the arsenal of LORAN-C measurement equipments. Instrumentation diagrams of the time domain measurement suites with both controllers are shown in Figures 7 and 8.

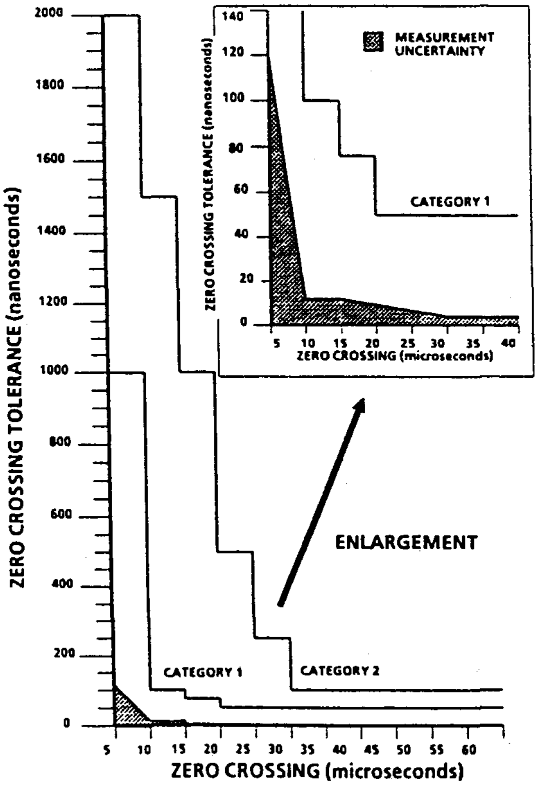


FIGURE 6. MEASUREMENT UNCERTAINTY OF HP-5180A

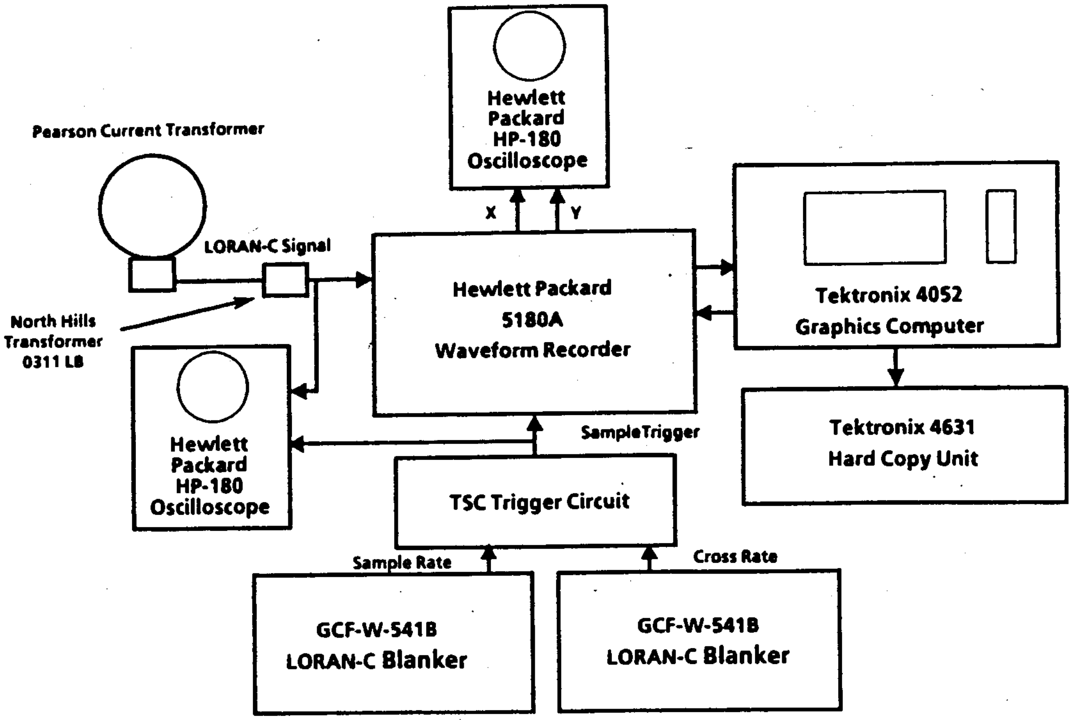


FIGURE 7. EQUIPMENT CONFIGURATION FOR MEASUREMENT OF TIME DOMAIN DATA USING TEKTRONIX 4052

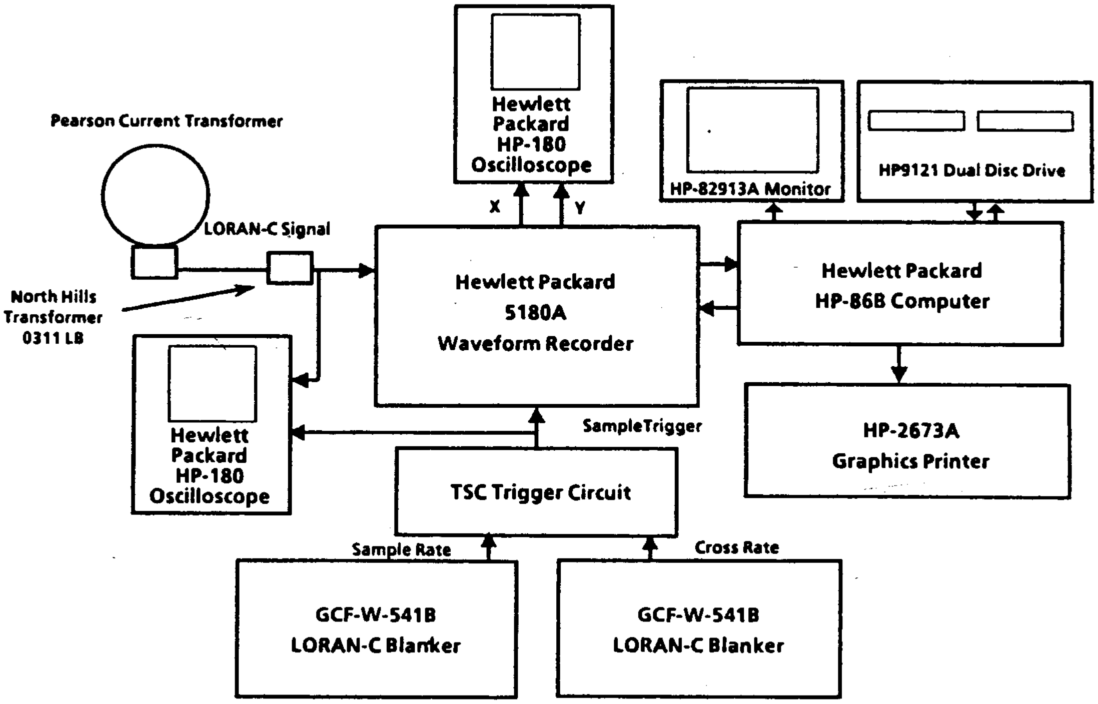


FIGURE 8. EQUIPMENT CONFIGURATION FOR MEASUREMENT OF TIME DOMAIN DATA USING HP-86

MEASUREMENT PROCEDURES

Time domain data were taken on-station, using waveforms obtained from the "Operate" Pearson current transformer, and at the near station site, using signals obtained from a loop antenna. COMDT INST M16562.4 states that all time domain performance requirements are based on measurements obtained from the current transformer. On-station data was used to establish station performance and the other data was used to assure the test team that on-station measurements were valid. Measurements were taken at each station for each transmitter, each rate and each coupler combination as appropriate.

Two methods were used to measure pulse energy at the 500 usec point. For the first six stations, two samples were taken using the HP5180A. The first sample examined the normal pulse. The second sample was time shifted precisely 300 usec and the pulse energy was established at 500 usec. For the last stations, the energy was determined by using an oscilloscope, measuring the pulse peak, then shifting the trigger precisely in time to measure the 500 us point. This latter method gave the same results, but proved to take much less time for gathering and analyzing data.

RESULTS

COMDT INST M16562.4 establishes a number of criteria for pulse performance in the time domain. Older generation transmitters, such as the AN/FPN-42, are designated Category 2 and have slightly reduced performance requirements. This is also true for stations which are dual-rated.

AN/FPN-42 Stations

On the whole, stations met or exceeded pulse specifications. The range of adjustments available to maintenance technicians produced notable variation in performance. Some stations exceeded the stringent Category 1 requirements for several parameters. After visits to several stations, patterns began to emerge. While pulses met shape requirements, zero crossings beyond the standard sampling point were progressively displaced, with displacement approximately matching the frequency in the pulse tail in the area of 60 to 130 usec. For reporting purposes, a new parameter, "N", the zero crossing beyond which cycle zero crossings were out of tolerance, was established. Figure 9 shows zero crossing offsets from a representative pulse observed at LORSTA Nantucket, referenced to the requirements. Complete results for AN/FPN-42 stations are summarized in Table 5. Figure 10 shows reconstructed pulses from LORSTAs Caribou and Jupiter.

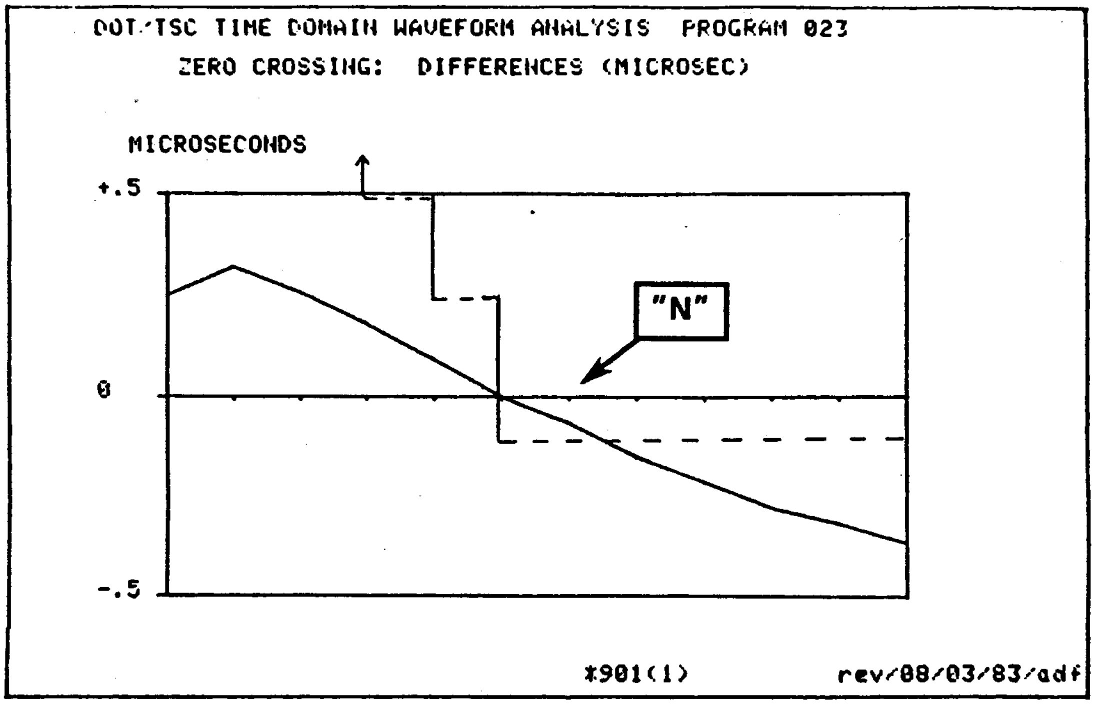


FIGURE 9. ZERO CROSSING ERRORS FOR LORSTA NANTUCKET

TABLE 5. TIME DOMAIN PERFORMANCE OF AN/FPN-42 TRANSMITTERS

SPECIFICATION	INDIVIDUAL PULSE SPECIFICATION							UNIFORMITY OF PULSES							
	HALF-CYCLE-PEAK AMPLITUDES			PULSE TRAILING EDGE		ZERO CROSSING		AMPLITUDE		ECD			TIMING		
	ENS 1%	1-8 <3%	9-13 <10%	SPEC	OBS	N*	>60us (1)	TOL %	OBS %	TOL us(2)	OBS +	OBS -	TOL ns(3)	OBS +	OBS -
NANTUCKET	0.67	<3.0	<10.0	0.0014A	<.0014	45	99.3	10	5.0	1.5	0.90	-0.57	± 100	23	85
JUPITER	0.60	<1.4	<21.3	0.016A	<.016	40	99.3	10	5.6	1.0	0.90	0.10	± 50	12	238
BAUDETTE	1.79	<3.3	<11.8	0.016A	<.016	45	99.7	10	4.4	1.0	-0.38	-0.79	± 50	3	-100
CARIBOU	0.29	<3.0	<10.0	0.0014A	<.0014	50	99.4	10	5.6	1.5	-0.00	0.21	± 100	10	86
CAROLINA BEACH	0.25	<0.7	<12.6	0.0014A	<.0014	45	98.8	10	3.0	1.5	-0.15	-0.07	± 100	-12	83

N* IS DEFINED AS THE NOMINAL ZERO CROSSING INTERVAL (IN MICROSECONDS) AFTER WHICH PULSE CROSSINGS EXCEED THE ZERO CROSSING LIMIT.

(1) Effective frequency in Khz. Specification 100 KHz ± 1 KHz.
(2) us-microsecond
(3) ns-nanosecond

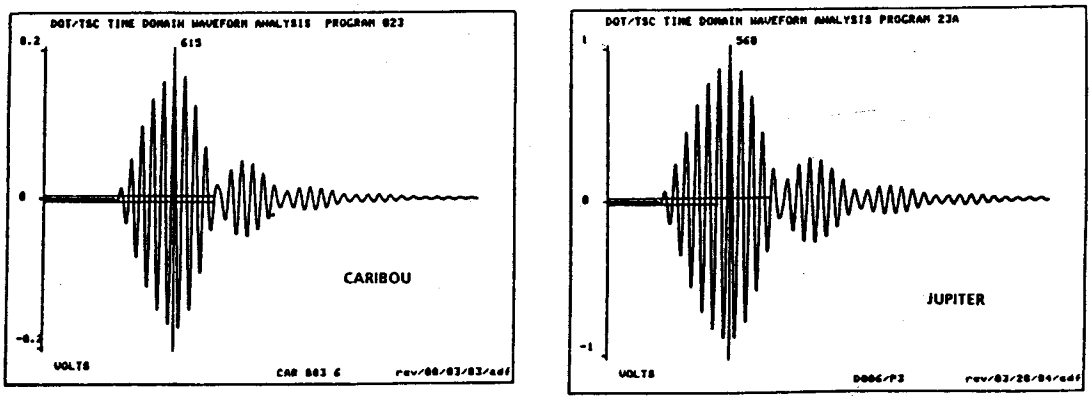


FIGURE 10. REPRESENTATIVE PULSE SHAPES FOR LORSTAS CARIBOU AND JUPITER

AN/FPN-44/45 Stations

Performance requirements for these transmitters are stricter than those for the AN/FPN-42. Each combination of transmitter/antenna proved capable of meeting the requirements, but there were variances between stations which placed some units out of tolerance. In addition to the zero crossing displacement noted with the AN/FPN-42, the transmitters showed greater "plus" code to "minus" code pulse differences. Station emissions were always balanced to achieve a stable sampling point and the assigned average ECD values, thus variations were not detectable at the System Area Monitors. Results are summarized in Table 6. Pulse shapes were much closer to those of the ideal pulse which can be seen in Figure 11, that of LORSTA Fallon. The pulse shape of LORSTA Middletown (without feedback) differs and is also shown in Figure 11.

TABLE 6. TIME DOMAIN PERFORMANCE OF AN/FPN-44/45 TRANSMITTERS

SPECIFICATION	INDIVIDUAL PULSE SPECIFICATION							UNIFORMITY OF PULSES							
	HALF-CYCLE-PEAK AMPLITUDES			PULSE TRAILING EDGE		ZERO CROSSING		AMPLITUDE		ECD			TIMING		
	ENS 1%	1-8 <3%	9-13 <10%	SPEC	OBS	N*	>60us (1)	TOL %	OBS %	TOL us(2)	OBS +	OBS -	TOL ns(3)	OBS +	OBS -
DANA	0.76	<1.7	<3.9	0.016A	0.0075	30	98.1	10	2.7	1.5	-0.35	-0.42	± 50	-6	82
MIDDLETOWN	0.94	<2.9	<6.3	0.016A	<0.016	50	99.8	5	4.0	0.5	0.45	-1.02	± 25	-12	134
FALLON	0.39	<0.5	<5.2	0.016A	0.00303	60	100.2	5	5.0	0.5	0.80	-0.37	± 25	-8	94
SEARCHLIGHT	0.61	<1.1	<8.1	0.0014A	<.0014	55	99.7	5	5.0	0.5	-0.39	-0.69	± 25	79	-3
GEORGE	0.49	<0.8	<4.5	0.0014A	0.00244	55	99.9	10	4.0	1.5	-0.01	-0.11	± 50	-50	-40

N* IS DEFINED AS THE NOMINAL ZERO CROSSING INTERVAL (IN MICROSECONDS) AFTER WHICH PULSE ZERO CROSSINGS EXCEED THE ZERO CROSSING LIMIT.

(1) Effective frequency in KHz. Specification 100 KHz ± 1 KHz.
(2) us-microsecond
(3) ns-nanosecond

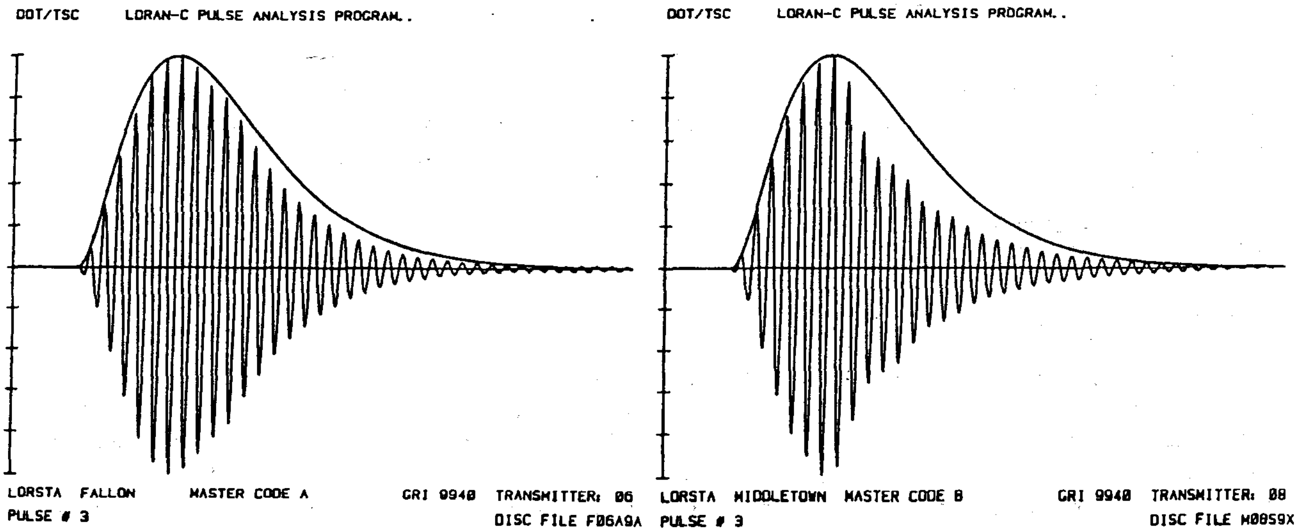


FIGURE 11. REPRESENTATIVE PULSE SHAPES FOR LORSTAS FALLON AND MIDDLETOWN

AN/FPN-64 Stations

The AN/FPN-64 transmitter must meet the most stringent, Category 1 requirements. With one parameter exception, all four stations were consistently within specifications, providing virtually identical performance. The exception parameter was pulse-to-pulse timing. In AN/FPN-64 transmitters, the first pulse is offset slightly, typically 60 nsec, from others in the group. The specification refers measurements of pulses 2 through 8 to pulse 1, thus stations were normally beyond tolerance.

TABLE 7. TIME DOMAIN PERFORMANCE OF AN/FPN-64 TRANSMITTERS

SPECIFICATION	INDIVIDUAL PULSE SPECIFICATION							UNIFORMITY OF PULSES							
	HALF-CYCLE-PEAK AMPLITUDES			PULSE TRAILING EDGE		ZERO CROSSING		AMPLITUDE		ECD			TIMING		
	ENS 1%	1-8 <3%	9-13 <10%	SPEC	OBS	N*	>60us (1)	TOL %	OBS %	TOL us(2)	OBS +	OBS -	TOL ns(3)	OBS +	OBS -
SENECA	0.39	<0.8	<4.4	0.0014A	<.0014	*	100.0	10	3.2	0.7	0.07	0.10	±50	-17	-11
MALONE	0.41	<1.1	<4.7	0.0014A	<.0014	*	100.0	10	3	0.7	-0.14	-0.19	±50	-22	-61
GRANGEVILLE	0.42	<0.9	<6.8	0.0014A	<.0014	*	100.2	5	2.3	0.5	-0.10	-0.11	±25	-49	-46
RAYMONDVILLE	0.35	<0.8	<4.3	0.0014A	<.0014	*	99.9	5	1.5	0.5	-0.07	-0.09	±25	-31	-34

N* IS DEFINED AS THE NOMINAL ZERO CROSSING INTERVAL (IN MICROSECONDS) AFTER WHICH PULSE CROSSINGS EXCEED THE ZERO CROSSING LIMIT.
* MEANS TRANSMITTER IS IN TOLERANCE

(1) Effective frequency in KHz. Specification 100 KHz ± 1 KHz.
(2) us-microseconds
(3) ns-nanoseconds

DISCUSSION OF OBSERVATIONS AND RESULTS

GENERAL

The Coast Guard is currently replacing all CONUS AN/FPN-42 transmitters with AN/FPN-64s. As a result, the performance limitations of this series of transmitters are recognized, but the focus of these comments will be on the results from the AN/FPN-44/45 and AN/FPN-64 stations.

FREQUENCY DOMAIN

In-Band Energy

With the exception of LORSTA Dana, all stations were within specification (+/- 0.1%). The combination of antenna and transmitter adjustment at Dana produced a nominal center frequency of 98.2 kHz. A study of data showed that if the transmitter signals had been centered at 100 kHz, performance would have met the standard.

Harmonics

While no performance level is specified, the harmonic levels transmitted by the AN/FPN-44/45 and AN/FPN-64 transmitters are small, approaching or below the guidelines specified in the "LORAN-C System Characterization" published by the Wild Goose Association in 1976. Harmonic signals from these transmitters are sufficiently low that they must be measured within 0.3 mile of the station because harmonics above 300 kHz are below typical background noise levels.

TIME DOMAIN

Individual Pulse Cycle Zero Crossings

One parameter consistently missed by AN/FPN-44/45 stations involved pulse zero crossings. The flat tolerance of +/- 50 nsec (Category 1, Single Rate) or 100 nsec (Category 1, Dual Rate) was not attained if the antenna and transmitter adjustment was more than a few hundred cycles off 100 kHz. Transmitter/antenna matching for these transmitters is accomplished through manual adjustments to the equipment. The automatically adjusted AN/FPN-64 had no difficulty meeting this parameter.

Performance Data Base

The variations in performance between stations is obvious. The results obtained from this program provide a data base which can be used for further study. Adjustment to operating procedures and/or modification to the basic specification can be made after analysis of equipment capabilities and examination of results.

ACKNOWLEDGEMENTS

Station personnel were very supportive of the TSC field team at all locations. Their efforts to facilitate measurements and crew logistics were appreciated and are gratefully acknowledged. Recognition is also extended to CDR W. Schorr, USCG, who provided technical assistance during early phases of the program.

BIOGRAPHICAL INFORMATION - FRANCIS W. MOONEY

Francis W. Mooney is a graduate of the U.S. Coast Guard Academy (BS) and the Air Force Institute (MSEE). During a 20 year career with the Coast Guard, he specialized in radionavigation systems, with the majority of his efforts in Loran-C. Mr. Mooney was a principal member of the design team for the current LORAN-C timing equipment and a member of the project team who planned and effected the LORAN-C expansion. He also served as the Regional Manager of the U.S. Coast Guard Atlantic Area when the current LORAN-C chains were placed in operation.

Since his retirement from the Coast Guard in 1982, Mr. Mooney has worked as a Senior Project Engineer at the U.S. Department of Transportation's Transportation Systems Center (TSC) in Cambridge, MA. At TSC he has led or conducted a number of evaluations into various technical aspects of the LORAN-C and Global Positioning Systems.

ABSTRACT

SKYWAVE INTERFERENCE ON LABRADOR SEA CHAIN

Cycle selection problems are being experienced off the southeast coast of Newfoundland, although within adequate SNR coverage range of the Angissoq transmitter. The results of investigations are discussed, indicating eveidence of skywave-groundwave interference and susceptibility of typical current user equipments. The possibility of achieving improved performance receiver modification is suggested.

Isaac Ginsberg

and

John Butler

Canadian Coast Guard

SKYWAVE INTERFERENCE PROBLEM
ON LABRADOR SEA CHAIN

Canada operates, jointly with the United States, one West Coast and two East Coast Chains. One of the latter, the Labrador Sea Chain, (Figure 1), was commissioned when Fox Harbour was completed in December, 1983, the other two stations having been part of previous chain structures. The coverage shown is what was predicted by the standard criteria of time delay stability, geometry and SNR. The coverage limit in the southeast quadrant, due to decreasing SNR, has been found to be quite representative in practice. However, in spite of this, cycle selection problems are being encountered well inside this limit.

The long distance from Angissoq had not previously been of particular concern. There were and are several other chains with similar coverage distances and, in fact, the previous North Atlantic Chain coverage, using the Angissoq station, was understood to be limited by the range from Sandur, much further away (Figure 2). At-sea tests off the coast of Newfoundland in 1977 had not revealed any serious problems of cycle acquisition of the Angissoq signal, other than in the extreme "Tail of the Banks" area. Even a preliminary test cruise through the area, using the new Chain in September 1983, did not catch any significant problems. However, user complaints began during the 1984 summer navigation season; the problem was poor cycle selection: no lock on, incorrect lock on or, sometimes, cycle jumping. These problems were experienced most frequently at sunrise and at sunset but not exclusively then.

Sea and shore tests quickly confirmed that these complaints were indeed valid. We now have a full year's data collection. In Figure 3, cycle acquisition failures are shown over a sample one month period. The receiver under test initiates a reacquisition attempt every 15 minutes, a failure being indicated by a small rectangle. Figure 4 shows another typical month. There are considerable variations, some better some worse, from day to day and among different receivers and (please note) among receivers of identical type. The results <u>are</u> affected by noise, and by RFI particularly from nearby Decca stations; incorrectly tuned notch filters <u>do</u> cause worse performance; however, eliminating <u>all</u> such well known factors does not eliminate the problem. All of this data was collected at St. John's Coast Radio Station (Figure 1.)

We are not thus far in a position to determine an overall trend with any degree of certainty. What is clear is that the problem is still present, and of the same order of magnitude. There was a notable absence of receiver tracking problems in May and June, 1985 evidently corresponding to the first three months of receiver tracking data in May, June and July of 1984. It remains to be seen to what extent this winter's problems will follow last years record for tracking and acquisition.

The area in which the skywave phenomenon has been found to create a significant problem is shown in Figure 5.

A meeting of Loran-C and radio propagation experts was held in Ottawa in Noverber 1984, including US Coast Guard and other government and private sector personnel. Some of them are here today. The consensus was that the most likely cause of the problem is skywave interference: strong ionospheric reflections coupled with low effective heights of the ionosphere. Why was the problem not present in the earlier sea trials? The most likely answer is that it was present. The common receivers of thos days, with wider bandwidth, were much less susceptible to skywave.

Subsequent measurements have confirmed these conclusions. Figure 6 shows measurements of delay and amplitude of the skywave relative to the groundwave. This data is also from St. John's, Nfld, taken this past July. The expected ionospheric trend is evident: a drop in skywave delay at sunrise together with reduced skywave amplitude, and a reversal at sundown. The potential for problems is evident, for example, around 5 a.m. and 9 p.m., when instances of low relative delay can occur simultaneously with a large skywave component. Figure 7 is another example, this time from the previous February. The sunrise and sunset periods, around 7:30 a.m. and 4:30 p.m., show similar and, in fact, measurably worse conditions. This data correlated well with cycle acquisition failures of user receivers. A 1977-era user set was installed and under the same conditions it did indeed perform much better than the modern version, as expected.

Figure 8 shows how typical wintertime skywave conditions in southeast Newfoundland compare to the RTCM standards, both original and revised. Sets meeting the standards should acquire successfully anywhere within the enclosed trapezoids.

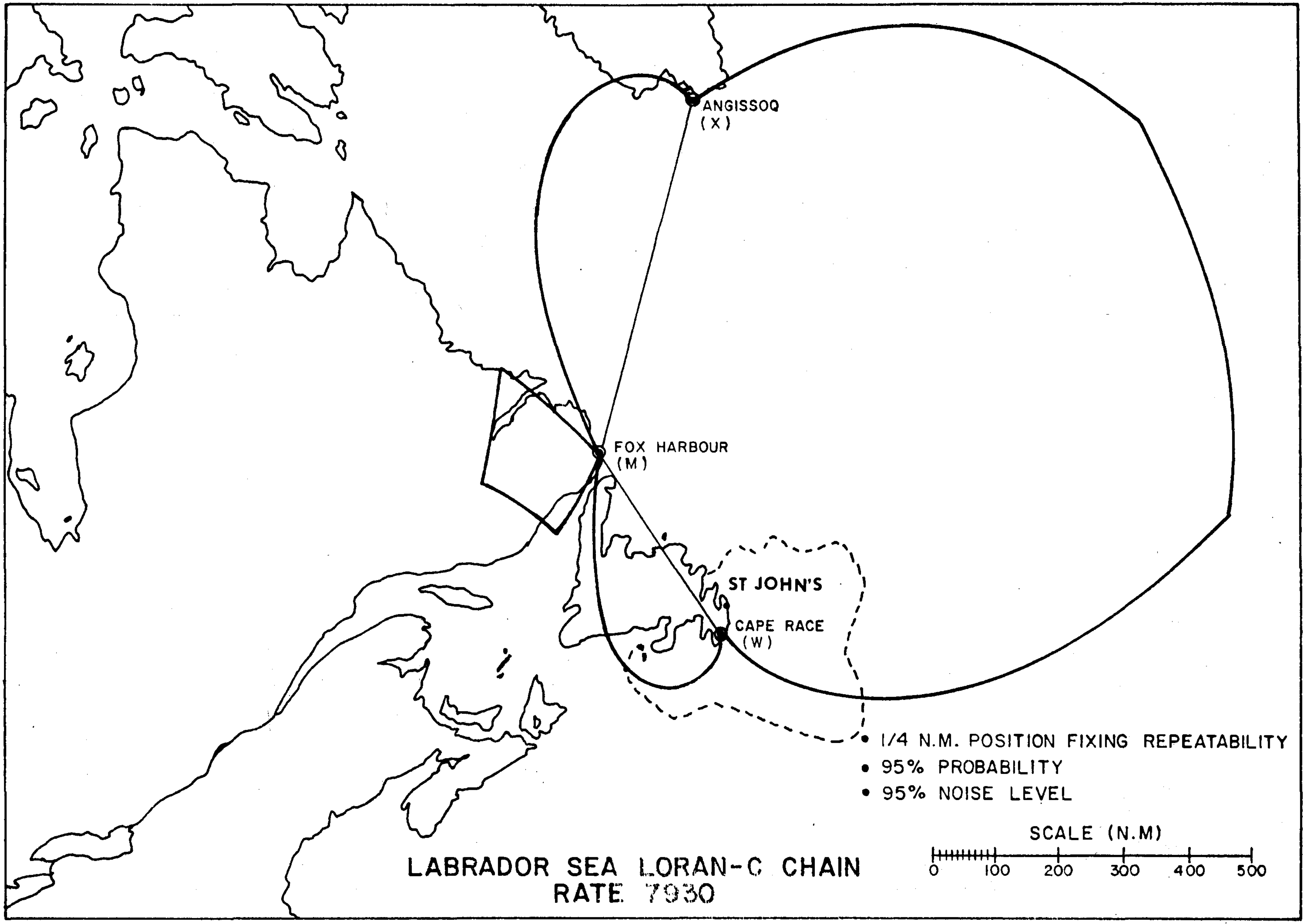
We are at this time, digging deeper into the receiver aspect, refining our measurement techniques, and obtaining more data on receivers of the type in use in the area. We have begun using a Loran C simulator, with simulated skywave, and initial tests are indeed confirming receiver susceptibility to the skywave parameters. There is, no doubt, potential for achieving considerably improved performance in the affected area by receiver design modifications. Whether such changes will be good enough to be worthwhile remains to be seen. Another question is whether wider bandwidths or other changes would make the receivers less useful for other areas. We have found that operating in the manual or tracking mode is usually more successful than in the acquisition mode. Some current models unfortunately do not allow such a choice.

We've explained what we're doing; we felt it would be of interest to the membership (especially receiver manufacturers), and we welcome your comments or questions.

BIOGRAPHICAL SKETCH

Isaac Ginsburg is a graduate of McGill University (1954), with a B. Eng. degree in Engineering Physics. He has been with the Canadian Department of Transport since 1957, engaged in planning and implementation of radio navigation, mobile communications and traffic control systems for air and marine services. Since 1974, he has directed Canadian Coast Guard engineering activities related to shore based navigation and surveillance systems.

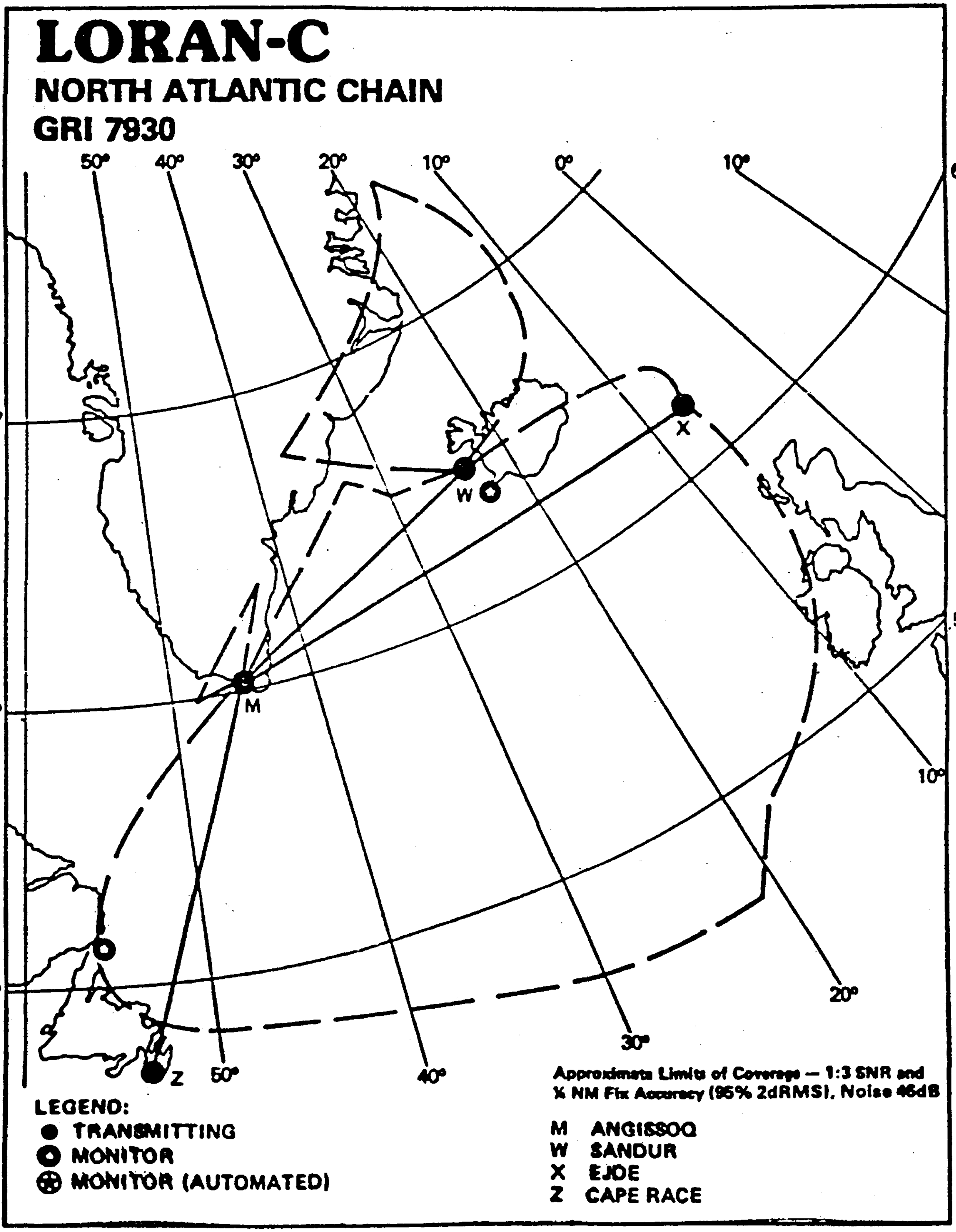
John Butler is a 1979 graduate of Memorial University of Newfoundland School of Engineering, specializing in Electrical Engineering. He was employed with the Newfoundland Telephone, and Newfoundland & Labrador Hydro Companies prior to joining the Canadian Coast Guard in 1981 as a Systems Engineer. His primary duties have been with marine navigation and communications systems. Since that time, he has moved to the position of Regional Superintendent of Engineering Services.



LABRADOR SEA LORAN-C CHAIN
RATE 7930

FIG 1.

FIG 2.


LORAN-C
NORTH ATLANTIC CHAIN
GRI 7930
50°
40°
30°
20°
10°
0°
10°
60°
70°
60°
50°
50°
10°
20°
30°
50°
40°
M
W
X
Z
Approximate Limits of Coverage — 1:3 SNR and ½ NM Fix Accuracy (95% 2dRMS), Noise 46dB
LEGEND:
● TRANSMITTING
MONITOR
MONITOR (AUTOMATED)
M ANGISSOQ
W SANDUR
X EJDE
Z CAPE RACE

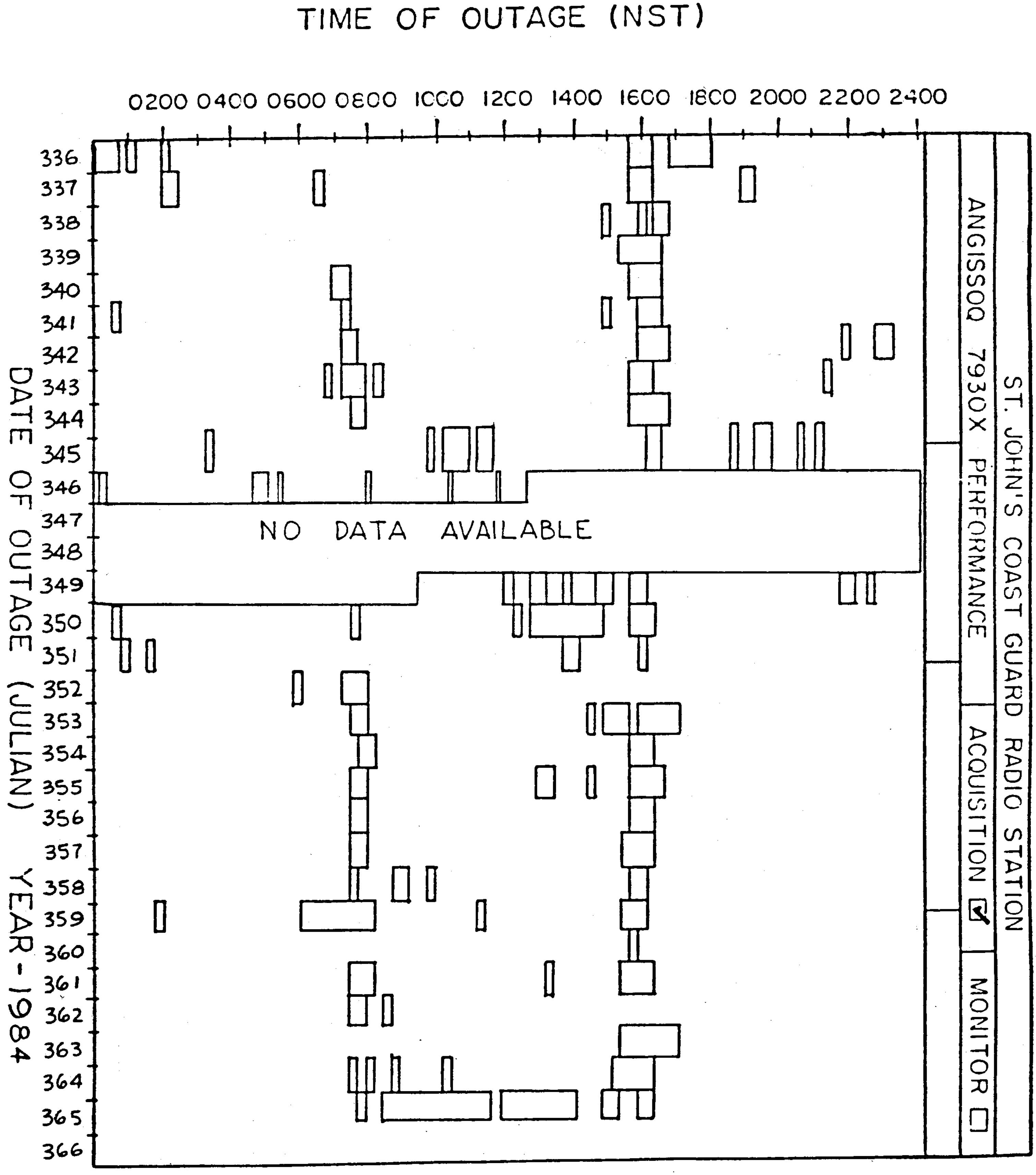

TIME OF OUTAGE (NST)
0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
DATE OF OUTAGE (JULIAN) YEAR - 1984
NO DATA AVAILABLE
ST. JOHN'S COAST GUARD RADIO STATION
ANGISSOQ 7930X PERFORMANCE
ACQUISITION ☑
MONITOR ☐

FIG 3.

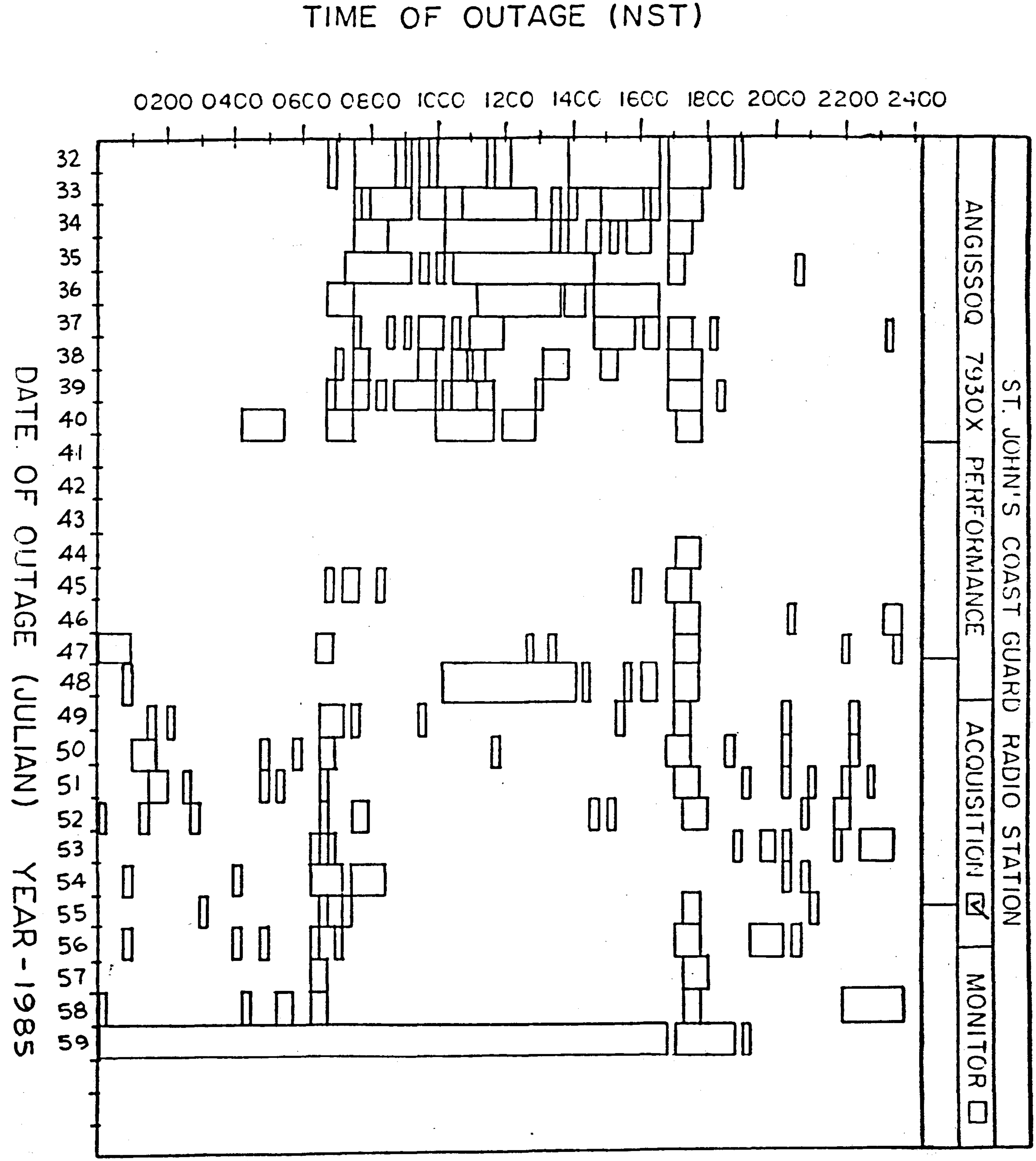
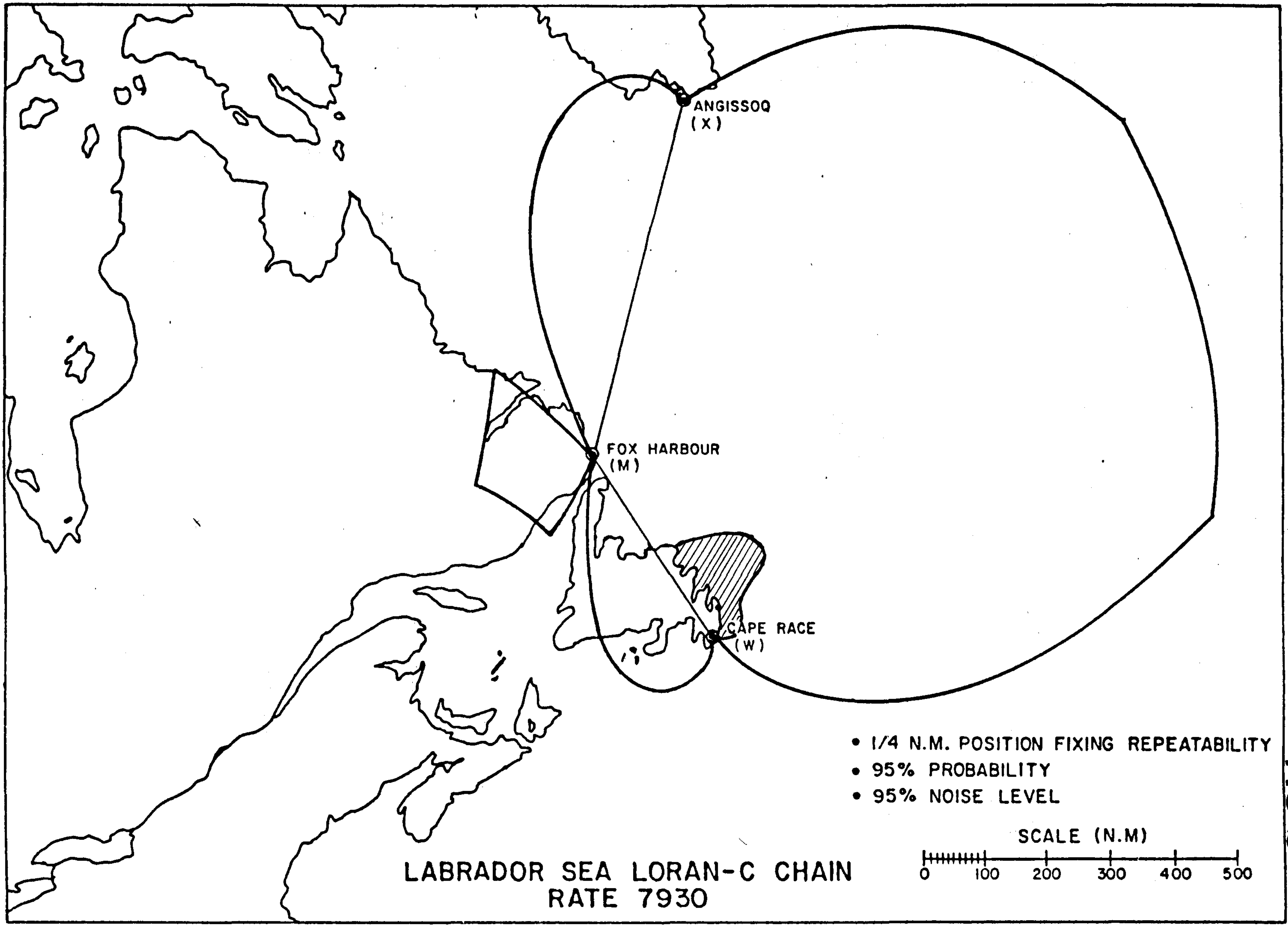

TIME OF OUTAGE (NST)
0200
0400
0600
0800
1000
1200
1400
1600
1800
2000
2200
2400
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
DATE OF OUTAGE (JULIAN) YEAR-1985
ST. JOHN'S COAST GUARD RADIO STATION
ANGISSOQ 7930X PERFORMANCE
ACQUISITION ☑
MONITOR ☐

FIG 4.



- 1/4 N.M. POSITION FIXING REPEATABILITY
- 95% PROBABILITY
- 95% NOISE LEVEL

LABRADOR SEA LORAN-C CHAIN
RATE 7930

FIG 5.

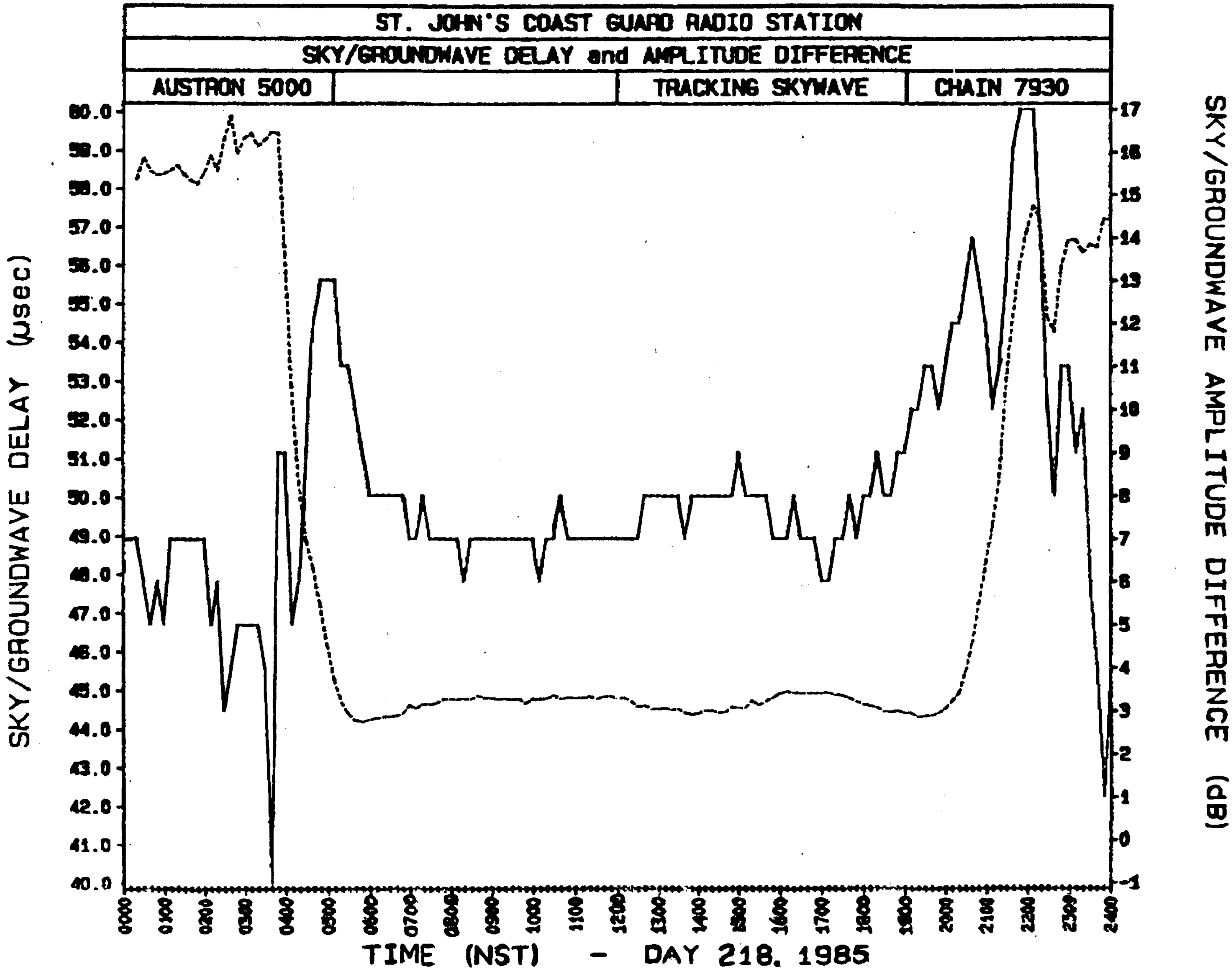
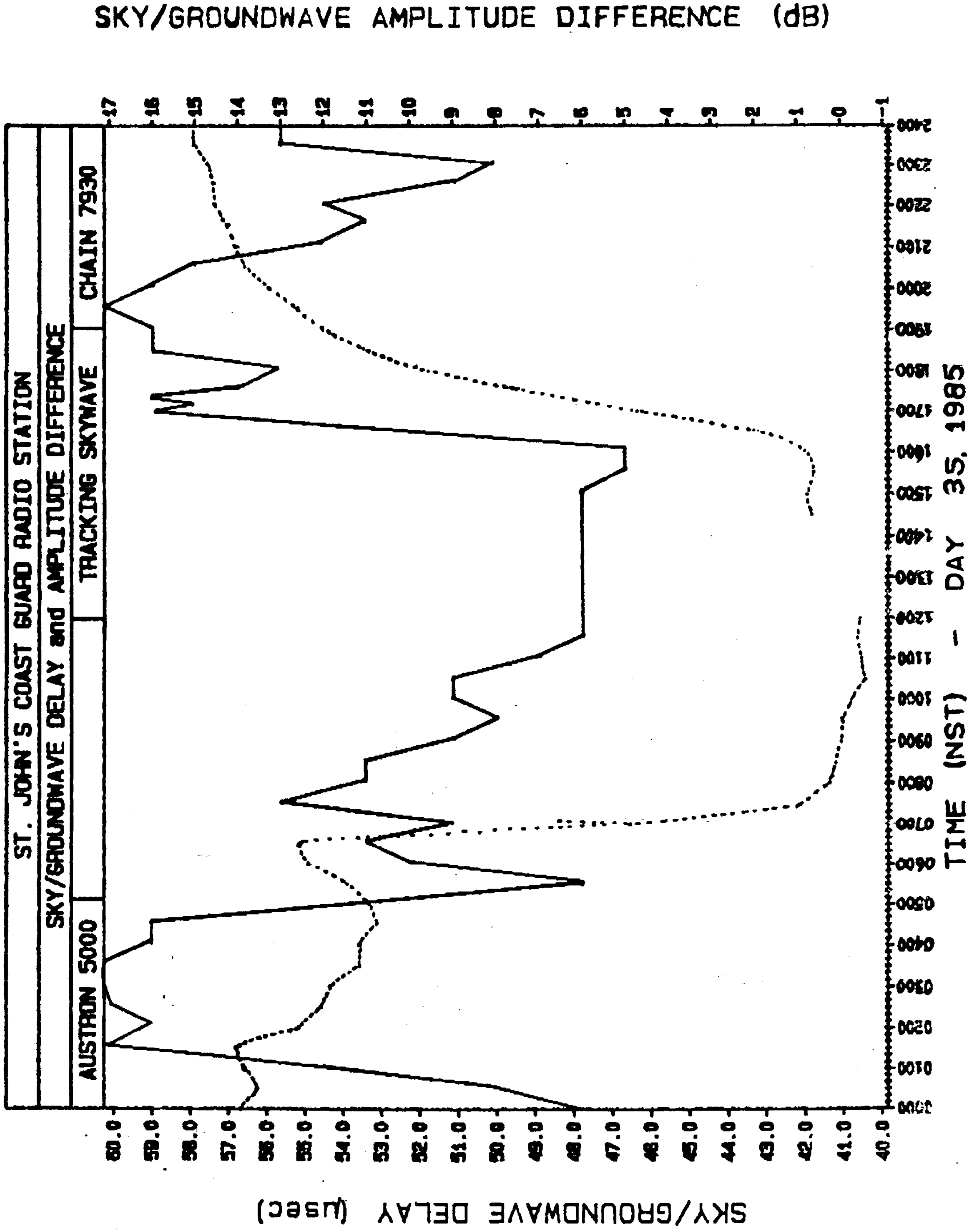

ST. JOHN'S COAST GUARD RADIO STATION
SKY/GROUNDWAVE DELAY and AMPLITUDE DIFFERENCE
AUSTRON 5000
TRACKING SKYWAVE
CHAIN 7930
SKY/GROUNDWAVE DELAY (μsec)
60.0
59.0
58.0
57.0
56.0
55.0
54.0
53.0
52.0
51.0
50.0
49.0
48.0
47.0
46.0
45.0
44.0
43.0
42.0
41.0
40.0
SKY/GROUNDWAVE AMPLITUDE DIFFERENCE (dB)
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
TIME (NST) - DAY 218, 1985

FIG.6

FIG. 7


SKY/GROUNDWAVE AMPLITUDE DIFFERENCE (dB)
ST. JOHN'S COAST GUARD RADIO STATION
SKY/GROUNDWAVE DELAY and AMPLITUDE DIFFERENCE
AUSTRON 5000
TRACKING SKYWAVE
CHAIN 7930
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
60.0
59.0
58.0
57.0
56.0
55.0
54.0
53.0
52.0
51.0
50.0
49.0
48.0
47.0
46.0
45.0
44.0
43.0
42.0
41.0
40.0
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
TIME (NST) - DAY 35, 1985
SKY/GROUNDWAVE DELAY (μsec)

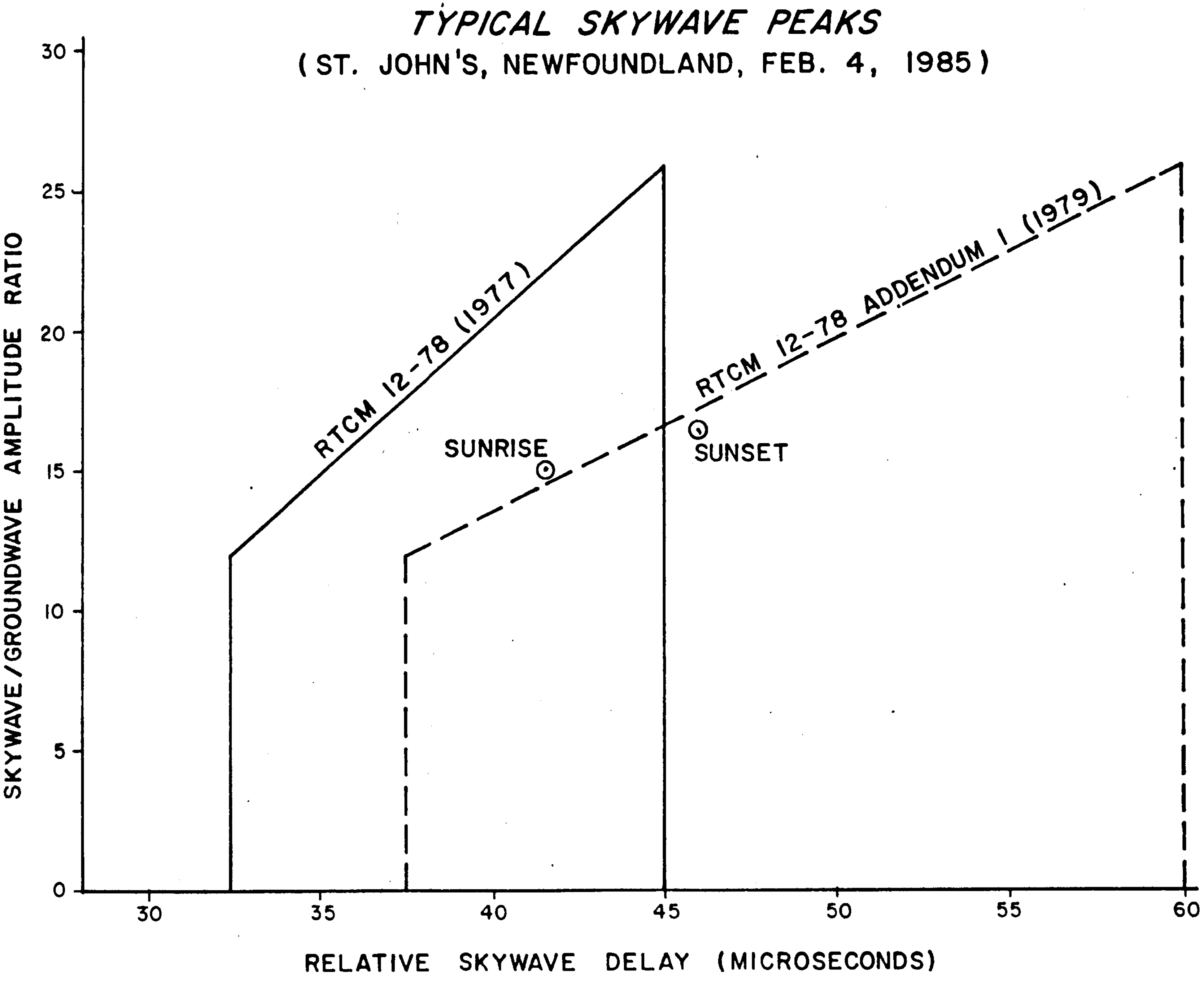

TYPICAL SKYWAVE PEAKS
(ST. JOHN'S, NEWFOUNDLAND, FEB. 4, 1985)
SKYWAVE / GROUNDWAVE AMPLITUDE RATIO
0
5
10
15
20
25
30
RELATIVE SKYWAVE DELAY (MICROSECONDS)
30
35
40
45
50
55
60
RTCM 12-78 (1977)
RTCM 12-78 ADDENDUM 1 (1979)
SUNRISE
SUNSET

FIG. 8

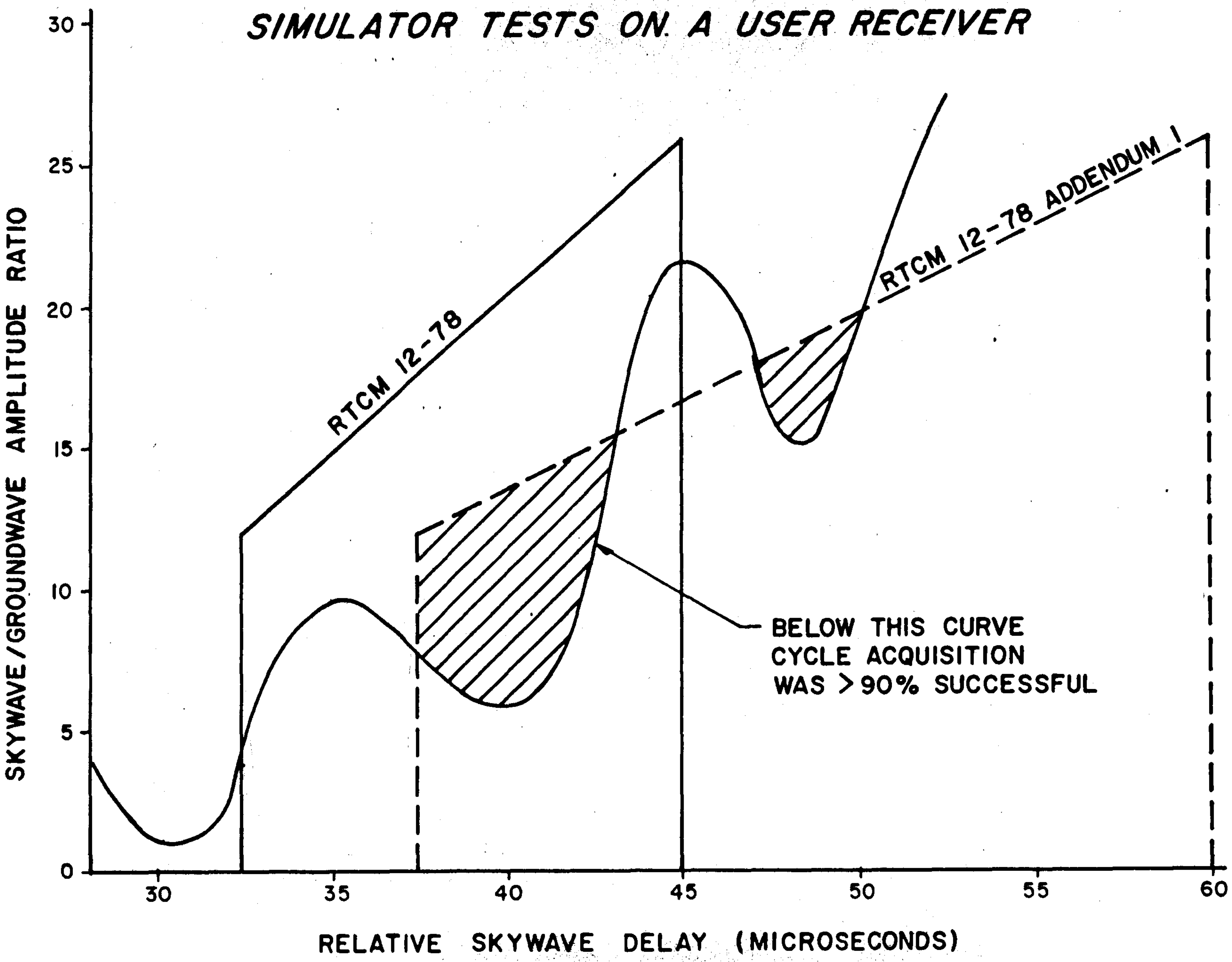

SIMULATOR TESTS ON A USER RECEIVER
SKYWAVE/GROUNDWAVE AMPLITUDE RATIO
0
5
10
15
20
25
30
RELATIVE SKYWAVE DELAY (MICROSECONDS)
30
35
40
45
50
55
60
RTCM 12-78
RTCM 12-78 ADDENDUM 1
BELOW THIS CURVE
CYCLE ACQUISITION
WAS > 90% SUCCESSFUL

FIG. 9

LORAN-C PERFORMANCE AS A TERRESTRIAL RNAV SYSTEM IN MASSACHUSETTS

FRANCIS W. MOONEY
U.S. Department of Transportation
Transportation Systems Center
Cambridge, MA 01945

ABSTRACT

During the period of January through April and also in August 1985, an engineering test team from the Transportation Systems Center(TSC) conducted LORAN-C and Global Positioning System(GPS) measurements at the TSC and in the counties around Boston, MA. The field tests, under the sponsorship of the Research and Special Programs Administration, were conducted to assess the capabilities of the navigation systems in conditions which are representative of the terrestrial environment. Parameters of interest included navigation accuracy (absolute and repeatable), interference susceptibility and signal availability. Two state-of-the-art LORAN-C navigator/receivers, the Digital Marine Northstar 7000 and the Megapulse Accufix 600 were used to provide LORAN-C data. A Litton LTN-700 and a Magnavox T-Set, standard positioning system(SPS) code receivers provided GPS data. This paper will describe the field evaluation and provide initial comparative information on the two systems.

INTRODUCTION

Use of radionavigation systems for mobile position determination in a terrestrial environment has been studied for the last decade. Much work was done with the LORAN-C system in the 70's, demonstrating that this concept was feasible, but that realization was complex. The introduction of the GPS presents a fresh opportunity to examine whether a radionavigation system can permit accurate position determination in the terrestrial environment without relying on other sensor input; e.g. odometer for velocity, compasses for direction, etc. The Research and Special Programs Administration commissioned the TSC to evaluate the GPS in conditions typical of the terrestrial environment. While not the principal effort, collection of concurrent LORAN-C data permitted comparison of the systems.

Static and underway tests were conducted during January through April 1985. A second GPS receiver, the Magnavox T-Set, was tested during August 1985. A complete set of test results will be presented in a report which will be distributed by the National Technical Information Service (NTIS). This paper presents a discussion of the conduct of the evaluation and a summary of the information processed to date.

POSITION REFERENCE SYSTEM

Accurate navigation evaluation requires establishing positions and control data in a common geodetic reference system. Anyone who has attempted a terrestrial evaluation of radionavigation(RNAV) systems has learned that local maps are based on the North American Datum-1927, a state plane reference system, relative surveys or any other system which satisfactorily serves the local user, e.g. real estate maps. Area RNAV systems, on the other hand, typically use an earth model established in the World Geodetic System (WGS-72). It is easy to lose tens of meters through conversion of one system to another. For this evaluation, static positions were converted to the WGS-72. Underway positions were precisely plotted according to a map scale, then overlayed to the map through "best-fit" techniques. Shifts to the position plots were found to be necessary for the LTN-700 which had a position "bias" offset and to accomplish the Additional Secondary Phase correction for LORAN-C. Test routes were selected with sufficient path complexity to ensure that inaccuracies of the navigation solution were apparent by the plotted position going off the highway, roadway or street.

TEST RECEIVERS

Two GPS and two LORAN-C receivers were used during the tests. All four were manufactured by different companies and characteristics are summarized in Tables 1 and 2. Typical of commercial products, brochures and equipment manuals don't provide enough information for direct specification comparison. Both GPS receivers were designed for engineering test purposes and are available for commercial purchase. Four versions of software were used in the LTN-700 and a developmental version was used in the T-Set (complete except for a special data output that was unnecessary for our tests).

TABLE 1. GPS RECEIVER SPECIFICATIONS

RECEIVER	LITTON LTN-700	MAGNAVOX T-SET
FORM	AVIONICS PACKAGE	DIGITAL COMPUTER TERMINAL
TYPE	SINGLE CHANNEL SPS MULTIPLEX(fast sequence)	DUAL CHANNEL SPS SEQUENTIAL
VELOCITY	600 M/S(meters/second)	400 M/S
ACCELERATION	40 M/S	6 M/S
TIME TO FIRST FIX	< 3 MINUTES	3-24 MINUTES
ACCURACY	40 M CEP, 100 M 2drms	35 M, 2D 90% PROBABILITY
GEODETIC REFERENCE	WGS-72	ALTITUDE CORRECTED WGS-72

TABLE 2. LORAN-C RECEIVER SPECIFICATIONS

RECEIVER	MEGAPULSE ACCUFIX 600	DIGITAL MARINE NORTHSTAR 7000
TYPE	SURVEY	GENERAL PURPOSE
STATIONS	MASTER & 4 SECONDARIES	MASTER & 4 SECONDARIES
TIME TO FIRST FIX	<5 MINUTES	<3 MINUTES
VELOCITY	60 KNOTS	150 KNOTS
ACCELERATION	UNSPECIFIED	UNSPECIFIED
ACCURACY	TD - 10 NANOSECONDS	TD - 10 NANOSECONDS
	L/L - 0.1 ARCSECOND	L/L - 0.01 MINUTE
ASF	MANUAL	AUTOMATIC
GEODETIC REFERENCE	WGS-72	WGS-72

The LORAN-C receivers were standard commercial units. The Accufix 600 was a navigator version of the Accufix 500, a high precision, survey grade, marine receiver. The tracking bandwidth of the Accufix 600 was modified to permit underway evaluations up to 60 mph (tests showed that receiver accuracy was not compromised). The Northstar 7000 was a general purpose, high quality receiver which can be used for marine, terrestrial and slow aircraft navigation.

DATA ACQUISITION AND ANALYSIS EQUIPMENT

While all receivers had RS-232 data outputs, none used any form of "hand shake" protocol. This requires the recording equipment to be able to take a message, store it and be ready for additional messages within the report cycle time of the test receiver. The data messages from the GPS receivers were quite long. After experiments with several microcomputers, a Hewlett Packard HP2647A graphics terminal was chosen to record data from the GPS receivers. The HP2647A is slow, but has a large buffer which could absorb the data messages and store them on tape. The LORAN-C receivers were interfaced with a HP86 computer, the standard computer used in the TSC mobile test facility (MTF). All navigation data was post processed at TSC on the HP2647A, the HP86 and also on a HP9845A scientific microcomputer. Position plots were done on a HP9872B plotter. Basic Loran-C and GPS static analysis programs for the HP9845 were provided by the Coast Guard Research and Development Center. Use of these programs saved several months of programming effort.

DATA ACCUMULATION AND MANAGEMENT

The receivers provided an enormous amount of data in a short period of time. A typical LTN-700 output during a navigation transit would include time, position (latitude,longitude and altitude), four sets of satellite(SV) identification and status (SV number, signal to noise number (SNR), altitude, azimuth, health), horizontal dilution of precision (HDOP), velocity (horizontal and vertical) and course. Each traffic transit, typically 5 minutes long, would fill a standard HP storage cassette. LORAN-C receivers would provide time, position, time differences (TDs), SNRs for each station tracked, course and speed. Actual output data and format varied considerably between units, requiring individual sort and analysis programs. Tapes and discs were numbered sequentially, carefully dated and a log of all test runs was maintained.

TEST ORGANIZATION

Static laboratory measurements were made to establish performance bases for each receiver, then the equipment was relocated to the MTF. The TSC MTF is a standard Plymouth Voyager window van, modified by a adding a fiberglass top to provide standing headroom. The MTF receives 115 VAC power from a small, attached trailer which houses two, 4kW generators. After receiver relocation to the MTF, satisfactory performance was established through comparative measurements at TSC. When comparison tests were complete, a series of survey and underway tests were conducted in the Boston area. Supplemental static laboratory tests were conducted with the LTN-700 in April to test the fourth version of software.

TEST CONDUCT

The availability of GPS signals dictated when test observations would be made. On the primary satellite pass, various combinations of the six functional satellites (SVs 6,8,9,11,12 and 13) were available. Four satellite navigation fixes with HDOP better than 2.0 were available for about 2 hours of the primary pass, while less accurate positions from other combinations were available for an additional 3 hours. A secondary, 3 satellite pass was also available. Figure 1 shows satellite availability on April 1, 1985. The bulk of the test data was obtained during the months of January through March 1985. Most observations were made between the local hours of two to six am. This presented optimal conditions for road transit because there was virtually no traffic. During August, when the T-Set was evaluated, the best HDOP conditions existed between six to eight pm. This also proved to be satisfactory because the peak of the Boston rush hour was past.

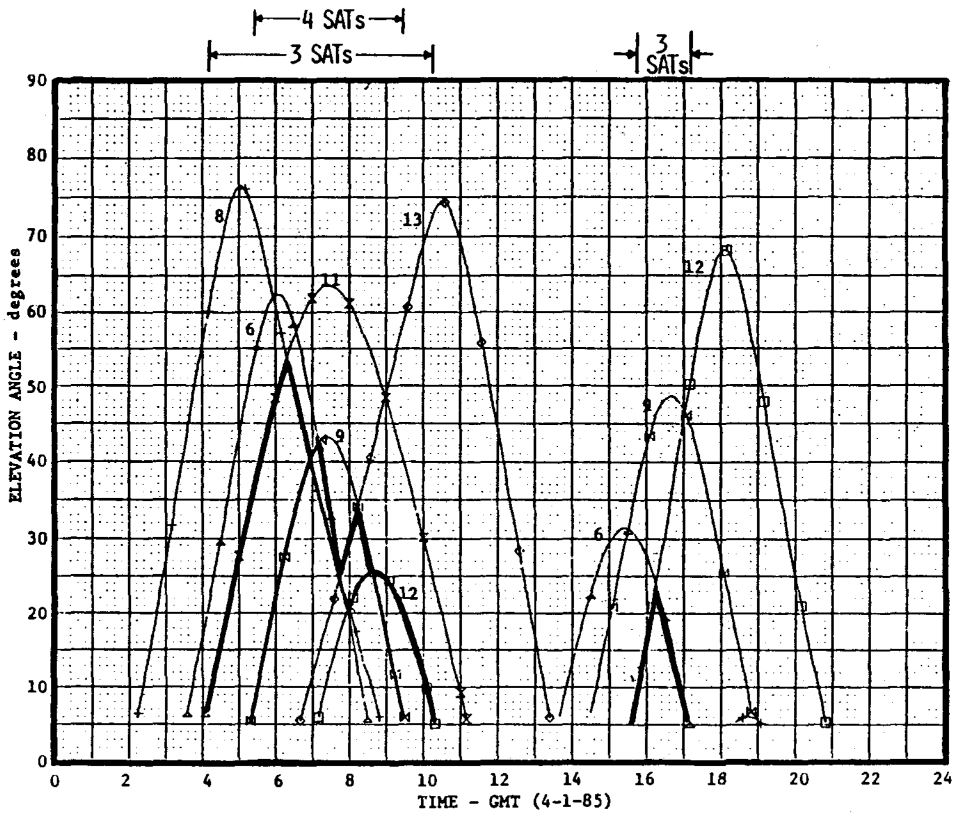


FIGURE 1. SATELLITE VISIBILITY IN BOSTON

TEST RESULTS

STATIC TESTS

Ground truth measurements were made at 5 first order sites. Three were in Boston and two were in Bedford, MA. The MTF was positioned within 3 meters of the Boston sites. A sixth site was studied for multi-path purposes and provided additional data for establishing LORAN-C performance. The LTN-700 showed an average position offset of 0.48 arcseconds in latitude and 1.49 arcseconds in longitude. A fourth software revision reduced the offsets to 0.48 arcseconds in latitude (14.8 meters) and 0.44 arcseconds in longitude (10.1 meters). An overall position error of 17.9 meters was realized. This performance is comfortably within equipment specifications. Tests with the T-Set at two of the sites produced better results; offset of 0.07 arcseconds in latitude (2.1 meters) and 0.16 arcseconds in longitude (3.7 meters), with an overall offset of 4.3 meters. Scatter plots for each of the receivers are shown in Figure 2.

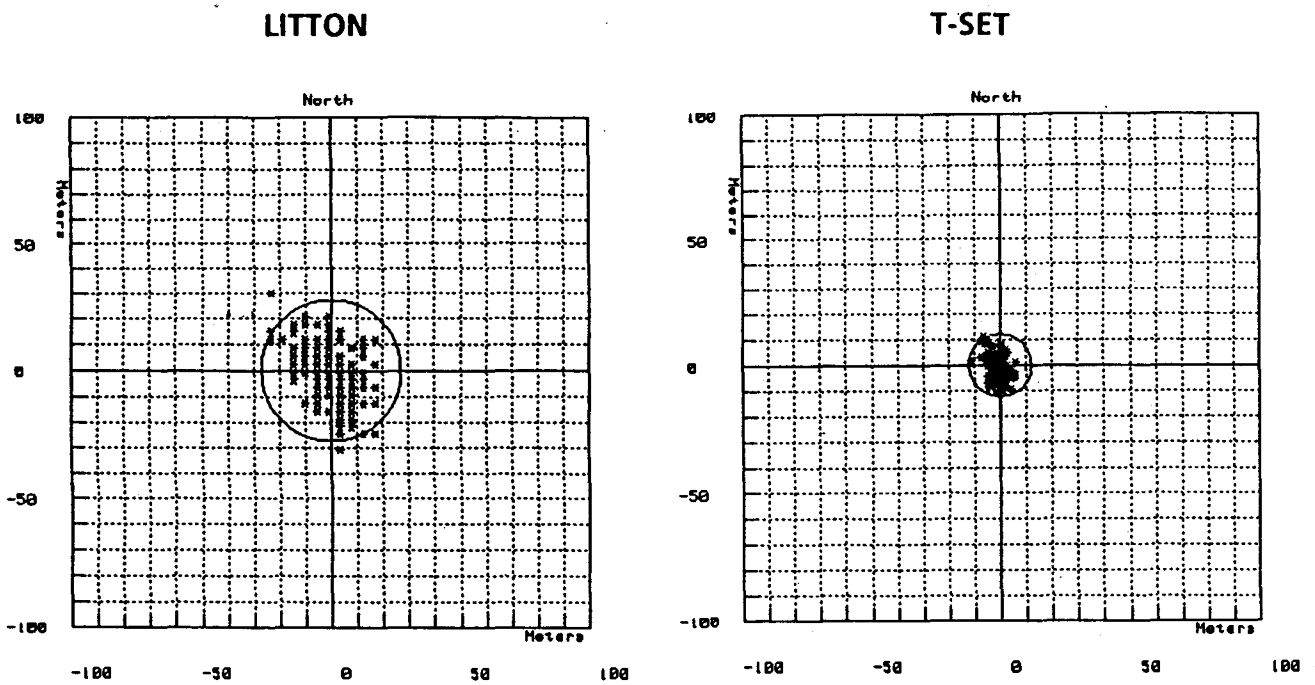


FIGURE 2. REPRESENTATIVE GPS SCATTER PLOTS AT ARTERY #12

LORAN-C

The gradients and crossing angles of LORAN-C signals in the Boston area are excellent. Scatter plots, some taken over a five hour period, showed variance of less than 50 ns. The two receivers normally agreed within 50 ns for all TDs. Typical scatter plots are shown for each receiver in Figure 3.

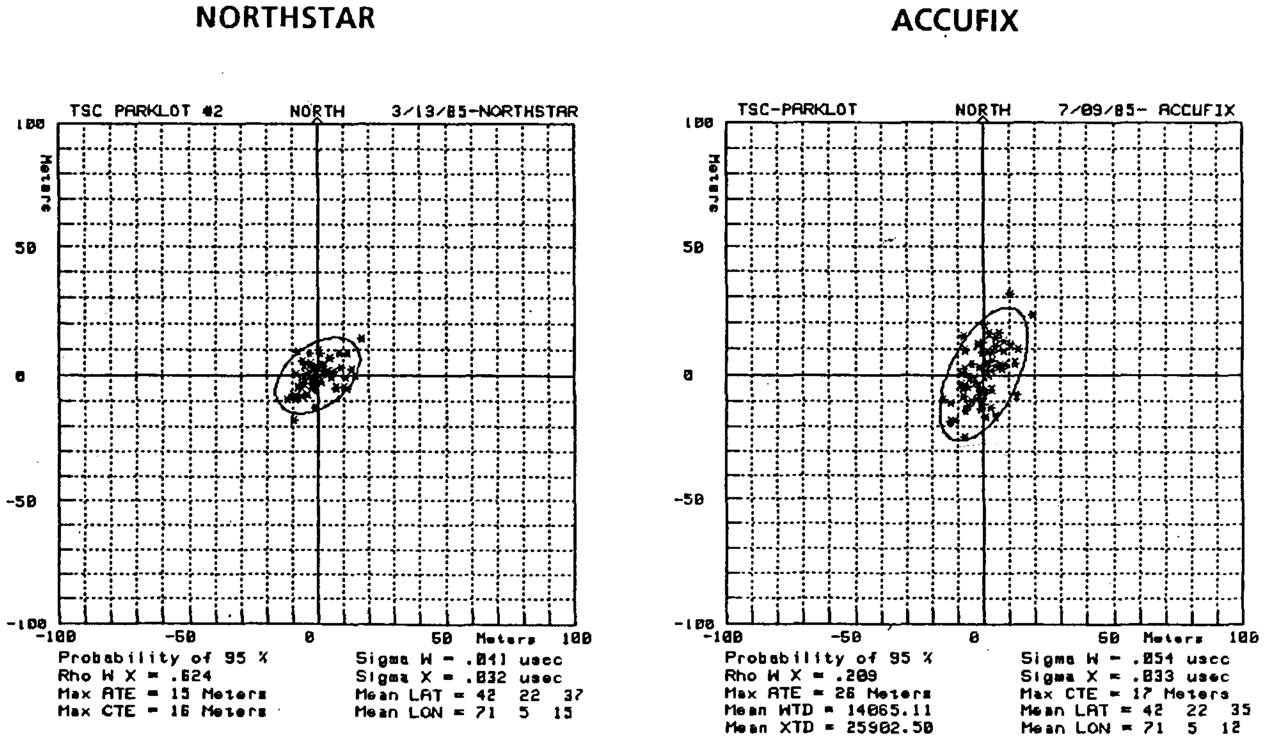


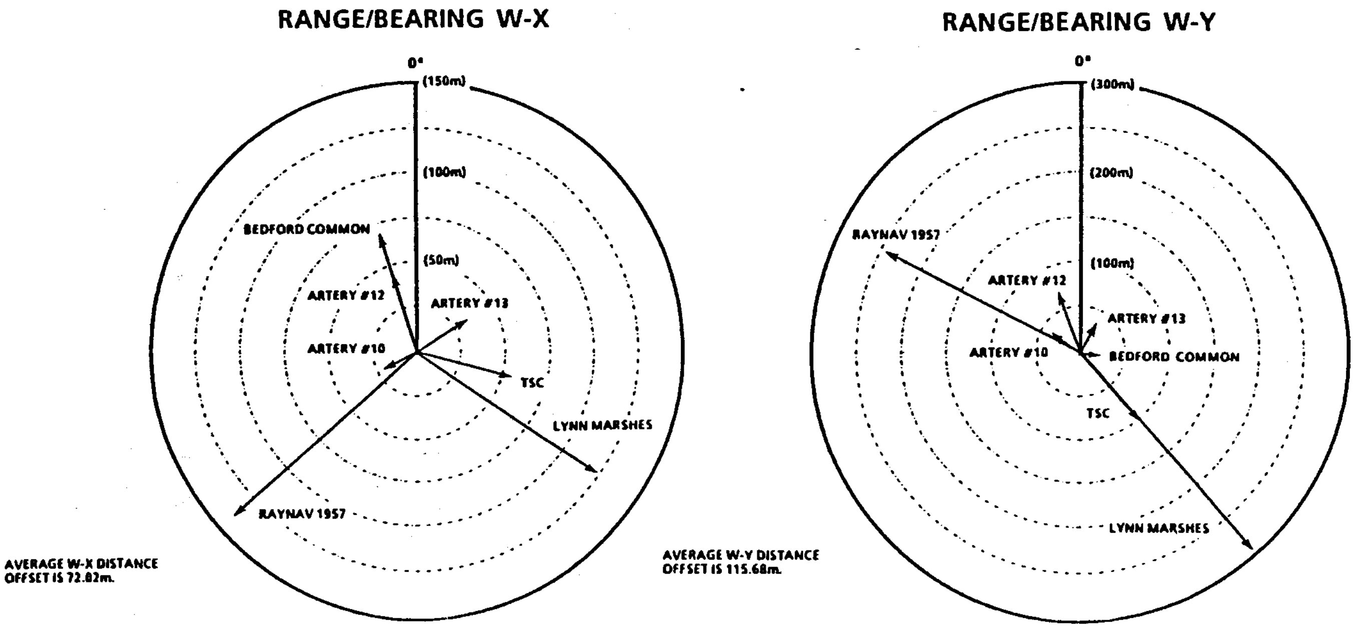
FIGURE 3. REPRESENTATIVE LORAN-C SCATTER PLOTS AT TSC

The latitude/longitude position from the receivers varied. This was expected since the Northstar 7000 has internal automatic insertion of Additional Secondary Phase Factor (ASF) corrections while the Accufix requires manual ASF insertion. LORAN-C accuracy was therefore dependent upon knowing ASF values for each point. Predicted TDs were calculated for each position using the standard USCG EEE-10A program which was provided by the Radio Navigation Division of USCG Headquarters(G-NRN-3). ASF numbers were calculated through differencing observed versus predicted TDs, then an average ASF value was produced for the area. ASF values for the static positions are shown in Table 3.

TABLE 3. ASF VALUES AT SURVEY POINTS

SITE	POSITION REFERENCE		ASF		
	LATITUDE	LONGITUDE	W	X	Y
ARTERY #10	N 42° 21' 59.53"	W 71° 03' 49.92"	0.67	2.07	0.39
ARTERY #12	N 42° 22' 0.55"	W 71° 03' 56.06"	0.83	1.92	0.27
ARTERY #13	N 42° 22' 1.13"	W 71° 04' 7.30"	0.94	2.34	0.43
TSC	N 42° 21' 51.00"	W 71° 05' 9.00"	1.00	2.47	0.40
BEDFORD COMMON	N 42° 29' 29.87"	W 71° 16' 44.81"	0.85	1.47	0.50
RAYNAV 1957	N 42° 28' 36.13"	W 71° 17' 15.26"	0.02	1.83	0.15
LYNN MARSHES	N 42° 25' 51.23"	W 70° 59' 49.75"	1.11	2.94	1.45
AVERAGE			0.77	2.13	0.51

In Boston, the WX triad produces the best accuracy, with the WY triad producing slightly less accurate fixes. Resultant position variations are shown in Figure 4. The WX triad produced offsets less than 150 meters, while the WY triad was within 300 meters. The vector diagrams suggest that the grid was warped at the RAYNAV and Lynn Marsh sites.



AVERAGE W-X DISTANCE OFFSET IS 72.82m.

AVERAGE W-Y DISTANCE OFFSET IS 115.68m.

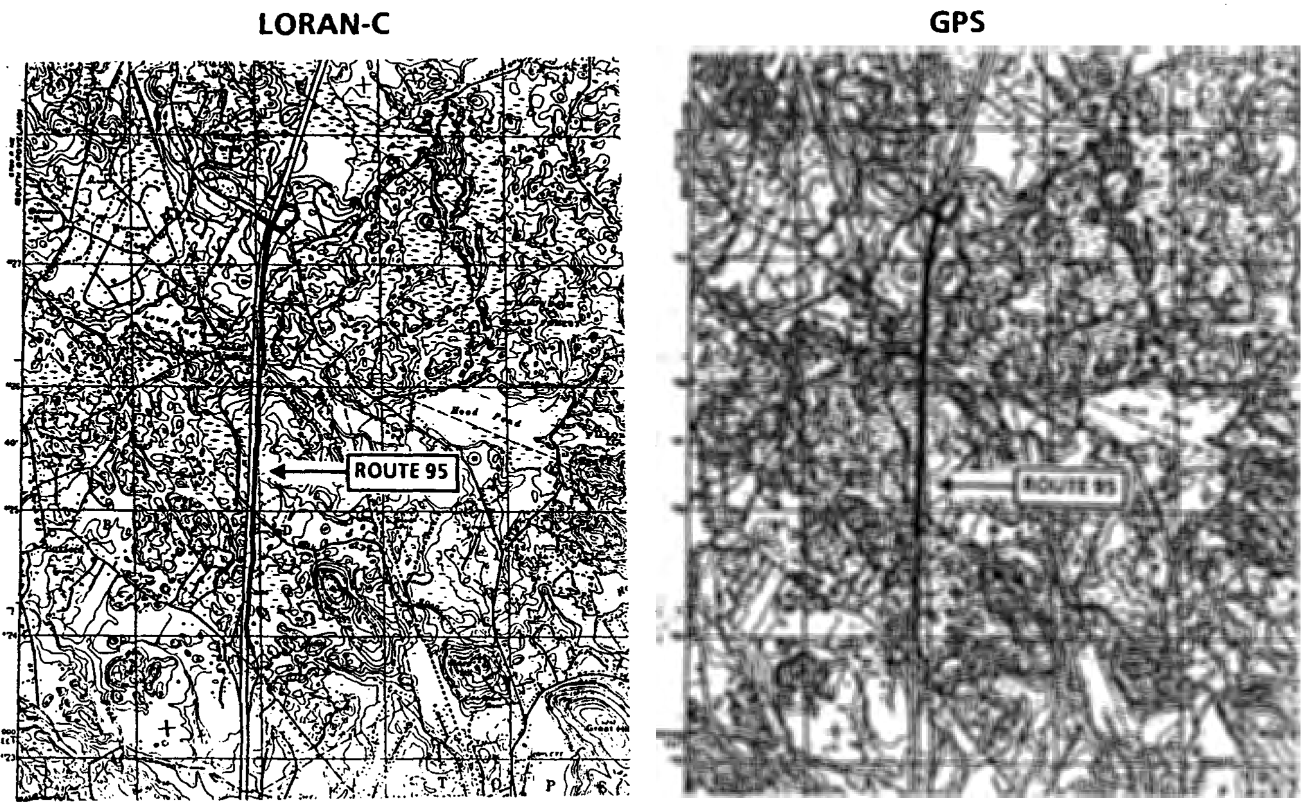
FIGURE 4. POSITION VARIATIONS FOR SURVEY POINTS

UNDERWAY NAVIGATION TESTS

Thirty controlled navigation transits were performed during the January through March 1985 tests and 8 additional transits were performed in August 1985. During these runs navigation data was collected at 1 second intervals for the LTN-700, 10 second intervals for the LORAN-C sets and 2-5 second intervals for the T-Set. Twenty-five of these transits were done on urban streets, 10 were in rural/suburban areas and 3 were done in a suburban, downtown setting. The total data set for these observations contained more than 500,000 items, with over 10,000 positions. Analysis was primarily accomplished through position plots. When positions strayed from routes, other data, such as signal to noise information, the number of SVs tracked, HDOP, etc. were examined.

Highway Transit

Both GPS and LORAN-C navigators provided accurate navigation information. When the MTF passed under overpasses and bridges, all receivers noted signal attenuation with lower SNR numbers. However, the units continued to track unless the MTF was stopped under the structure. Figure 5 shows representative examples for GPS and LORAN-C sets.



LORAN-C

GPS

FIGURE 5. REPRESENTATIVE HIGHWAY TRANSIT POSITION PLOTS

Suburban/Rural Road Transits

Transits were made along Topsfield/Ipswich road. It is a secondary, macadam road, flanked by utility service lines. Both systems provided reasonably accurate track information. For the LORAN-C units, this was a surprise because troubles have been previously encountered due to power lines on this route.

Small City (urban)

Transits were made in downtown Salem, a small city with a well defined business district. The streets featured no power lines and were flanked by 3-4 story buildings. About one third of the transit was over a railroad tunnel. The route included several turns, representative of normal urban transit. Neither system provided a satisfactory navigation track. The LORAN-C receivers maintained lock, but the position reference had errors. The GPS receiver tracked 4 satellites less than 20 percent of the time, and three satellites, the minimum necessary for a fixed altitude navigation solution, less than 50% of the time.

Large City (urban)

The majority of urban transits were made in Boston, where it was possible to get a mix of wide and narrow streets, flanked by structures of varying heights. Data were taken on a number of routes, then two were selected for repeat runs. The first route involved transit of Cambridge Street, continuation on Tremont Street, turning onto Boylson Street and ending adjacent to the Boston Common, a public park. Structures started at 3-4 stories, abruptly changing to high rise, 25 story, in the Government Center area, 6-15 stories along Tremont Street and were non-existent at the Boston Common. The street width varied from 100 to 150 feet.

The second route involved a loop around Boston Garden, transiting Commonwealth Avenue to Massachusetts Avenue and return. Structures were non-existent at the start, transitioning to 4-6 stories along Commonwealth Avenue and then disappearing upon return to the Boston Gardens. Commonwealth Avenue is about 200 feet wide, with a center island covered with trees. The routes are shown in Figure 6.

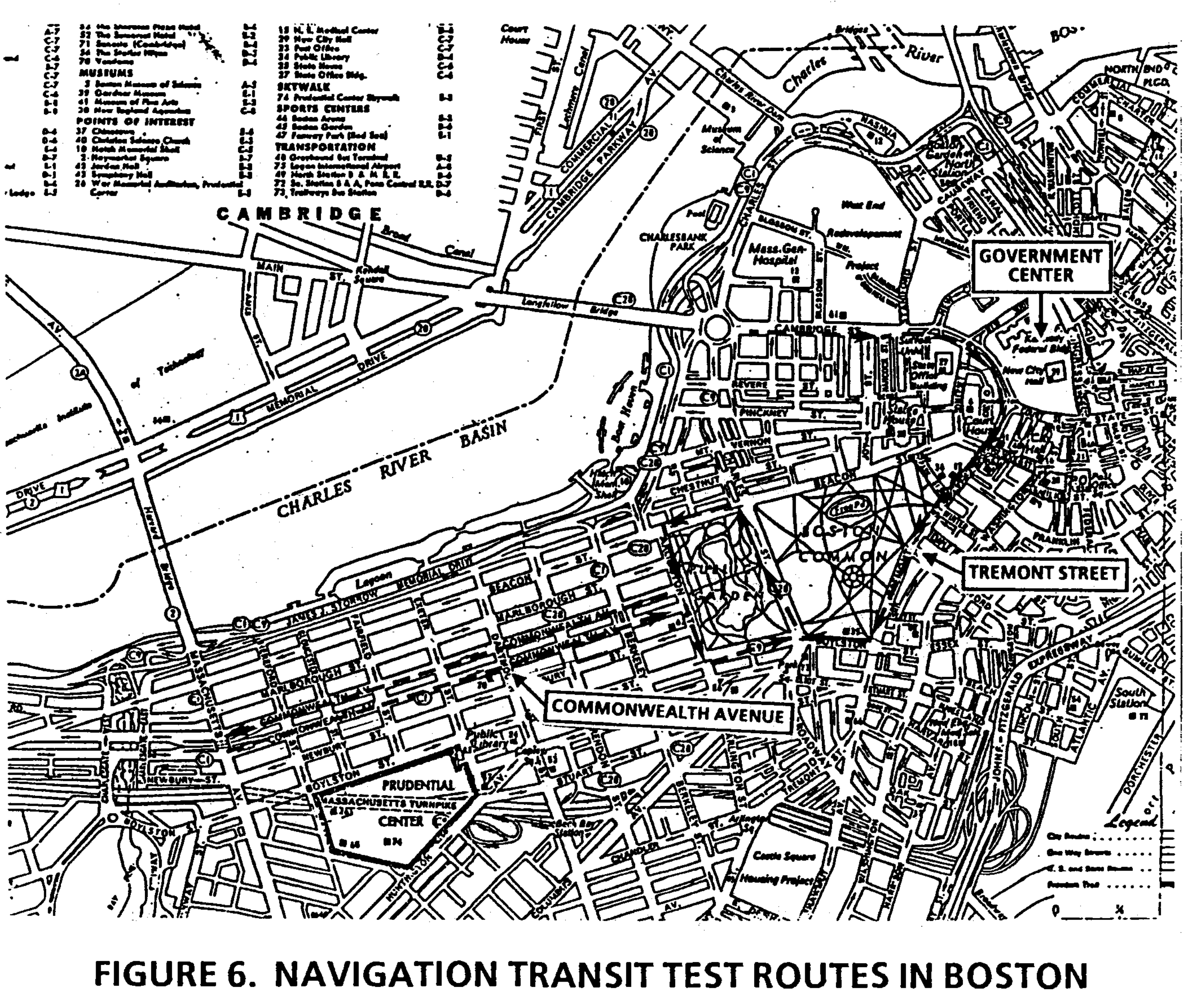


FIGURE 6. NAVIGATION TRANSIT TEST ROUTES IN BOSTON

GPS

The GPS sets were not able to maintain an accurate navigation position when driven through areas where the streets were flanked by high rise buildings (greater than 10 story). Mixed results were obtained in less constricted areas. While six satellites were typically above a 7.5 degree elevation angle, it was apparent that buildings often blocked signals. On Tremont Street, the high rise route, four satellites were tracked less than 50% of the time, and three less than 70%. By restricting the LTN-700 to an altitude hold fix (3 satellites), it was possible to make reasonably accurate runs on Commonwealth Avenue (3 satellites available 75-95% of the time). Representative position plots are shown in Figure 7.

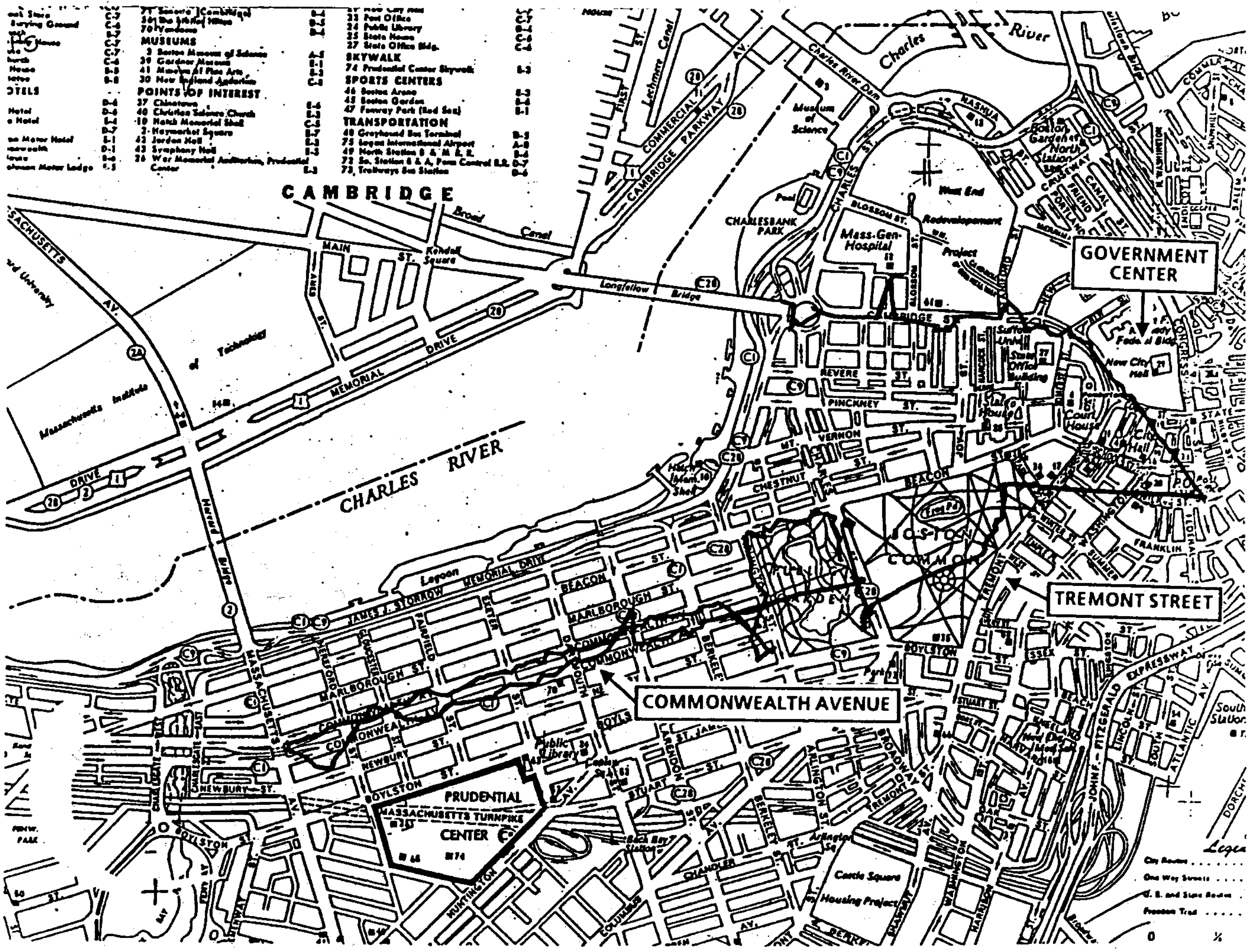


FIGURE 7. REPRESENTATIVE GPS POSITION PLOTS IN BOSTON

LORAN-C

The LORAN-C sets were able to maintain lock and provide a reasonably accurate navigation reference except in the Government Center area. This was part of the Tremont Street run, characterized by high rise buildings and underground subways. Both LORAN-C receivers indicated a drop in SNR of over 20 dB in the Government Center area. Representative position plots are shown in Figure 8. A transit from one of survey markers on Nashua street is included with the Tremont Street run.

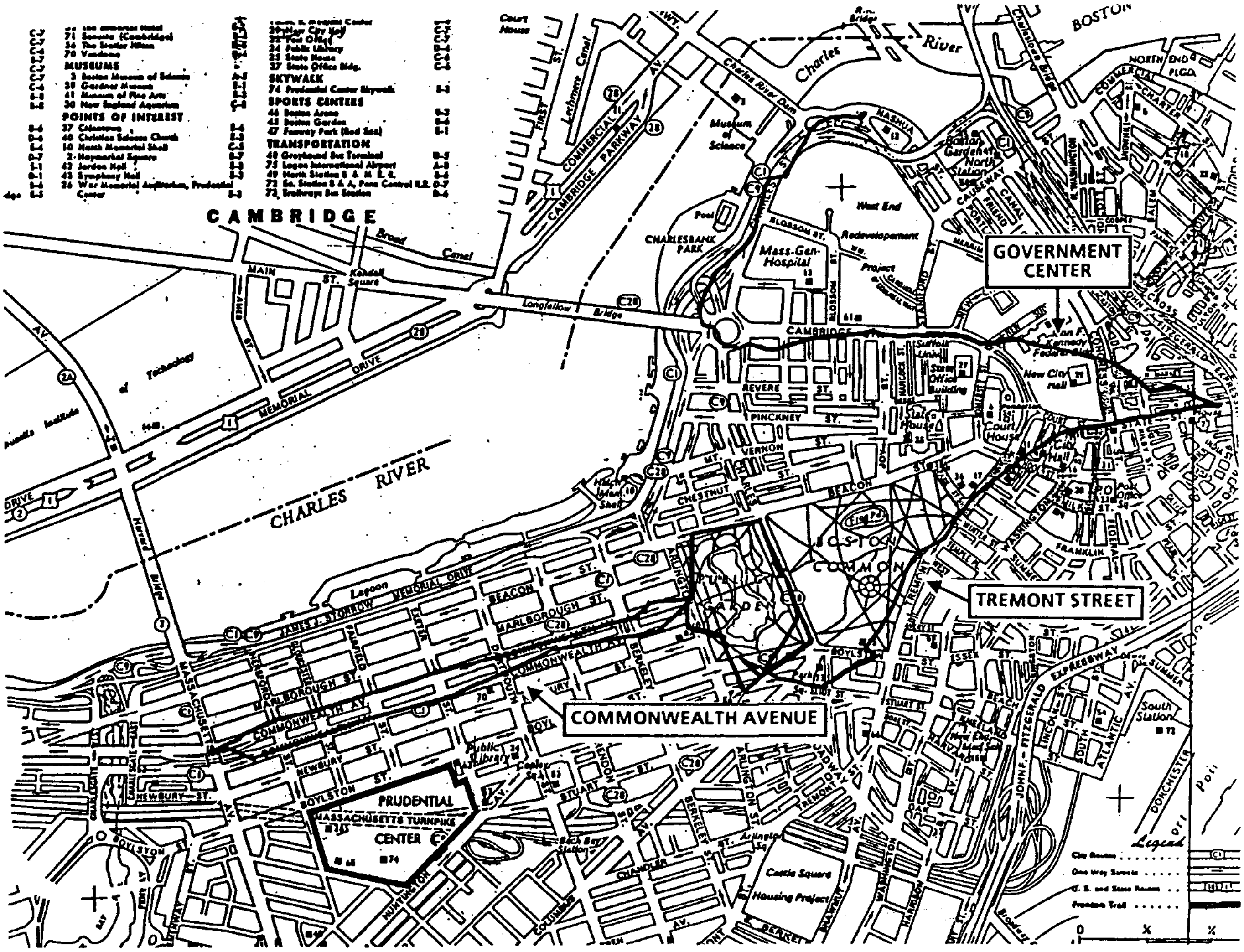


FIGURE 8. REPRESENTATIVE LORAN-C POSITION PLOTS IN BOSTON

INTERFERENCE TESTS

A series of controlled observations were made to detect receiver sensitivity to emissions in the vicinity of power substations, UHF/VHF television transmitting sites and at modular telephone transmitter sites (approximately 800 mHz). The LORAN-C receivers lost lock and indicated low SNR when within 400 feet of the power station, but recovered as the MTF left the area. The GPS receivers indicated no problems at any of the sites.

FOLIAGE TESTS

No foliage of significance was present for the January through March tests. The T-Set was tested for one day at a number of sites along Lockwood Lane in Topsfield, MA. Foliage, from a mixture of oak, pine and maple trees, varied from none to a leafed arch, 50 feet off the road. Signal attenuation was readily apparent, with SNR levels dropping 7 to 10 dB when satellite elevation was less than 40 degrees. Rising satellites were not seen until above 20 degrees, with the initial acquisitions SNR approximately 10 dB lower than baseline, unobstructed measurements. These tests and results are considered preliminary because of the limited scope of the tests. Additional tests will be conducted at another time.

DISCUSSION OF OBSERVATIONS AND RESULTS

GENERAL

The task of melding an area radionavigation system like LORAN-C or GPS with local maps is formidable. These tests were specifically designed to minimize translation effects. The evaluation stressed establishing the capabilities of the radionavigation systems to provide accurate fixing in a terrestrial environment.

Problems with the navigation solutions for both systems were noted in the Government Center area. Receivers detected a decrease in SNR (LORAN-C) or signal blockage (GPS). In view of the great difference in system characteristics, the coincidence of difficulty is noted, but no attempt to establish a common cause was made. Additional investigation is indicated if either system is seriously considered for application in Boston.

LORAN-C

Tests of the LORAN-C system continue to show that use of the system for terrestrial navigation is feasible when coverage is adequate. Two results will be noted.

ASF

The ASF variations, hence position variations, determined in these tests, fall well within the maritime accuracy goal of 1/4 nm, but are too large to permit identification of individual urban streets in Boston. Establishment of multiple calibration points throughout a terrestrial service area might keep the accuracy at acceptable levels.

Power Station Interference

These tests reaffirmed the fact that LORAN-C signals are masked by noise when in the vicinity of utility stations. No effort was made to investigate sensitivity of the receivers to power lines along roadways. Power lines were buried where urban transits were made during these tests.

GPS

The navigation runs on highways and rural roads were excellent, indicating that the system may provide an excellent capability. The tests also showed that a satellite visibility problem exists in urban environments with the current satellite constellation. TSC engineers are examining the data base to determine how representative these results are with regard to the operational system. An analysis will be included in the project report. The signal attenuation observed during foliage tests also may be significant. Additional foliage tests will be conducted in 1986.

ACKNOWLEDGEMENTS

Throughout the test period, Mr. David Pietrazewski, of the Coast Guard Research and Development Center, provided daily status reports on the GPS system. This information was used to ensure that any problems noted by the receivers were caused by local phenomenon rather than the GPS system. LCDR Robert Gazlay, of the Radionavigation Information Branch, USCG Headquarters (G-NRN-3) provided the computer programs which were used to predict LORAN-C time differences as well as those necessary to transform positions from one coordinate system to another. CWO Daniel Slagle, of the Coast Guard Research and Development Center, provided the computer programs, normally used for the LORAN-C Harbor Monitor Program, which were used to analyze static data. The assistance of these people facilitated the conduct of these tests and their efforts are gratefully acknowledged.

LORAN-C WEST COAST STABILITY STUDY

LTJG Matthew M. Blizard
CWO3 Daniel C. Slagle

U. S. Coast Guard Research & Development Center
Avery Point, Groton, Connecticut 06340-6096

ABSTRACT

The United States Coast Guard Research and Development Center (R&DC) has been conducting a multi-year Loran-C Stability Study of the U.S. Harbor Harbor Approach (HHA) areas. For this project, an extensive database of Loran-C Time Difference (TD) information has been collected along the West Coast from San Diego, California to Vancouver Island, British Columbia. This information shows that the repeatability of Loran-C on the West Coast is significantly better than the advertised "1/4 nautical mile" as many experienced users know. During the collection and analysis of this data, several factors which effect the repeatability of Loran-C have been identified and will be presented. These items include seasonal changes, RF interference, chain control procedures, and transmitter switching.

Previous final reports on the stability of Loran-C have been published, including the Northeast/Southeast report, and most recently the West Coast report. The information contained within this paper is a synopsis of the findings in the West Coast report.

BACKGROUND

Since the mid-1970's, the U.S. Coast Guard has been conducting studies on the suitability of using Loran-C as a precision aid for navigation in the HHA areas of the continental United States. Establishment of the St. Marys River mini-chain began in 1977, and with it, sparked the development and testing of HHA guidance equipment, the investigation of Loran-C chain Augmentation Techniques, and the Loran-C Stability Study as stated in references (1) and (2). Data collection, necessary in evaluating the accuracy of chain control, was performed by a Data Collection Unit (DCU). The initial DCU was an Internav receiver, model 101, which evolved to the model 204, an interface, and a Texas Instrument model 733 data terminal. Perceiving the need for an improved and more sophisticated data collection system, the R&D Center developed the Type-C Harbor Monitor Set in 1979/1980. This system consisted of an Internav LC-404 receiver, a PCM-12 microcomputer and a telephone modem. With five new Type-C sites installed along the St. Marys River, the post data edit process was eliminated, and data collection quality improved.

Expansion of the Loran-C Stability Study continued, moving on to monitoring of the Northeast U.S. Loran-C Chain (GRI 9960). In September of 1980, the first Type-A monitor was installed at Seneca, New York. The Type-A monitors were designed to be located at chain control stations where TD data could be collected from the A1 and A2 Austron 5000 control sites using the data control lines. A PCM-12 microcomputer for data collection and a telephone modem for data retrieval are used for the Type-A monitors. As the project progressed, additional Type-C monitors were installed in a clockwise fashion from New England to the Gulf of Mexico including the Southeast U.S. Chain (GRI 7980).

When word of the possible R&D Center shutdown was received in October 1981, the need for an "off the shelf" monitor set was perceived for ease in support, maintenance, and quick configuration. Consequently, by February 1982, plans for the Type-D monitor were completed. By May, the first of many Type-D sets were completed. Consisting of an Internav LC-404 receiver, a Hewlett-Packard 9915 microcomputer with telephone modem, and a power distribution/interface system, the Type-D system (Figure 1) provided for the automatic control and monitoring of the receiver.

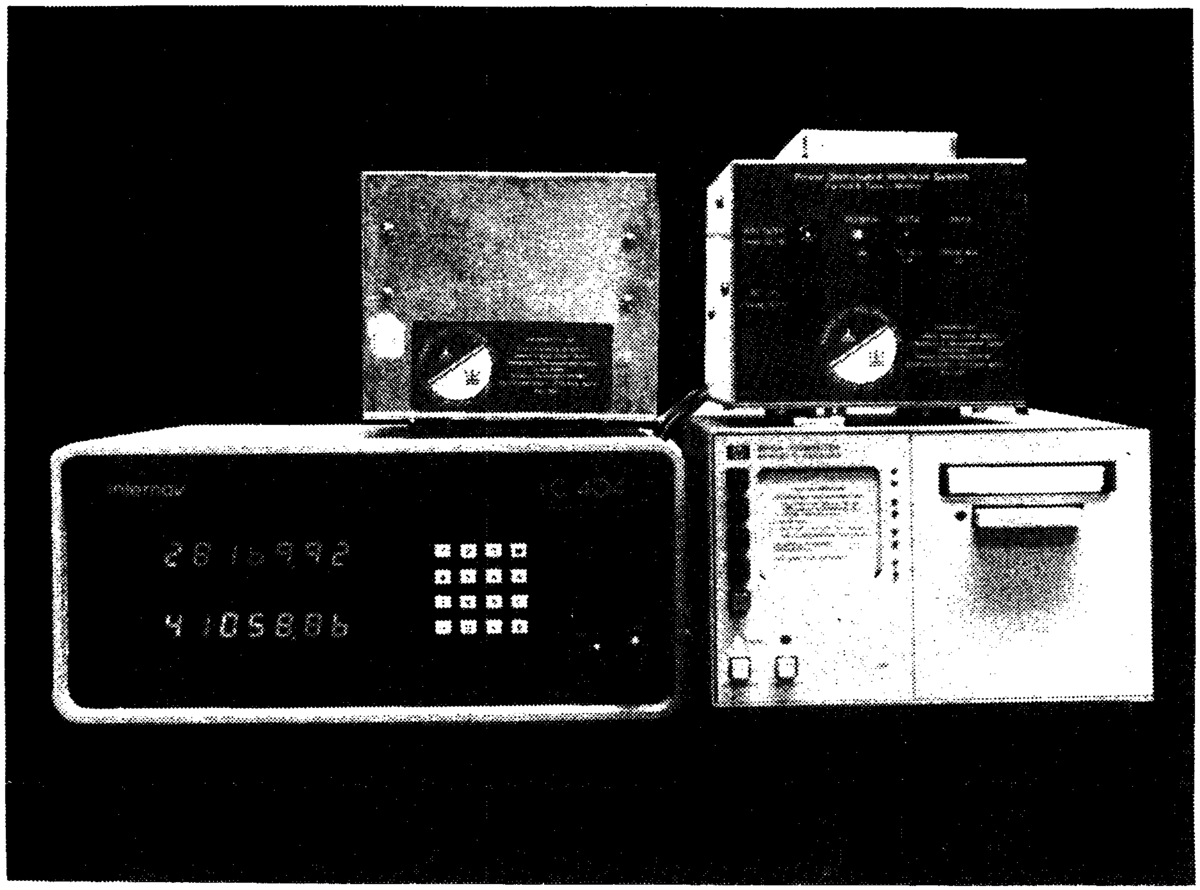


Figure 1 Point Vicente Type-D HMS

In August of 1982 the first of 9 Type-D monitors on the U.S. West Coast was installed at Point Vicente (Long Beach) California. Table 1 is a list of the West Coast site locations, along with the chain being monitored, type of site, and when they were installed.

San Diego, CA	9940	Type-D	February 1984
Pt. Vicente, CA	9940	Type-D	August 1982
Cambria, CA	9940	Type-D	May 1983
San Francisco, CA	9940	Type-D	June 1984
Brookings, OR	9940	Type-D	June 1983
Astoria, OR	9940	Type-D	August 1982
Astoria, OR	5990	Type-D	February 1984
Tacoma, WA	5990	Type-D	September 1982
Neah Bay, WA	5990	Type-D	August 1982
Comox, BC	5990	Type-D	September 1983
Middletown, CA	9940	Type-A	August 1982
Williams Lake, BC	5990	Type-A	December 1983

Table 1: West Coast HMS Sites

Data Collection

The Type-D monitor, as previously mentioned, is capable of collecting TD data in either a low or high density mode. In the low density mode, four one-hour sampling periods are conducted every twenty-four hours. During each sampling period, the receiver is polled by the on-site computer every 40 seconds for TD data. At the completion of each sample period, the computer stores on magnetic tape and internally: Julian day, sample hour, number of samples, maximum and minimum TD (excursion from the mean), mean TD value, standard deviation, and the average signal to noise ratio. The sampling periods for the West Coast chains begin at 0300Z, 0900Z, 1500Z, and 2100Z.

In the high density mode, data is also collected from the receiver every forty seconds. However, each hour now consists of four 15 minute sample periods, and data is collected every hour. This gives 96 sample periods per day, with the same statistics performed on the data. Due to the larger amount of data to be stored, storage in the high density mode is limited to about 4 days, depending on the number of secondaries being tracked.

The Type-A monitors, which are located at the chain control stations, operate in the low density collection mode only. The sample periods and statistics are the same as with the Type-D, with the exceptions that the signal to noise ratios are not collected and the data is stored internally only.

Data Retrieval

Data retrieval is performed by a system called "Data Retrieval And Management System" (DRAMS). As described in References (1) and (3), DRAMS can be operated manually or automatically. When operated automatically, a timer set at 1:00 AM loads and executes the data retrieval program on a HP 9845 computer every Monday and Thursday morning. All sites are sequentially called and the data is sorted into files and stored on the hard disk with a printout waiting for the operator on arrival. Should any of the data have problems, or if a site should be down, the information is stored in an "as collected file" which the operator can then manually inspect. The site can also be called manually to check out the system.

REPEATABILITY

During the data collection process, and particularly the analysis of the data for the West Coast Report, several aspects of Loran-C on the West Coast became quite clear. They can be classified into two categories, which are: the inherent stability, and factors which degrade the stability. Both of these categories will be discussed in some detail, along with specific examples.

Seasonal Changes

To appreciate the stability of Loran-C on the West Coast, one must first visualize the drastic geological and climatic changes which affect the signal. In the South, there are both low and high deserts, along with the Rocky Mountains and fertile farm lands. To the North, there are again large mountains, along with rain forests and the extremes of both winter and summer. With these types of changes, seasonal variations similar to the .5 μsec and greater changes experienced in the Northeast U.S. and the Great Lakes area would be expected. The data collected by the HMS, however, shows the seasonal variations from Point Vicente, California to Puget Sound, Washington are of similar magnitude to the Southeast U.S. chain. Figures 2 through 5 are examples of the annual repeatability of Loran-C which can be expected from southern California to northern Washington state.

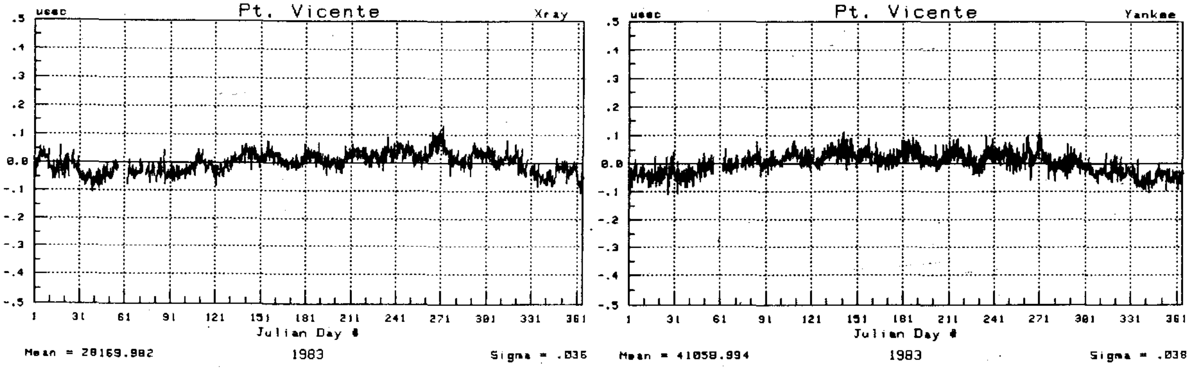


Figure 2 Point Vicente, California 9940 Xray and Yankee

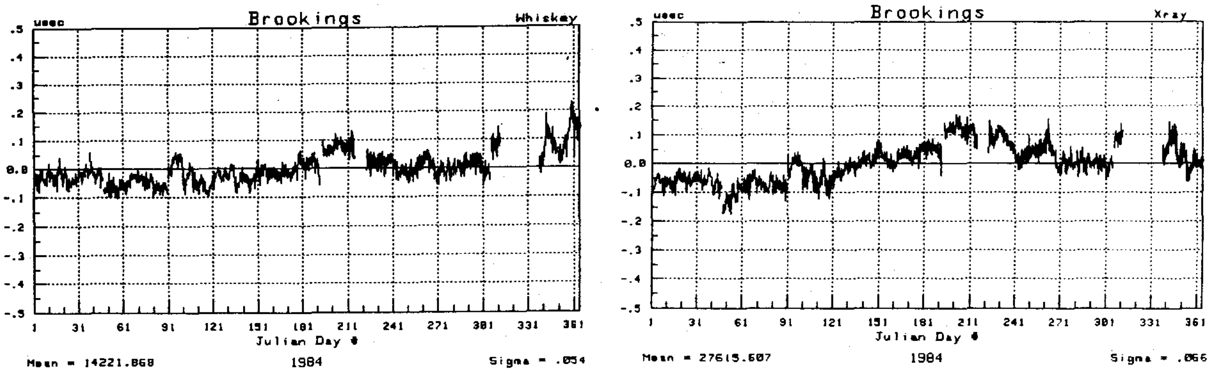


Figure 3 Brookings, Oregon 9940 Whiskey and Xray

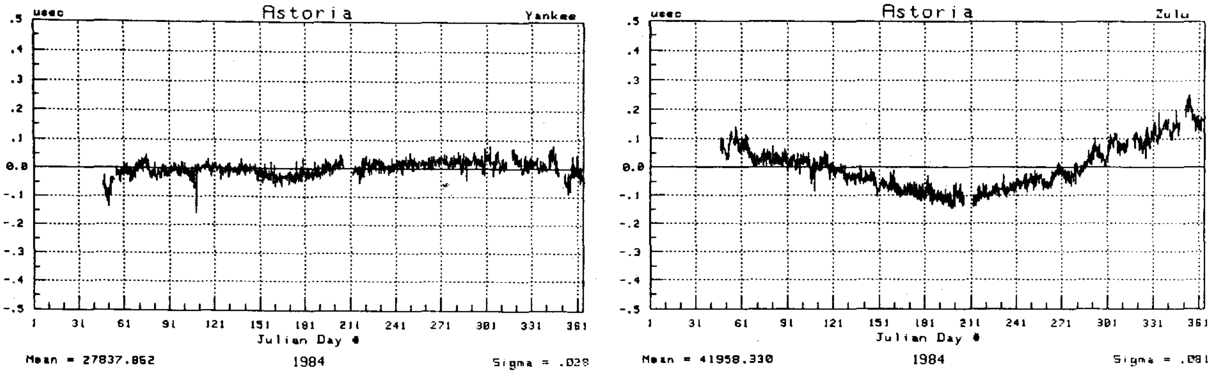


Figure 4 Astoria, Oregon 5990 Yankee and Zulu

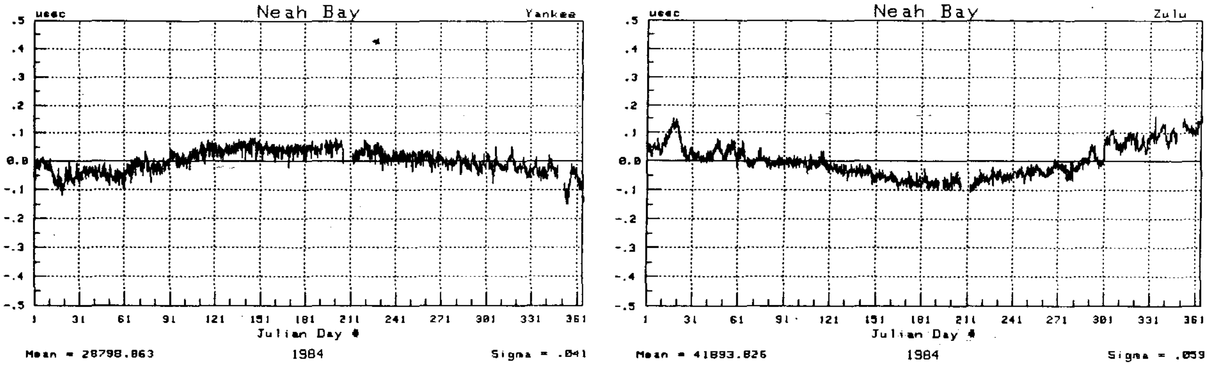


Figure 5 Neah Bay, Washington 5990 Yankee and Zulu

The preceding figures should be taken as the average seasonal stability, with many areas which are closer to the System Area Monitor (SAM) being much better. Figures 6 through 9 are the 95% confidence ellipses and 2 DRMS positional repeatabilities at the locations of Point Vicente, Brookings, Astoria, and Neah Bay. As these figures show, the positional repeatability is significantly better than the advertised 1/4 nautical mile.

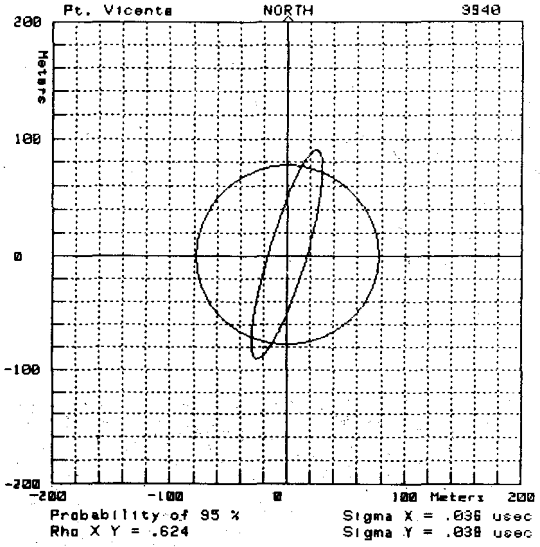


Figure 6 Point Vicente, CA
Error Ellipse

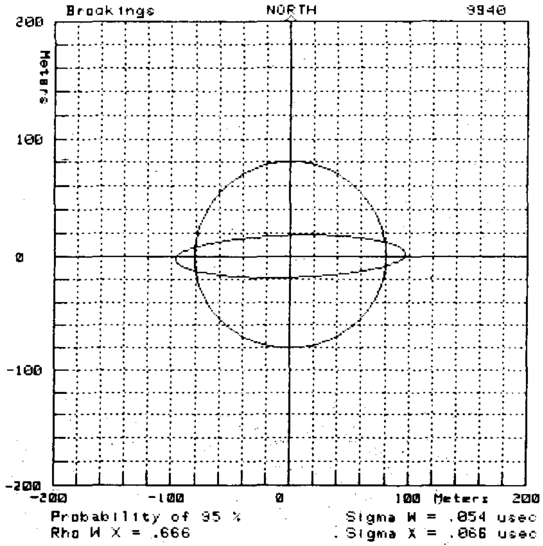


Figure 7 Brookings, OR
Error Ellipse

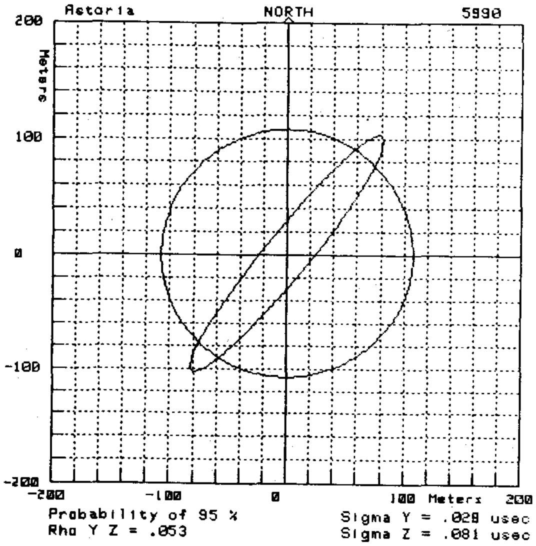


Figure 8 Astoria, OR
Error Ellipse

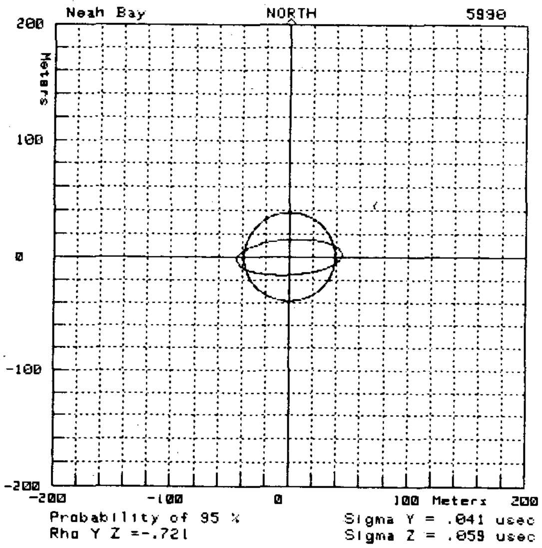


Figure 9 Neah Bay, WA
Error Ellipse

As stated earlier, several factors which affect the repeatability of Loran-C on the West Coast have been identified. They are radio frequency interference, chain control effects, and transmitter switching.

Radio Frequency Interference

Radio frequency interference, a major concern when installing any Loran-C receiver, was evident on the West Coast, both nearby and within the Loran-C band of 90-110 kHz. RF interference, detected using a Hewlett-Packard 141T spectrum analyzer, was most noticeably observed at the San Diego, California and Tacoma, Washington Harbor Monitor sites. Our intent in this discussion is not to differentiate between near-synchronous and synchronous interference, but rather to identify and elaborate on several RF frequencies which affect Loran-C on the West Coast.

When the San Diego HMS site was installed in early 1984, we detected interference at 90.5 kHz (inband) and also at 127 kHz. Due to the signal strength of the two frequencies, as shown in Figure 10, an external notch was necessary and was installed. Data collection continued throughout the summer, but a marked difference in the data was noticed in the fall. In November, a technician was sent to the site. He found interfering signals at 90.5 kHz and 106 kHz, but nothing at 127 kHz, as shown in Figure 11.

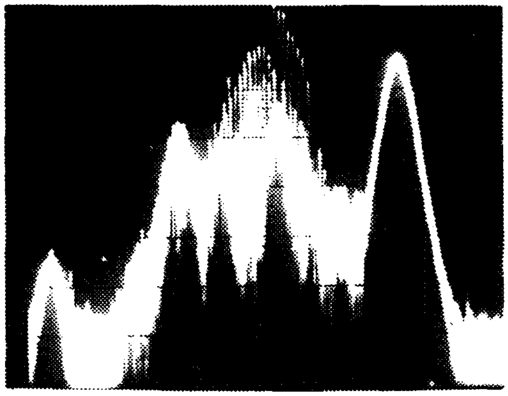


Figure 10 February Spectrum

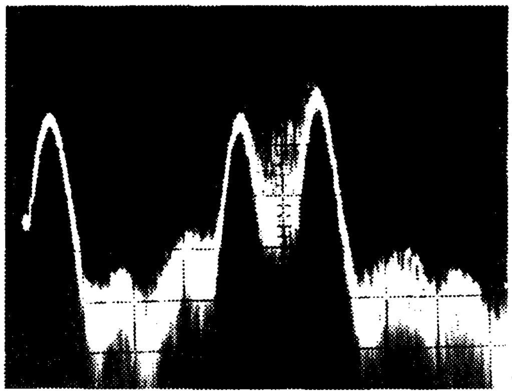


Figure 11 November Spectrum

Assistance was requested from the Federal Communications Commission (FCC) which verified the presence of both the 90.5 kHz and 106 kHz signals. The FCC was unable to locate the source of the 90.5 kHz signal, because it was intermittent. However, they were able to identify the 106 kHz signal as a second harmonic from a local Navy transmitter. Informal conversation with the FCC bore out that the local Navy transmitter had changed frequency in October because it was interfering with the local broadcast band. This would explain why the 127 kHz signal dropped out and the 106 kHz started causing problems in the fall. In May of 1985 the R&D Center removed the monitor from San Diego due to the poor quality of data being collected, after efforts to clear up the problem proved fruitless.

Tacoma, Washington was also of notable interest as a location where RF interference affected our data acquisition and collection. During the sixteen months that this site was in operation, a significant amount of the data was considered of poor quality. The problems experienced at this location were attributed to the intermittent Navy transmissions at 76.3 kHz. From what we can determine, the strength of the 76.3 kHz signal in the Seattle-Tacoma area is so strong that it caused the 100 kHz tuned Loran-C coupler to oscillate. Figures 12 and 13 show the spectrum pictures of the received Loran-C signal at Tacoma with and without the 76.3 kHz signal being on air. With the limited information presented, the Loran-C receiver would be suspect. However, conversations with users in the area indicate that many other types of receivers are suffering similar problems which limit the use of Loran-C in the Seattle-Tacoma area.

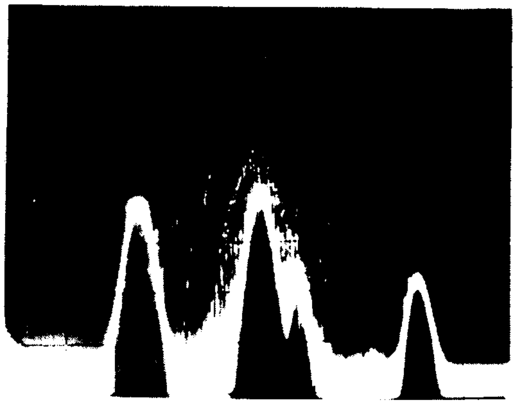


Figure 12 Tacoma With 76.3 kHz

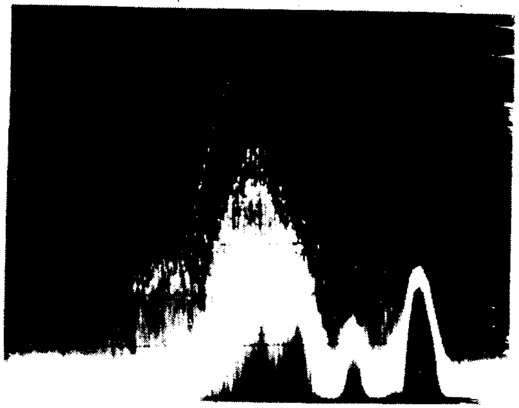


Figure 13 Tacoma Without 76.3 kHz

Chain Control Effects

The SAM, which contains the primary Loran-C receiver for maintaining the Control Standard Time Difference (CSTD) of a secondary, is called the Alpha-1 (A-1) site. Should the A-1 receiver fail or need maintenance, a backup monitor called the Alpha-2 (A-2) at another location is used to maintain a correlated CSTD within tolerance. In December 1984, the 9940 Whiskey A-1 monitor was moved from North Bend, Oregon to Point Cabrillo, California. The reasons for the move are now moot, but the effects on the knowledgable user may be significant. TD data collected on the Whiskey secondary, both with the Type-D and Type-A monitors, indicate that the annual mean TD within the service area was shifted by 200 to 300 nanoseconds. In Figures 14 through 17, the same graphs as in Reference (5), the offsets are quite clear. By plotting the Whiskey TD data from Julian day 184 to 365 of 1984 on the right side, and Julian day 1 to 183 of 1985 on the left side, the magnitude of the offset is apparent. Realizing that there are many ways to present the data, this method was chosen to amplify the age-old saga that "a picture is worth a thousand words".

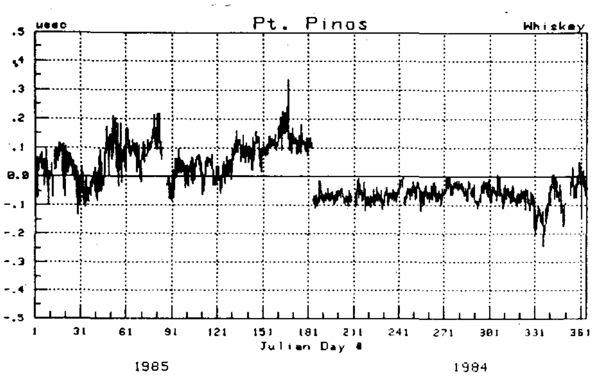


Figure 14 Point Pinos, CA
(A-2) 9940 Whiskey

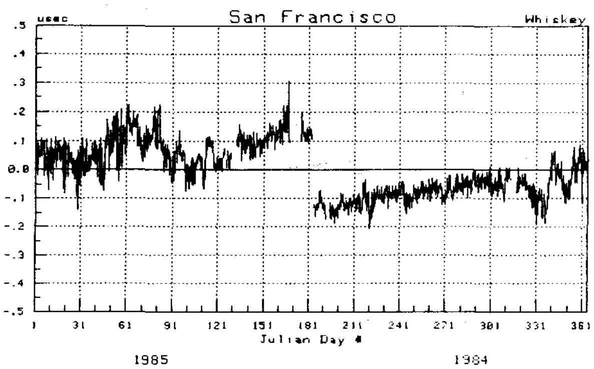


Figure 15 San Francisco, CA
9940 Whiskey

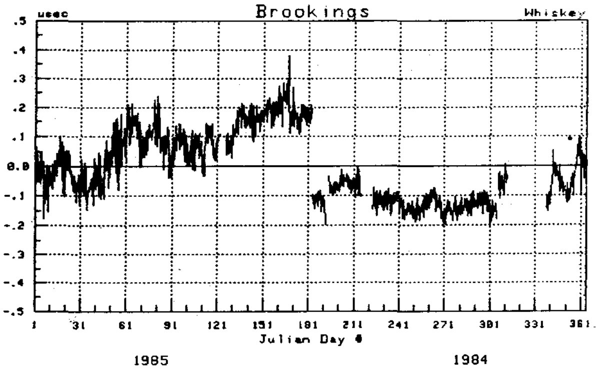


Figure 16 Brookings, OR
9940 Whiskey

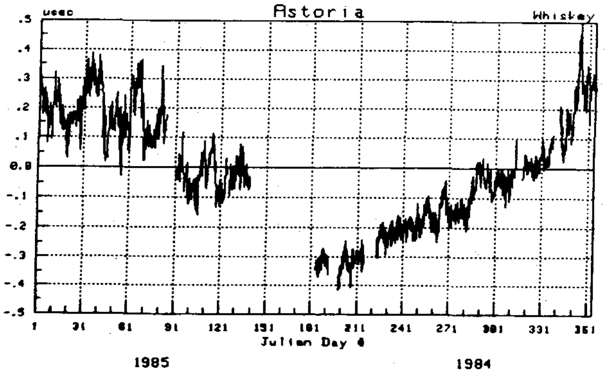


Figure 17 Astoria, OR
9940 Whiskey

In terms of positional grid shift, this is dependent upon the geometry of the coverage area; i.e., what are the Whiskey gradients and the crossing angles of the secondaries like? The sophisticated user, applying Loran-C in the repeatable mode, may find his "past" position moved by more than 300 feet. (In taking a 300 nanosecond offset and using a typical gradient of 1000 ft/ μsec, the Whiskey LOP is shifted approximately 300 feet.) Additionally, depending on the crossing angle, the difference in positions (past vs. present) could be quite a bit more than the 300 feet just computed. Even though this example sounds severe, it is plausible.

Any time a control site is moved, changes to the grid should be anticipated. These changes should be limited to the seasonal variations, with little change to the long term mean. Chain control switching, as proposed in Reference (5), should "be planned so that is done during periods when the magnitude of the long term effect can be minimized". For what must have been a valid reason, the determination of the CSTD at Point Cabrillo appears to have been performed during the winter (December) rather than in the spring or fall.

Transmitter Switching

The results of switching the AN/FPN-44A tube transmitters in the U.S. West Coast chain (9940) located at Fallon, Nevada (Master); Middletown, California (Xray); and Searchlight, Nevada (Yankee) can be seen in Figure 18. An obvious square wave TD offset function with a period of approximately 28 days is revealed by the LC-404 HMS receiver. Upon further examination of this pattern and the cause, we find that the AN/FPN-44A transmitters are routinely switched every 14 days for maintenance. In other words, transmitter number one comes on line every twenty-eight days. Excerpts from the chain control records, as discussed in Reference (4), indicate that when the master transmitters are switched, manual phase adjustments (MPA's) are made routinely in order to maintain the CSTD. These timing adjustments are done in twenty nanosecond steps, with a total of forty nanoseconds normally inserted.

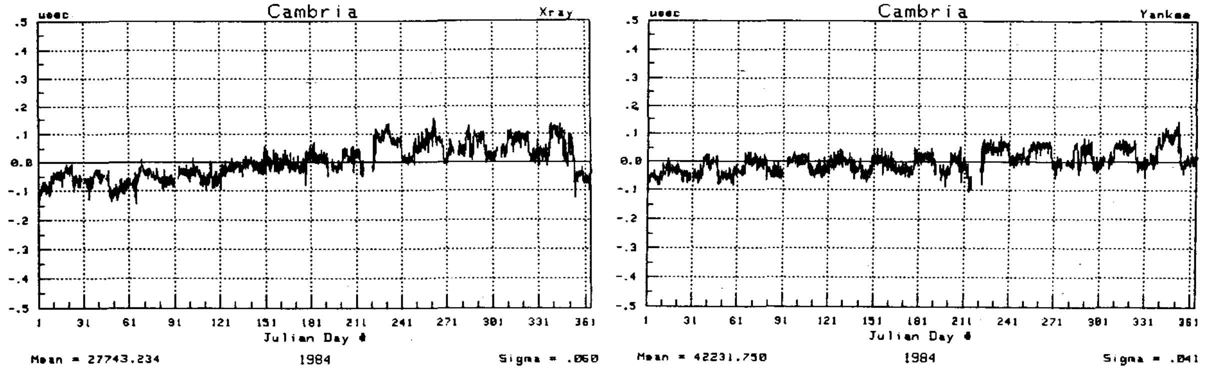


Figure 18 Cambria 9940 Xray and Yankee

The presence of this square wave function, which exists throughout the coverage area, is most evident near the SAM as Figures 18 and 19 show. Although many user receivers are unlike the narrowband, hardlimited front-end of the LC-404, in that they do not display tens of nanoseconds, a forty nanosecond error/offset would most likely be detected and applied in the TD to latitude/longitude conversion algorithm. While this may not be significant to the normal user, the sophisticated or precision user would be affected.

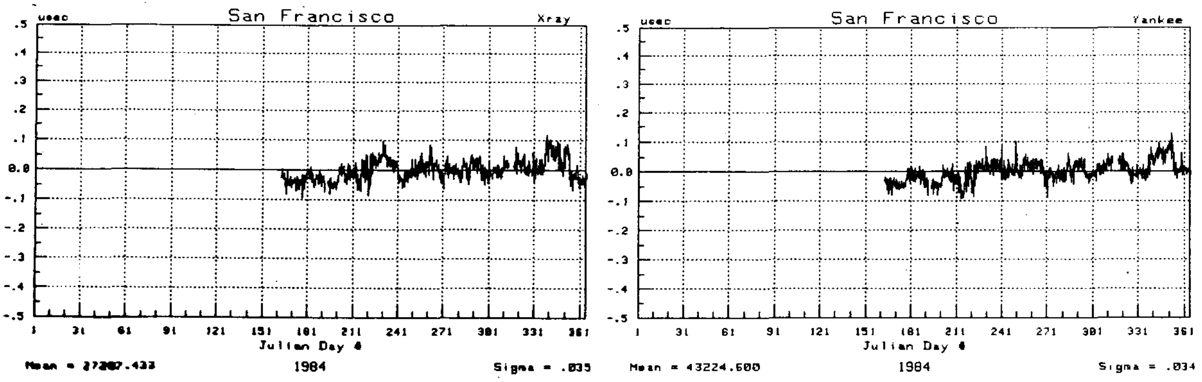


Figure 19 San Francisco 9940 Xray and Yankee

CONCLUSIONS

The HMS database, considered of sufficient density and quality to model the repeatability characteristics of Loran-C, supports the following findings as already discussed.

1. The repeatable performance of Loran-C along the U.S. West Coast is considered quite good, and in most areas significantly better than the advertised "1/4 nautical mile" system.

2. Chain control changes on the 9940 Whiskey secondary may have affected the sophisticated users.

3. The switching of the AN/FPN-44A transmitters is evident within our database. Its effect with repeatability, as compared to the 8-20 meter minimum performance as stated in the FRP for the HHA areas, is noticeable.

4. Seasonal effects are more dominate in the northern latitudes.

The intent of this paper is to give a brief preview/synopsis of the "soon to be published" West Coast Report. With regards to identifying and discussing the factors affecting the repeatability of Loran-C, and how they apply to the requirements in the FRP, a more in-depth analysis of the data is conducted in the report.

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3. HP-9845 Data Retrieval and Management System (DRAMS); Documentation of 20 December 1983.

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5. Taggart, D.S., Slagle, D.C., "Loran-C Signal Stability Study: U.S. West Coast", rough draft, June 1985.

The opinions or assertions contained herein are the private ones of the writers and are not to be construed as official or reflecting the views of the Commandant or the Coast Guard at large.

BIOGRAPHICAL INFORMATION

LTJG MATTHEW BLIZZARD, USCG
CWO DAN SLAGLE, USCG

Matthew Blizard graduated from the U.S. Coast Guard Academy in 1981 with a Bachelor of Science degree in Electrical Engineering. Following graduation, he reported aboard the Coast Guard Cutter DEPENDABLE as the Communications Officer and later to be the First Lieutenant. His next assignment was at Purdue University where he received his Masters Degree in Electrical Engineering in 1984. LTJG Blizard reported to the Coast Guard Research and Development Center in Groton, Connecticut in January 1985. Since August, LTJG Blizard has taken over as project engineer and project manager for the LORAN-C Stability Study and the Differential LORAN-C project.

Dan Slagle has been in the U.S. Coast Guard for nineteen years. He spent two years in CG Headquarters, Office of Research and Development before moving to his present assignement at the USCG Research and Development Center, Groton, Connecticut where he is involved with Loran-C signal stabilities studies and projects dealing with differential Loran-C.

SYNCHRONIZATION OF THE FRENCH LORAN CHAIN WITH THE AID OF GPS

Robert B. Goddard
Racal-Megapulse, Inc.
Bedford, Massachusetts

ABSTRACT

A major requirement of the French rho rho Loran-C chain was to automatically control the transmitter times of transmission (TOT's) in a fixed relationship to a clock that is remotely located from both transmitters. A tolerance of 50 nanoseconds was the goal.

Automatic control of the chain timing requires several time difference inputs (TD's) to the chain control algorithm. Providing these inputs with sufficient accuracy presented a number of interesting instrumentation problems including:

How to compare the time of arrival (TOA) of a Loran signal with a clock to a 10 ns accuracy?

How to measure the TOA of a Loran signal in the presence of a 700 foot antenna?

How to measure the TOT of a transmitter when sitting under the transmitting antenna?

How to insure that the chain is under proper control.

This paper addresses Megapulse's approach to solving these problems and presents some of the initial results.

I. Description of Control Problem

The Loran-C system, termed Systeme National de Radionavigation (SNR), installed by the French Navy consists of two 250 kW transmitters to be used in the range/range mode. The transmitters are located at Lessay (master) in the Northwest of France and Soustons in the Southwest. The system control center and a standard clock are located near Brest. See Figure 1.

The requirement is that the time of transmission (TOT) of the Lessay transmitter be in synchronism (+ or -50ns) with the standard clock which is termed Temps Atomique de Brest (TAB). The Soustons transmitter TOT is required to be at a fixed emission delay (+ or -30ns) with respect to the Lessay TOT. This requirement means that the TOT's must be controlled in absolute time as opposed to the usual relative control. Also because the reference clock is remotely located from the transmitters, the propagation times between the transmitters and the clock are parameters in the control equations.

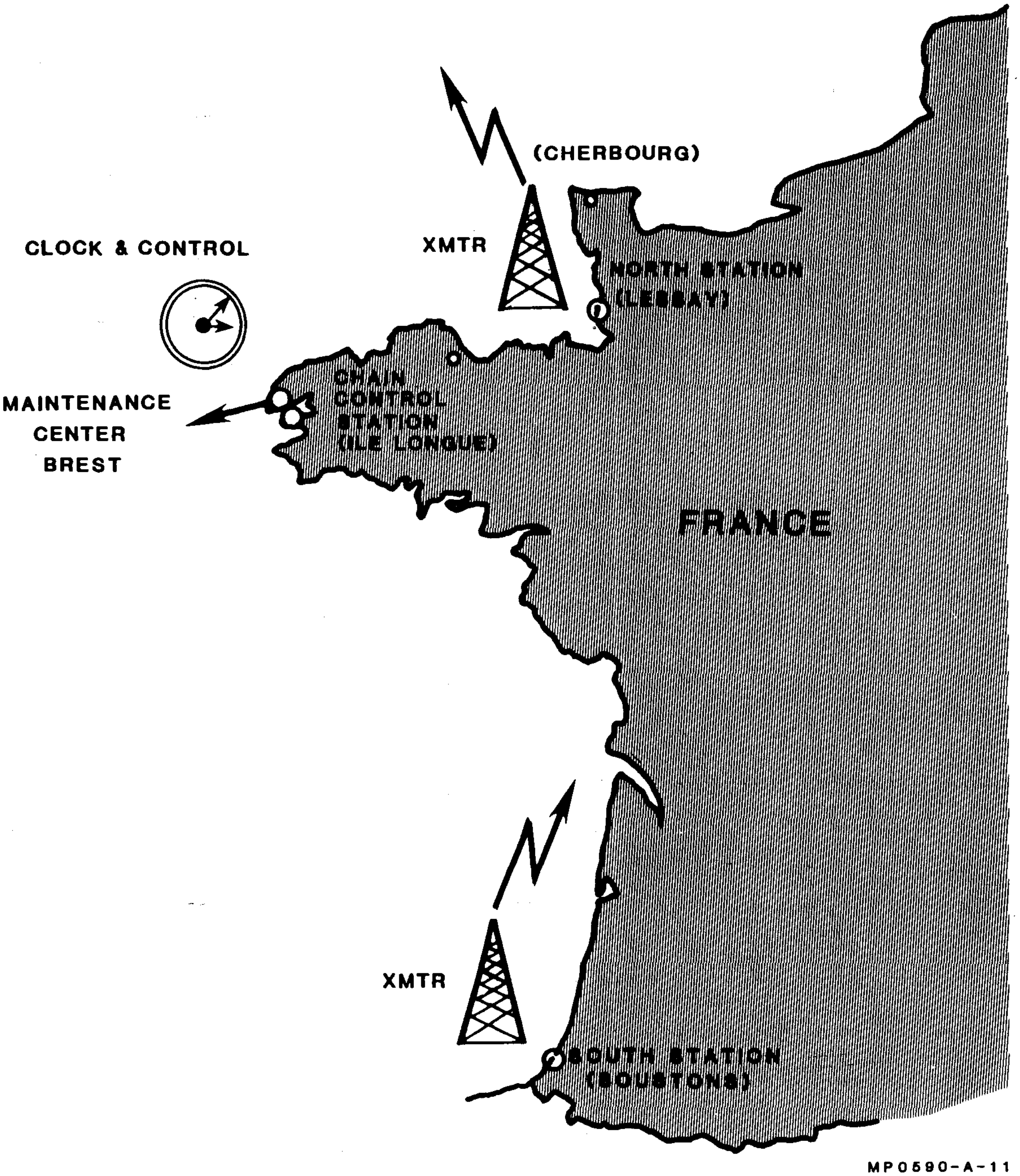


Figure 1. SNR Loran-C System

The basic timing diagram of the system is shown in Figure 2. The terminology used is as follows:

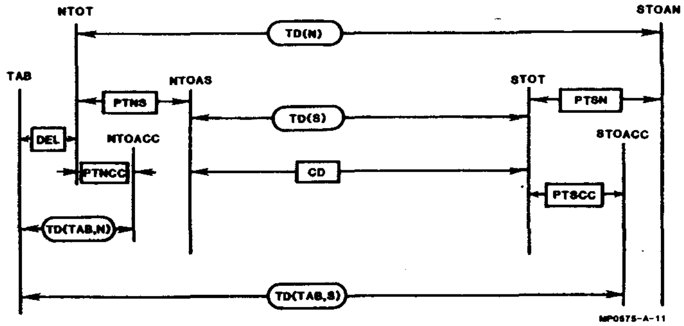


Figure 2. Basic System Timing

TAB - Temps Atomique de Brest
TOT - Time of Transmission
TOA - Time of Arrival
PT - Propagation Time
N - Lessay (north) transmitter
S - Soustons (south) transmitter
CD - Coding Delay
CC - Chain Control colocated with TAB near Brest
TD( ) - Time difference
DEL - Offset of NTOT from TAB
Examples: NTOAS = North time of arrival at south
PTSCC = Propagation time from south to chain control

There are six unknown quantities to be determined by measurements. These are the four propagation times, (PTNS, PTSN, PTNCC, PTSCC), the offset of NTOT from TAB (DEL), and the coding delay (CD). These quantities are shown in the rectangular boxes in Figure 2. Assuming reciprocity, PTNS = PTSN, we are left with five unknowns. The measurements we can make (TD's) are enclosed in circles and there are four of them; NTOAS with respect to (wrt) STOT, STOAN wrt NTOT, STOACC wrt TAB, and NTOACC wrt TAB. The two TD's at the transmitters allow CD and PTNS to be determined, but we are left with one more unknown than we have measurements. The control algorithms used will be covered in a separate paper, but one possible solution is to assume that PTSCC which is essentially an all seawater path remains constant.

We turn now to the topic of how the above measurements are made and how the TOT synchronization is checked.

II. Control System Description

Figure 3 illustrates the major components of the SNR chain control system. At the chain control center there are redundant PDP/11's and monitor receivers. Modems connect the online PDP/11 to redundant four wire phone lines to each transmitter site. At each transmitter site redundant modems enable communication with the two monitor receivers and the two remote control units (RCU's) of the transmitter. Frequency multiplexing discriminates between receivers and RCU's. Each receiver and RCU has its own ID number so that they can be individually addressed by the PDP/11. The RCU's periodically communicate with chain control, and automatically switch phone lines and modems until a useable comm link is found.

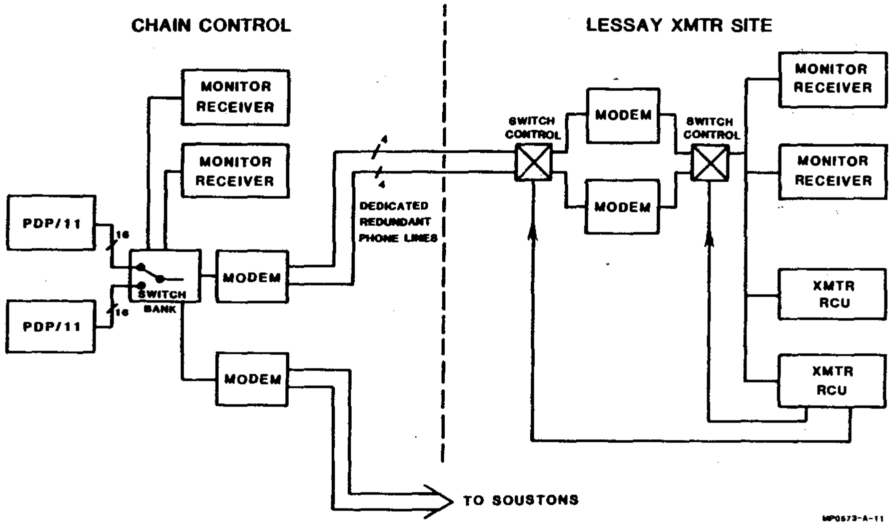


Figure 3. SNR Communication System

The PDP/11 polls all six monitor receivers every 30 seconds. The TD's and status information returned provide the inputs to the chain control algorithm which is part of the PDP/11 software. The chain control algorithm determines when a transmitter timing adjustment (LPA) is required and automatically sends an LPA command to the appropriate RCU. As a matter of interest the RCU's automatically transmit any change in transmitter site conditions to chain control as well as relaying commands to the transmitter. The transmitter status messages are received by the PDP/11's, are logged and are used to update the control center color graphic displays which continually show the state of the transmitters and the control center equipment.

III. Measurements at the Transmitters

At each transmitter we need to measure the time interval between its TOT and the TOA of the signal from the remote transmitter. Another constraint was that the receiving antenna be located on the transmitter site. Thus it could be located outside the ground plane but would still be within 300 meters of the large antenna. There are two problems with this location of the receiving antenna. The remote signal is scattered by the large antenna and the composite field seen by the receiving antenna may contain an unwanted phase shift. The second problem is that the field from the transmitting antenna is very large (above the dynamic range of a normal receiver) and contaminated by several components which are not present in the field several wavelengths away.

a) Measuring the TOA of the remote signal

Previous work indicates that the scattered field 300 meters from a 220 meter tuned antenna would be no greater than a few tenths of the size of the incident field. If the scattered field were in quadrature (worst case) and 0.3 of the incident field, a phase shift of 500 ns would result. Although this relationship may be stable it was decided to discriminate between the two fields by using a loop antenna, placing it 300 meters from the big antenna, and at right angles to the baseline between the transmitters. A discrimination of greater than 40 dB between the incident and scattered field was obtained. This discrimination should reduce any phase shift caused by the scattered field to less than 5 ns.

b) Measuring the effective TOT of the local signal

As was pointed out above it is difficult to accurately measure the TOT of a signal from a 250 kW transmitter when only 300 meters away from the antenna. It was decided to measure the TOT indirectly. In the SNR a timing pulse from the timer controlling the transmitter was used to generate a simulated Loran signal. The timing pulse used must, of course, have a fixed relationship, in time, to the effective TOT of the transmitter. This is a reasonable assumption since a control loop within the transmitter maintains a fixed relationship between the timing pulse and the antenna current.

The simulated Loran signal is delayed to the later part of the GRI and then sent via a cable to a small loop antenna which couples the simulated signal into the receiving loop. This was done to insure that any phase changes occuring between the receiving antenna and the receiver would be experienced by both the remote signal and the simulated signal. Figure 4 illustrates the setup.

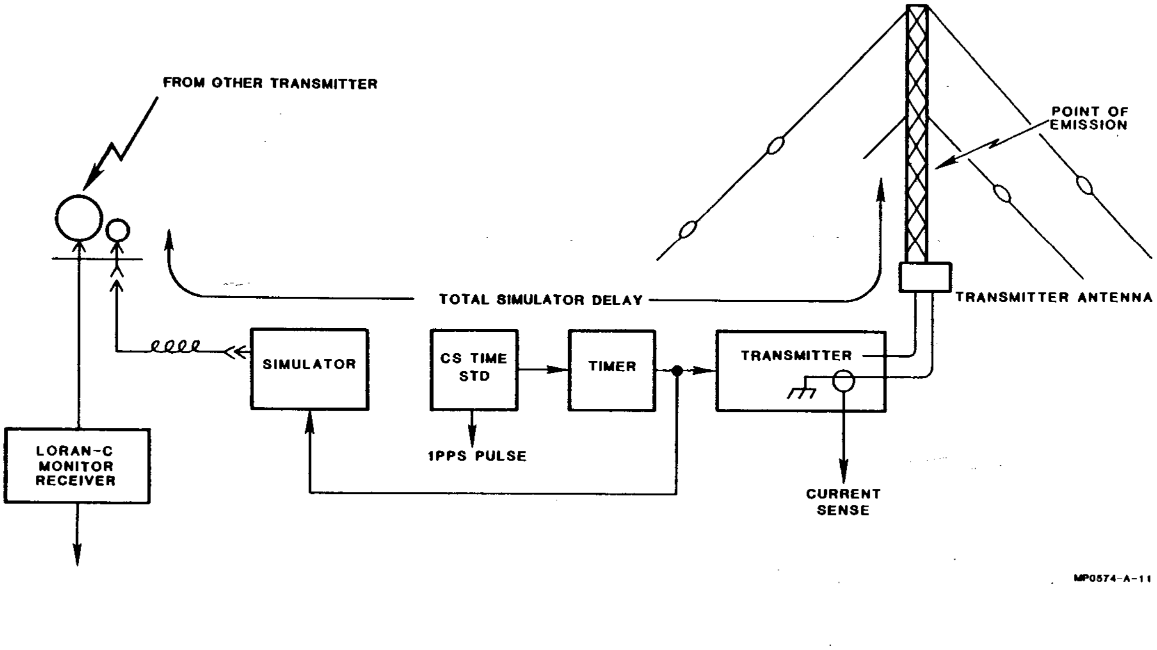


Figure 4. TD Measurement at Transmitter Site

It now remains to determine the exact delay between the effective TOT of the transmitter and the arrival time of the simulated signal at the receiving antenna. The top timing diagram of Figure 5 for the secondary transmitter suggests that if we go out on the baseline extension by 8 or more wavelengths and measure the coding delay while recording TD(s), we can then calculate the simulator delay. A similar situation exists at the master site where coding delay plus twice PTNS is measured on the baseline extension.

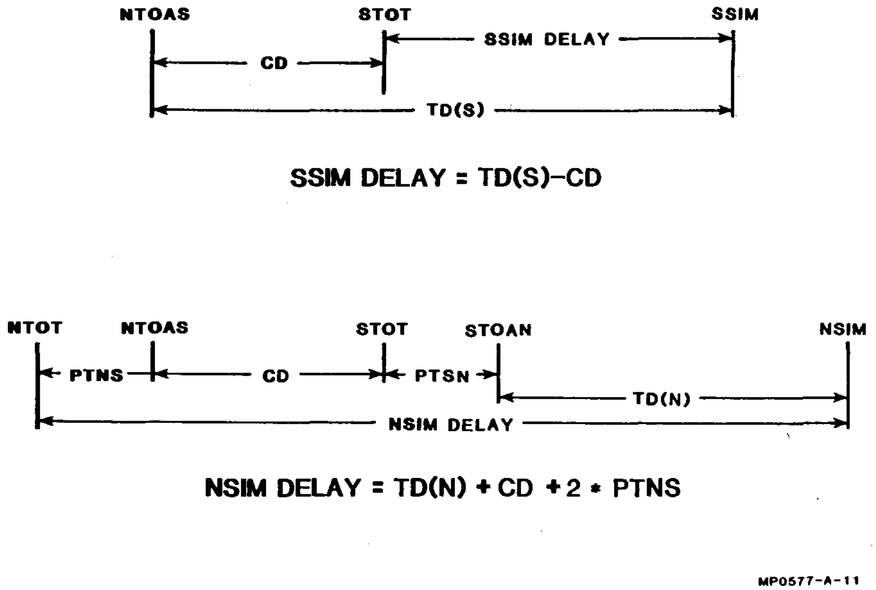


Figure 5. Timing Diagram at Soustons (Top) and Lessay (Bottom)

Having once calibrated the simulators in this fashion the PDP/11 can now continually calculate the coding delay and PTNS from the monitor TD's and the known delays.

IV. Measurements at Chain Control

The problem at the chain control site is how to measure the TOA's of the transmitter signals with respect to the standard clock, TAB. Here again, because of possible phase shift changes between the receiving antenna and the receiver sampling point, it was decided to use an intermediate simulator. A reference pulse from the TAB controls the timing of the Loran simulator. After suitable delay the simulator output is then piped to the receiving antenna location and radiated into it via a small whip. In this case the receiving antenna is a whip because it must receive signals coming from two different directions.

The simulator delay (TAB to third cycle zero crossing of the radiated simulated signal) can be measured directly with a high quality counter and suitable gating waveforms.

The simulator also included the ability to set its output in coincidence with universal time since the transmissions are required to by synchronized to UTC.

Figure 6 depicts the situation at chain control.

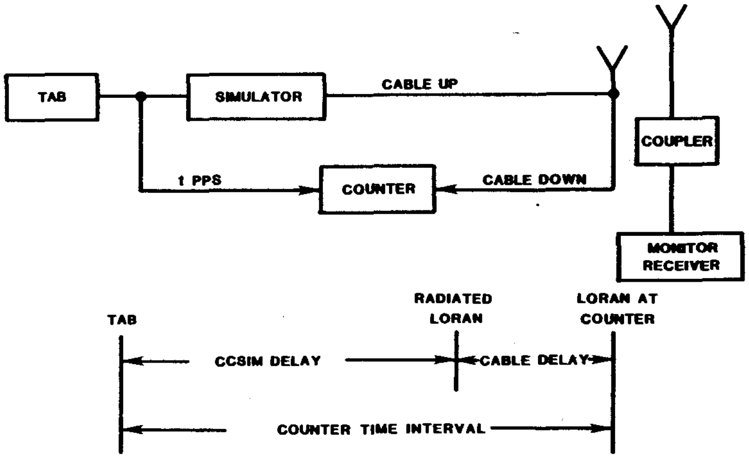


Figure 6. Simulator Delay Measurement at CC

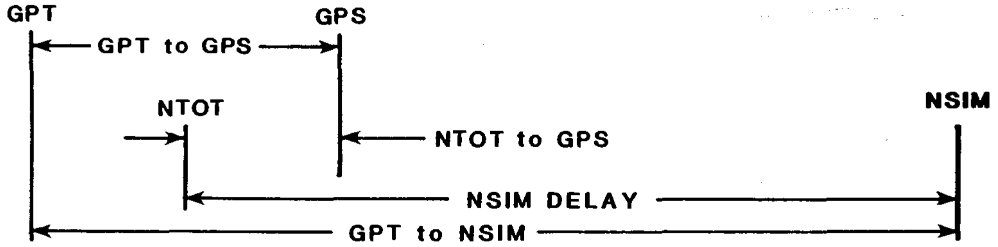
V. Verification of Chain Synchronization

At this point we have enough information to control the relative timing between the two transmitters but we don't know their TOT offsets with respect to UTC since we don't accurately know the propagation times from the transmitters to chain control. In the old days we would have determined the propagation times by running back and forth with a traveling clock. Nowadays we have the benefit of GPS which, when used in the common view mode, is very accurate (10 or so ns) and a lot more convenient.

Three GPS receivers (Trimble 5000A's) were colocated at chain control and the relative offsets of their corrected clocks were determined. One receiver was then deployed at each of the three sites. By simultaneously measuring the offset of TOT and GPS time at the transmitter sites and the offset of TAB and GPS at chain control we can calculate the offset of the TOT's with respect to TAB; i.e., UTC.

a) Offset of TOT with respect to GPS Time

Figure 7 shows the timing of events at the north transmitter. GPT stands for the group trigger from the transmitter timer which initiates both a transmitter pulse group and a pulse group from the Loran simulator.



MP0578-A-11

Figure 7. Measurement of NTOT to GPS

GPT to NSIM was previously measured with a counter.

NSIM DELAY was measured as described above.

GPT to GPS can be measured with the Trimble 5000A which conveniently contains a counter for this purpose. Note that GPT occurs once per GRI, but we are measuring it with respect to a once per second pulse internal to the Trimble. This procedure gives us the least significant portion (up to 99.999 us) of the result. Crude observation tells us the most significant part of the answer.

We now know the offset of NTOT with respect to GPS and can get STOT offset in a similar fashion.

b) Offset of TAB with respect to GPS

Timing at chain control is shown in Figure 8. The Trimble tells us the offset between the GPS and the TAB 1 second clocks. Knowing this offset, the TD's at chain control, and the previously measured CCSIM DELAY, we can calculate the offsets of NTOACC and STOACC wrt GPS.

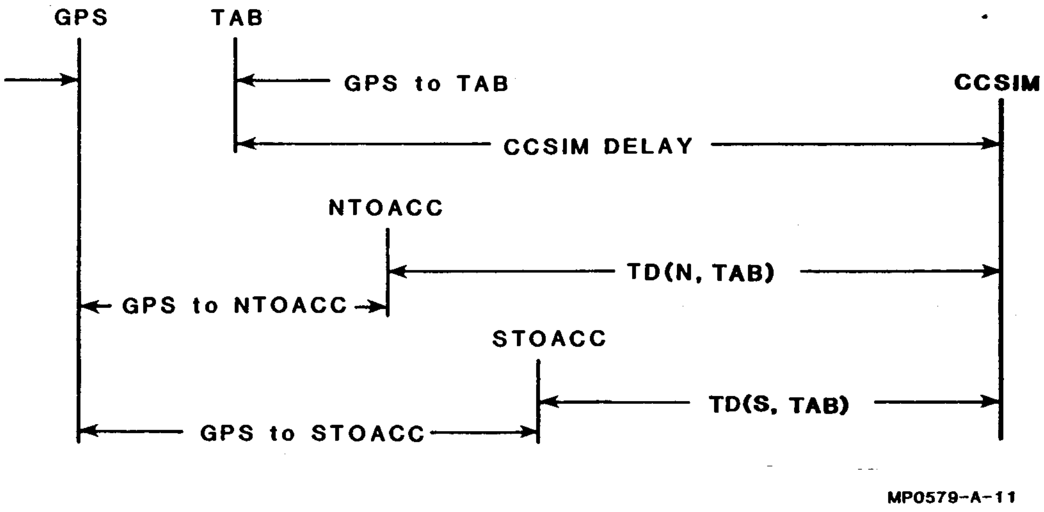


Figure 8. GPS Measurement at CC

c) Final Control Values

Taking into account the GPS receiver offsets we can now determine:

DEL (offset of NTOT wrt TAB) = (GPS to TAB) - (GPS to NTOT)
PTNCC (prop time from N to CC) = (GPS to NTOACC) - (GPS to NTOT)
PTSCC = (GPS to STOACC) - (GPS to STOT)

Finally we are in a position to calculate the receiver TD's which, when used as the control values in the chain control algorithm, reduces DEL to zero, and keep the chain aligned to UTC. The alignment remains correct only as long as the propagation times do not change. How changes in propagation times is handled is the topic of a separate paper.

VI. Conclusions

To date the limited data available indicates that the goal of controlling the transmissions to within 50 ns of UTC is being met. All of the monitoring equipment (simulators and receivers) are redundant and agreement between them is generally within a few nanoseconds. However, the synchronization check using the GPS receivers has only been done twice.

Until now the GPS data is taken separately at each site. Under a follow-on contract these receivers will be integrated into the system such that they can be interrogated from the chain control. This change will give a continuous check on chain synchronization and the ability to incorporate GPS data into the chain control algorithm, if desired. A fall-back position which doesn't rely on GPS would be retained, just in case.

VII. Acknowledgements

To the French Navy for building the SNR system, for excellent cooperation throughout the program, and for permission to publish this paper.

To Martin Poppe for participating in many of the early conceptual meetings and for first suggesting the use of common view GPS.

R. B. Goddard

Biography

September 17, 1985

Robert B. Goddard is manager of Software Engineering for Megapulse, Inc. As well as heading the development effort for the monitoring and control system of the SNR, he was instrumental in designing the transmitter monitoring system for the Saudi Arabian transmitters, and in bringing the Suez Canal system to the point of acceptance.

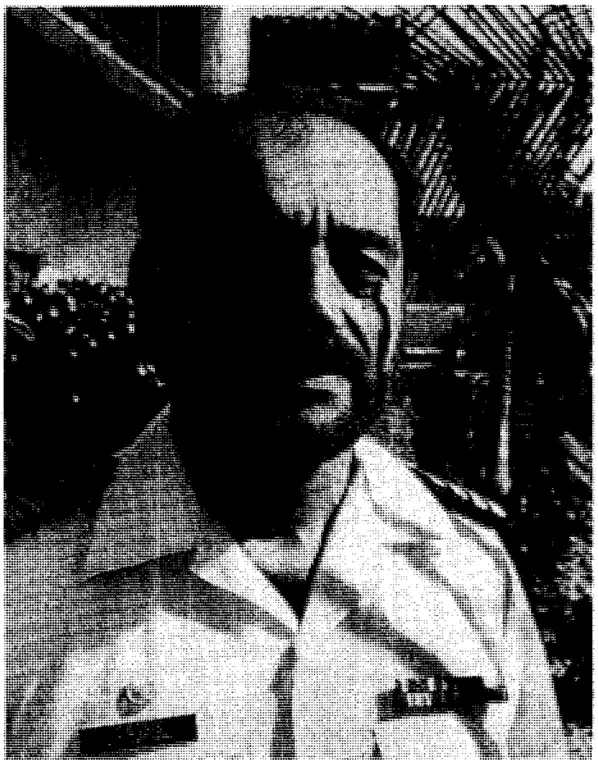
Previously at Internav, Mr. Goddard played key roles in developing the first successful low cost receiver, the first micro-processor receiver, the first commercial coordinate converter, and the LC 404 and CORT receivers.

At LFE in the mid sixties, he headed the group which developed the airborne ARN-94 and manpack PSN-2 for the U.S. Army.

TECHNICAL SESSION No. 3 - MARITIME TECHNOLOGY

Session Chairman - CAPT Robert H. Cassis (USCG)
Commanding Officer,
USCG Support Center - Alameda, CA

SESSION CHAIRMAN



CAPT Bob Cassis

SPEAKERS

(l to r) John Honey, Russ Doughty, Al Frost (back) CAPT Bob Cassis, CDR Bill May, Ralph Anderson, Kurtis Maynard, LCDR Gary Westling, Bob Miller

OCEAN DUMPING WITH LORAN-C

Russell A. Doughty
Robert D. Crowell
Daniel S. Birdsall
David H. Pianka
Robert H. Reust

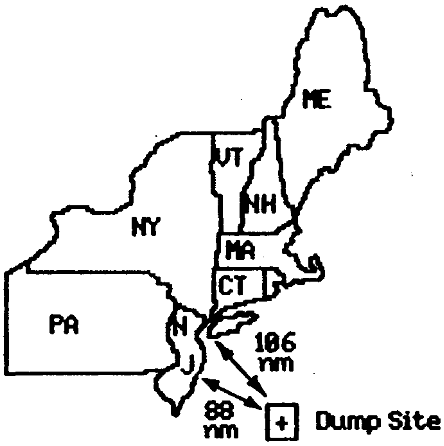
Office of Research and Development
U.S. Coast Guard
Washington, D.C. 20593

ABSTRACT

The dumping of treated sewage sludge, hazardous chemicals, and toxic materials in our oceans continues to be a problem. There is continued pressure from state governments and the U.S. Environmental Protection Agency (EPA) to move designated dumping areas farther from shore. This raises the cost and time required to monitor those operations for compliance with regulations. An Ocean Dumping Surveillance System (ODSS) that uses LORAN-C for vessel tracking has been developed to enhance enforcement operations. This paper discusses the design and operation of a pilot system for use aboard various sludge and acid waste carriers in the New York and New Jersey coastal area. Particular attention is paid to ease of operation through use of touch-screen technology.

INTRODUCTION

Since 1972 the U.S. Coast Guard has been charged with monitoring ocean dumping and the enforcement of ocean dumping regulations. Until now this monitoring has been performed by a combination of Coast Guard aircraft and ships, radar, and observers (generally called "ship riders") placed aboard vessels that are engaged in dumping operations. Recent changes in EPA regulations will close the dump site located in 60 feet of water about 12 nautical miles from New York City. These changes will also require that all sewage sludge dumping be done at a site now used for hazardous waste disposal located in 6,000 feet of water about 106 nautical miles from New York City as shown in figure 1. The current methods of monitoring these sludge dumping operations are no longer practical at such an extended range due to the increased demand on the Coast Guard's personnel and material resources. An electronic system that will provide the identification, location, and dumping status of all vessels and barges engaged in dumping operations in the New York/New Jersey area has been developed by the Coast Guard's Office of Research and Development at its R&D Center in Groton, Connecticut.



106 MILE DUMPSITE
FIGURE 1

APPROACH

Two basic approaches to system operation were considered during the early design period:

1. Record all dump mission information on magnetic tape, disk, bubble memory, or other mass storage media aboard the dumping vessel for processing and review after each dumping mission.

2. Send dump mission information at frequent intervals over a communications link to a base station located at an existing Coast Guard operations center for near immediate processing and display to the watchstander.

The second approach was selected since it offers the important advantage of detecting violations almost as soon as they occur. This increases the probability of apprehending violators or of stopping an accidental discharge in the wrong location and limiting damage to the environment. In addition, the base station operator is alerted to failures of the ODSS, or attempts at tampering with the ODSS as they occur. This eliminates the difficulties that can occur in attempting to verify the occurrence of dumping violations using recorded information that is discovered to be invalid only long after completion of the dumping mission in question. These advantages necessitate the use of a moderately complex communication system, however, it is felt that system operation is so improved by its use that this is justified.

DESIGN CONSTRAINTS

Having decided on the basic approach, several questions that were considered in the basic design of such a system were: What will it cost? Who will pay for it? Who will buy it? Who will install and maintain it? Who will inspect it?

The Coast Guard's Office of Marine Environment and Systems (the Coast Guard program manager or "CGPM" for the ODSS) is tasked with surveillance of ocean dumping and incineration under the Marine Protection, Research, and Sancturies Act. The CGPM requested that the part of the system placed aboard a dumping vessel be held to a cost of under $10,000 each when purchased in quantity.

In the mid-seventies a system using cassette tape storage for tracking sewage sludge vessels was demonstrated feasible. At that time industry was not willing to risk development of such a system, correctly judging that no market. The system discussed in this paper is developed to the point where the CGPM has a choice between buying it with a design specification and furnishing it to dumping operators, or requiring procurement and use of a functionally equivalent system (defined by performance specification) by dumping operators. This decision has not yet been made. The only certainty is the base station will be procured and operated by the government and remote units from any source will be required to communicate with it in what will become a standard format.

The CGPM stressed that any ODSS used by the Coast Guard must minimize the workload on watchstanders at the base station and the personnel at the operations centers that must prepare ocean dumping reports for the EPA and other government agencies. The watchstanders often are personnel with little or no technical training. This demands particular attention be given the design of the man-machine interface.

During the development of the pilot system it became apparent that the communications subsystem would present the greatest challenge in view of the overall remote unit cost constraint. Many avenues, including meteor burst, spread spectrum HF, Time and Frequency Diversity HF, VHF and satellite systems were studied. Just as low band VHF-FM was selected as the best cost versus performance choice, the operating scenario began to change.

In June of 1985 the EPA succeeded in obtaining a December, 1987 deadline for complete phase-out of the 12 mile dump site. Between now and then the percentage of sewage dumping at the 106 mile site will gradually increase, with a 20 percent target mandated by May, 1986. as the New York City government and its contracted sludge dumping operators realized the EPA was indeed going to close the 12 mile site, they began to look more closely at the prospect of moving operations to the 106 mile dump site. Most of the vessels and barges engaged in dumping operations would have to be certified for ocean operations to transit to the 106 mile site. This could involve increasing crew size, providing additional crew accomodations, and many other changes that would make operation of most of these vessels and barges economically impractical at the 106 mile site. This has led to the concept of using the existing vessels and barges as lighters for several specially constructed larger (15,000 gross tons or more) barges, vessels or converted petroleum tankers that would transit to the 106 mile site and perform the dumping operation. Since the communications system is a significant portion of the cost of the remotes, this would allow more expensive but proven satellite communications equipment to be installed on the large barges while low cost VHF equipment could be employed on the smaller vessels that would operate in the vicinity of the harbor and the base station. This would keep the average cost of the remote within the design constraint of $10K.

While the pilot system discussed in this paper is designed for monitoring sewage sludge dumping in the New York - New Jersey area, the system is of modular construction (both hardware and software) to allow for future use in other areas, at longer ranges, with other cargoes, and with other methods of disposal.

SYSTEM CONFIGURATION

The pilot system used in the New York area uses one base station and four remotes. The basic elements of the base station are depicted in figure 2.

The base station consists of a Hewlett-Packard HP-1000 minicomputer system with 1 megabyte of random access memory (RAM) and 16.5 megabytes of hard disk data storage, two HP-150 Touch Screen desktop computers, two printers, a low band (40 MHz) VHF transceiver and an Advanced Electronic Applications, Inc. model PKT-1 packet radio network controller that conforms to ISO Standard 3309/4335 communications protocols. The HP-1000 uses a realtime, multi-tasking operating system and is the heart of the base station.

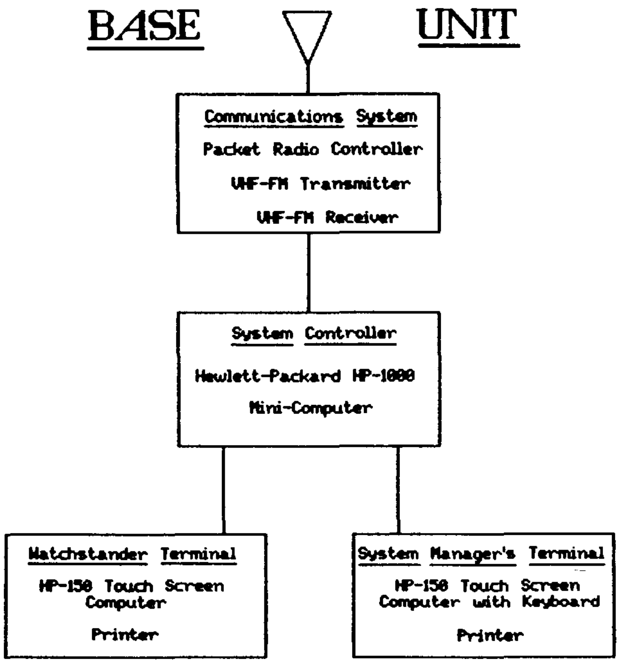


FIGURE 2

The base station performs several tasks under the control of three separate groups of programs running simultaneously on the HP-1000: The Base Station Data Collection and Storage program, the Watchstander Display and Touch-terminal program group, and the ODSS System Manager's Console program.

The Data Collection and Storage Program consists of approximately 3000 lines of FORTRAN 77 code. This program:

- Maintains the ODSS system date and time.

- Polls the remotes at regular intervals depending upon their location and status.

- Receives, verifies, interprets responses from remotes, and determines their status.

- Manages its own communications subsystems (phone lines, radios, satellite links, etc.).

- Computes operating zone of remotes (in/out of port, co-location with dump zone rated barge (i.e., cargo transfer points).

- Computes vessel status for each remote

- Computes average vessel draft for each remote

- Updates status and history data sets in the database

- Sends date and time corrections to remotes to maintain uniform time throughout the system.

The base station determines status of a vessel in accordance with the following definitions:

- Inactive - vessel has been at the dock with no A.C. service power for the past hour.

- Docked - vessel is at its assigned berthing location.

- Underway In Port - vessel is moving on the west side of the Verrazano Narrows Bridge.

- Underway At Sea - vessel is moving on the east side of the Verrazano Narrows Bridge.

- Transferring Cargo - vessels draft is decreasing while the vessel is co-located with a larger sludge carrier rated for transit to the dump site.

- Dumping - vessel is in the proper dump zone at the proper time for its cargo and dumping permits and its draft has decreased past the threshold for dumping detection.

- Dumping Out of Zone - vessel's draft has decreased past the threshold for dumping detection and it is not located within a dump zone for the cargo being discharged.

- Forbidden Zone - vessel is in an area designated as a loading point for cargo for which the vessel has no permit.

- Near Dump Zone - vessel is about 1/4 nm from the dump zone. This status is not displayed and used only to make automatic changes in polling rate.

While the remote collects data every two minutes, it is polled automatically at intervals determined by the remote's status and location as shown in table 1.

ITEM	INTERVAL	SAMPLES
Inactive	60 min.	1
Docked	60 min.	1
Underway In Port	20 min.	1
Underway at Sea	20 min.	1
Transferring Cargo	10 min.	5
Near Dump Zone	10 min.	5
Dumping	10 min.	5
* Dumping Out of Zone	10 min	5
In Forbidden Zone	10 min.	5

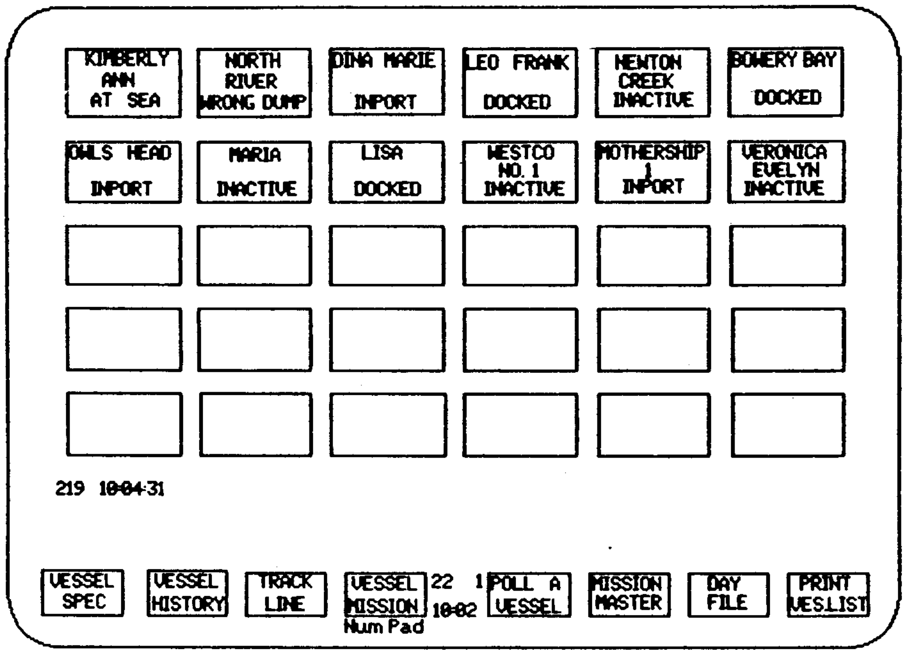
* - Gets last 10 updates then switches to this interval

NOTE: A sample is taken every two minutes by each remote.

Table 1 - Polling Intervals

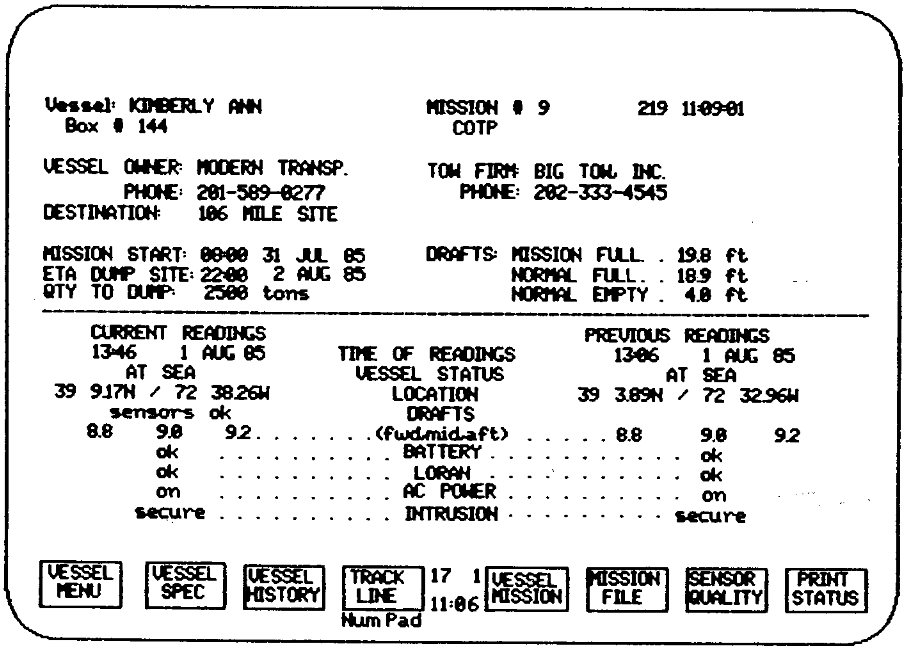
The Watchstander Display and Touch-terminal program group consists of aproximately 12,000 lines of PASCAL code. These programs interpret the information gathered by the Data Collection and Storage program and put it in a format that can be easily understood by people with little technical training or computer experience. All watchstander interaction with the system is through the touch-screen of an HP-150 personal computer operated as a terminal under control of the HP-1000 minicomputer. The system uses a series of touch-activated display screens for presentation to the watchstander. These screens are briefly defined below and some samples are depicted in figures 3 through 6. Note that the boxed areas of the display are all "touchpads." For example, touch the box with the vessel's name in it on the system VESSEL MENU screen shown in figure 3 and the detailed VESSEL STATUS (fig. 4) for that vessel replaces the VESSEL MENU screen. Touch any of the commands displayed in the bottom row of the VESSEL MENU screen and the system will request that you select a vessel for that command. You then touch the appropriate vessel name box and the system will produce the requested data such as VESSEL HISTORY or VESSEL SPECIFICATION (fig. 5 & 6). At any time you can obtain a printout of the current display by touching the "PRINT" command.

o Vessel Menu - All vessels in the data base and the current status of each. This is the default "top level" screen -- if another display screen had been selected using the touch pads and it was not used for a preset period of time, the system would return to the VESSEL MENU screen. Any change in status will cause the appropriate vessel's status indication to blink and an audible alarm to sound. Any



VESSEL MENU

FIGURE 3



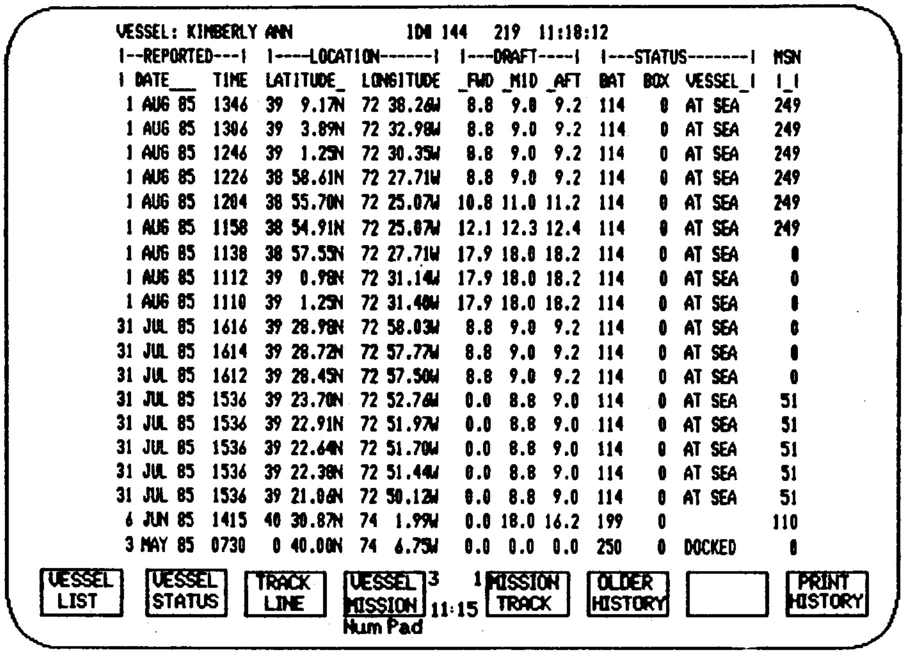
```
Vessel: KIMBERLY ANN                    MISSION # 9        219 11-09-01
  Box # 144                               COTP

VESSEL OWNER: MODERN TRANSP.            TOW FIRM: BIG TOW, INC.
       PHONE: 201-589-0277                 PHONE: 202-333-4545
DESTINATION:   106 MILE SITE

MISSION START: 00-00 31 JUL 85          DRAFTS: MISSION FULL . 19.8 ft
ETA DUMP SITE: 22-00  2 AUG 85                  NORMAL FULL. . 18.9 ft
QTY TO DUMP:   2500 tons                        NORMAL EMPTY .  4.0 ft
--------------------------------------------------------------------------
    CURRENT READINGS                                PREVIOUS READINGS
    13-46    1 AUG 85      TIME OF READINGS          13-06    1 AUG 85
       AT SEA               VESSEL STATUS                AT SEA
 39 9.17N / 72 38.26W          LOCATION           39 3.89N / 72 32.96W
     sensors ok                 DRAFTS
  8.8     9.0     9.2. . . . . . .(fwd.mid.aft) . . . . . 8.8      9.0      9.2
          ok    . . . . . . . . . . BATTERY . . . . . . . . . . ok
          ok    . . . . . . . . . .  LORAN  . . . . . . . . . . ok
          on    . . . . . . . . . . AC POWER. . . . . . . . . . on
        secure  . . . . . . . . . . INTRUSION . . . . . . . . secure
```

VESSEL STATUS

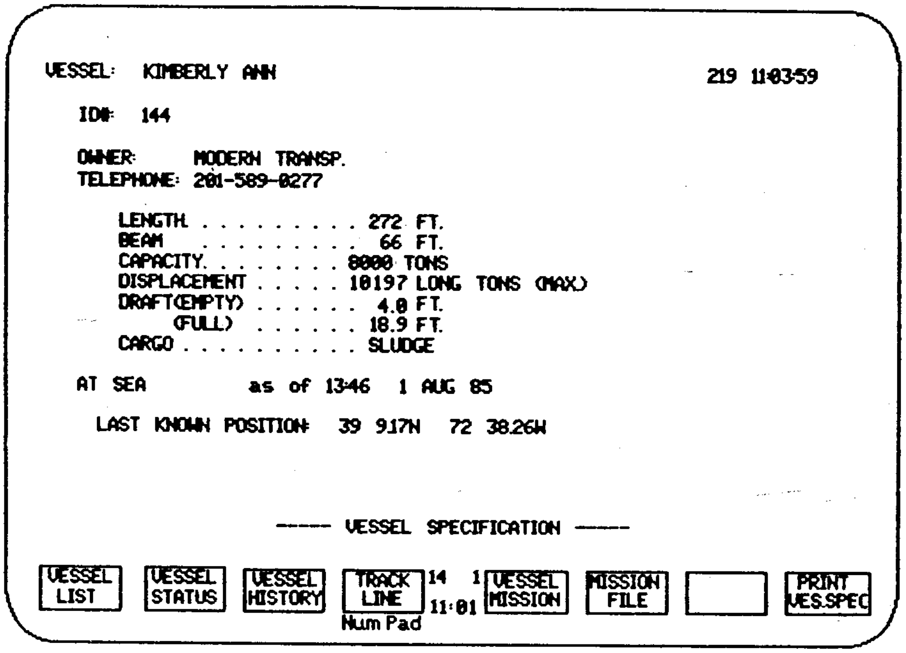
FIGURE 4



```
VESSEL: KIMBERLY ANN              ID# 144   219  11:18:12
|--REPORTED---|  |----LOCATION------|  |---DRAFT----|  |---STATUS-------|  MSN
| DATE___    TIME  LATITUDE_  LONGITUDE  _FWD  _MID  _AFT  BAT  BOX  VESSEL_|  |_|
  1 AUG 85  1346  39  9.17N  72 38.26W   8.8   9.0   9.2  114    0  AT SEA    249
  1 AUG 85  1306  39  3.89N  72 32.98W   8.8   9.0   9.2  114    0  AT SEA    249
  1 AUG 85  1246  39  1.25N  72 30.35W   8.8   9.0   9.2  114    0  AT SEA    249
  1 AUG 85  1226  38 58.61N  72 27.71W   8.8   9.0   9.2  114    0  AT SEA    249
  1 AUG 85  1204  38 55.70N  72 25.07W  10.8  11.0  11.2  114    0  AT SEA    249
  1 AUG 85  1158  38 54.91N  72 25.07W  12.1  12.3  12.4  114    0  AT SEA    249
  1 AUG 85  1138  38 57.55N  72 27.71W  17.9  18.0  18.2  114    0  AT SEA      0
  1 AUG 85  1112  39  0.98N  72 31.14W  17.9  18.0  18.2  114    0  AT SEA      0
  1 AUG 85  1110  39  1.25N  72 31.40W  17.9  18.0  18.2  114    0  AT SEA      0
 31 JUL 85  1616  39 28.98N  72 58.03W   8.8   9.0   9.2  114    0  AT SEA      0
 31 JUL 85  1614  39 28.72N  72 57.77W   8.8   9.0   9.2  114    0  AT SEA      0
 31 JUL 85  1612  39 28.45N  72 57.50W   8.8   9.0   9.2  114    0  AT SEA      0
 31 JUL 85  1536  39 23.70N  72 52.76W   0.0   8.8   9.0  114    0  AT SEA     51
 31 JUL 85  1536  39 22.91N  72 51.97W   0.0   8.8   9.0  114    0  AT SEA     51
 31 JUL 85  1536  39 22.64N  72 51.70W   0.0   8.8   9.0  114    0  AT SEA     51
 31 JUL 85  1536  39 22.38N  72 51.44W   0.0   8.8   9.0  114    0  AT SEA     51
 31 JUL 85  1536  39 21.06N  72 50.12W   0.0   8.8   9.0  114    0  AT SEA     51
  6 JUN 85  1415  40 30.87N  74  1.99W   0.0  18.0  16.2  199    0             110
  3 MAY 85  0730   0 40.00N  74  6.75W   0.0   0.0   0.0  250    0  DOCKED       0
```

VESSEL HISTORY

FIGURE 5



```
VESSEL:  KIMBERLY ANN                                    219  11:03:59

   ID#:  144

   OWNER:      MODERN TRANSP.
   TELEPHONE:  201-589-0277

      LENGTH . . . . . . . . . .  272  FT.
      BEAM   . . . . . . . . . .   66  FT.
      CAPACITY. . . . . . . . .  8000  TONS
      DISPLACEMENT . . . . .  10197  LONG  TONS  (MAX)
      DRAFT(EMPTY) . . . . . .    4.0  FT.
           (FULL)  . . . . . .   18.9  FT.
      CARGO . . . . . . . . . .  SLUDGE

   AT  SEA          as  of  13:46   1  AUG  85

     LAST  KNOWN  POSITION:   39  9.17N   72  38.26W


                   ----- VESSEL  SPECIFICATION -----
```

VESSEL SPECIFICATION

FIGURE 6

change in status that is also a violation (arriving at the dump zone early, dumping in the wrong location) causes the vessel's name to blink and an audible alarm to sound. This is necessary since the watchstander has search and rescue and other higher priority work making it impossible for him to remain in the immediate vicinity of the ODSS base station console.

o Vessel Status - The current status of a specified vessel. Mission data and the previous transmission of vessel status are also displayed. This display generally contains any vessel information that normally changes such as position or draft. Touching the "PRINT" command will print the screen contents.

o Vessel Specification - Information regarding a specific vessel that usually does not change such as owner, cargo capacity, and permit data.

o Vessel History - All entries in the history data set can be displayed for a specified vessel. The history information can be printed for any range of the data between two date-time specifiers.

o Vessel Trackline - A representation of the New York Harbor area is displayed with the vessel location for the last 70 entries in the database. The vessel location is indicated by a dot for each entry unless dumping when an asterisk designates location.

o Mission Track - Similar to Trackline except the locations are displayed only for the designated mission.

o Dumpsite Track - Similar to Trackline except the area shown is only that of the dumpsite and surrounding water.

o Vessel Mission - Displays information regarding a specified mission. If no mission is currently active for the specified vessel, one can be defined with information provided by the required dump notification from a vessel operator and entered by the watchstander using the touchscreen. Vessel operators are required to provide advance notice of intent to execute a dumping mission and must include their ETA at the dump site, cargo, and other particulars as part of this notification. If there is an active mission for the specified vessel, information such as the ETA at the dumpsite can be changed by the watchstander. Although the system normally handles the task of ending a mission, the watchstander can manually perform this function if necessary.

o Mission File - All history entries relating to a specified mission are displayed along with mission start time, ETA at dump site, and mission end time.

o Draft Sensor Quality - This screen allows the watchstander to select which draft sensors (out of the three normally installed on a sewage sludge barge) will be used when the system determines the draft of the vessel.

o Mission Master File - A list of all missions currently held in the mission data set. This information includes vessel, mission number, mission start and end times, and ETA at the dump site.

The System Manager's Console program consists of about 4000 lines of PASCAL code and allows editing of the vessel specification data set and generation of various reports from the database. It also allows generation of completed forms that the EPA and other local, state, and national regulatory bodies require of the Coast Guard in its role as enforcement agency for ocean dumping operations. The system uses a separate printer for these functions to avoid interference with the data gathering mission of the system and its watchstanders. The system manager will periodically "stream" all the information from the 16.5 megabyte disk drive to a cartridge tape drive. This information may then be used by the EPA or other agencies in studies of dumping operations to investigate long-term distribution patterns in the dump zones and their relationship to life-science or other data gathered during the same period by other systems and people for various purposes.

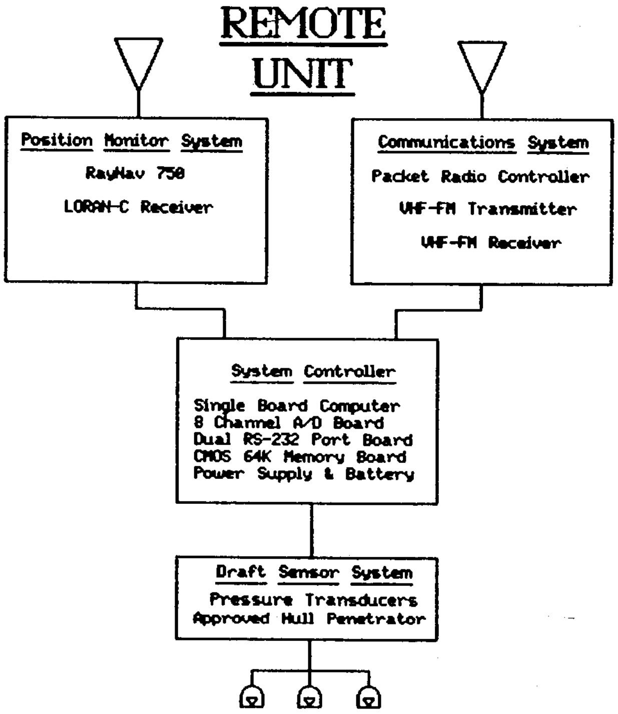


FIGURE 7

The basic elements of a remote unit are depicted in figure 7. Each remote includes: a small computer, a RAYNAV 750 LORAN-C receiver, a packet radio controller, a VHF-FM transmitter, receiver, and 40 watt power amplifier; three pressure transducers (Druck PTX 160/D, 20 psia), and; a battery-backed power supply. The computer is a single-board type using the STD bus and an 8085 microprocessor. An eight channel analog-to-digital converter card, a two channnel USART (two RS-232 ports), and a 64 kilobyte CMOS memory card also reside on the bus. The relatively large CMOS memory enables the remote to store up to 4000 samples (about 7 days) of data during periods where radio or satellite communication is unreliable.

The software for the system was developed using Microsoft's CBASIC-80 on a development system. This software was then compiled and transferred to 8085 machine code and "burned into" PROM, making it non-volatile during periods of total power loss (including the battery back-up).

LORAN-C was chosen to provide the vessel location data for several reasons:

- The accuracy of the system as stated in reference 1 is forty meters or better in the area of the dump site, New York Harbor, and the area in between.
- System availability and reliability is high.
- System has been tried in legal system in the past and found to be accepatable as evidence in law enforcement situations similar to ocean dumping.
- The system is low cost.

Many techniques for sensing the actual dumping of the sludge were considered at the start of design effort. These ranged from simple "dump door" switches to flow rate sensors. Ideas such as these have their merits, however, they either require sophisticated anti-tampering schemes or have reliability problems that the design team felt unmanageable for practical field application. In addition, a slightly different set of sensors would have been required for each dumping vessel. The final choice, that of using pressure transducer derived indication of vessel draft as a dumping indicator, makes for a "universal" detector that will work using the same equipment on all the sludge vessels. This is an important consideration for any system that will have to be installed and maintained in the work-a-day world of a sludge vessel. The concept of using pressure transducers in this application was validated by placing a motion sensing system aboard a sludge barge and simultaneously recording its readings for displacements, velocities, and accelerations in each of three dimensions with readings from two pressure transducers; one located forward and one located aft on the hull of the barge. A third pressure transducer is installed amidship for redundancy. Analysis of the test data indicated that one hundred samples from the transducers provided a reliably accurate indication of draft. The only concern in using pressure transducers is prevention of marine fouling. Several different anti-fouling paint additives are being evaluated on the prototype remote unit installations. The treatment found most effective will be recommended to the CGPM.

OPERATION

A discussion of system operation will start with the remote, since it is the origin of data for the rest of the system.

Every two minutes the remote's computer scans all the peripheral devices in the remote. It obtains the date and time from its own real-time clock, position information and receiver status from the LORAN-C receiver, pressure readings from each of the three pressure transducers, and "housekeeping" data concerning the level of charge in the batteries, and whether or not someone has tampered with the the remotes enclosure, the pressure sensors or their connecting cables. In addition, the remote's PROM contains the boundaries of any forbidden zones containing facilities that dispose of materials the vessel is not permitted to carry and dump. Should a vessel enter one of these zones for longer than twenty minutes (this period is adjustable), the remote will set a flag that will be read by the base station on its next interrogation.

The pressure transducers are read at a rate of about three samples a second; one hundred samples are averaged to determine a draft indication that is removed from wave and vessel motion effects.

Communication chores are supervised by the packet radio controller connected between the RS-232 port on the remote's single board computer (SBC) and its radio transceiver. The packet controller handles everything needed to send and receive data: packaging the data into data bursts called "packets", modulating the radio transmitter, and listening for incoming packets from the radio receiver, and demodulating these for use by the remote's SBC. The packet controller contains its own 6809 microprocessor, thus freeing the SBC from the tasks of checking the integrity of received packets and keying the transmitter. It uses a formally established protocol that allows any packet equipped remote or base station to act as a relay station when asked to do so by other packet controllers on the same radio channel. In addition, it furnishes the SBC with the status of the communications in progress via a parallel port so that the SBC can include this information in its communciations to the base station. Best of all, thanks to the popularity of this technique with radio amateurs, it does all this at bargain prices (under $500 in quantities of one). In fact, the PKT-1 packet controller used in the prototype ODSS was developed by Advanced Electronic Applications, Inc. as a result of the kit manufacturing efforts of the Tuscon Amateur Packet Radio (TAPR) Corporation.

The 64 kilobytes of CMOS memory in the remote allow the remote store several days worth of data should a problem develop with the communications system. Although the ODSS is intended to operate with continuous interrogation of the remote units by the base station, the memory can also hold data should the remote move out of range of the base station. Once the remote returns to within range of the base station all the store data will be forwarded to the base station for storage in the database and display to the watchstander.

The base station instructs the packet radio controller to interrogate each remote unit based on the polling intervals shown in table 1. Any remote unit that doesn't respond will be interrogated a second time. Should this attempt fail, the base station may be programmed to switch to an alternate communications channel or another base station transceiver located miles away near a different portion of the route to a particular dump site. The base station can dial-up transceivers over the commercial telephone network or make use of the built-in repeater functions of the packet radio controllers. Should communications be unsuccessful through all other alternate communications channels, the base station will move on to the next remote unit and record a "COMMS LOST" indication in the status data set of the database. This indication will also appear on the VESSEL MENU display screen for the watchstander.

Once the packet controller responds with a valid message to the base station computer, the remote's clock is checked for agreement to within +/- one minute of the system clock and ensure the LORAN-C receiver has not malfunctioned. Should the clock be in error, it will be set to the correct time by the base station on the next interrogation. The base station will attempt to correct a malfunction of the LORAN-C set on the next interrogation by commanding the remote's SBC to remove and then reapply power to the LORAN-C set. This forced reset of the LORAN-C set usually clears such problems as cycle slip errors or similar troubles.

The remote unit's reply is then decoded into the proper components for analysis. The readings from the pressure transducers are converted to draft indications and averaged so that FULL/DUMPING/EMPTY status is determined. The INPORT/AT SEA, NEAR ZONE and IN ZONE status are determined by applying preset limits for the boundaries of dump sites and forbidden zones to the location data from the remote unit. The information is then formatted and displayed to the watchstander with the appropriate visual and audible alarms for status changes or violations. The database is opened and the information stored in the correct data sets. While the display to the watchstander is always based on the latest interrogation of the remote, the system checks to see that the current interrogation is not a duplicate of the last one saved to the database. Duplication is possible since the remotes update their information for broadcast to the base station only once every two minutes. Should an interrogation occur sooner than a new update occurs, it will contain the same data.

CONCLUSION

Electronic monitoring of ocean dumping operations of all types will almost certainly become more widespread in the years to come. The concept of placing a "black box" aboard a vessel engaged in dumping operations is viewed as a logical first step in this area. Although the system discussed in this paper relies on established systems for position determination and communications, it offers little room for improvement in its basic operation beyond evolutionary ones such as replacement of LORAN-C with GPS. As the base of monitored vessels, vehicles, and aircraft expands, it may be possible that a dedicated satellite system be used to provide simultaneous monitoring of a wide variety of land and ocean based waste management programs. Such a system could provide both the communications and positioning information needed. While the cost of such a system is still high, it is coming down all the time. This cost could also be shared by other programs such as those used for tracking crop dusting operations to obtain maximum coverage with the minimum of pesticides. The authors believe electronic monitoring of activities related to the environment for purposes of law enforcement is just beginning to develop and that activity in this area will expand significantly in the near future.

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Full Name: Russell A. Doughty, Jr.

Current Position: Chief, Radio Aids to Navigation Section,
Navigation Systems Technology Branch,
Systems Technology Division,
U.S. Coast Guard Office of R&D

Affiliation: Member: IEEE Ocean Engineering Society
IEEE Computer Society

Professional Career Highlights: Mr. Doughty received a Bachelor of Science Degree in Electrical Engineering from Northeastern University in 1972. From 1970 to 1983 he served in the Ocean Engineering Division of Coast Guard Headquarters where he worked in the area of automated lighthouse systems design. In 1983, Mr. Doughty began his present job in the area of radionavigation sytems research and development.

DIFFERENTIAL LORAN-C...WHERE DO WE REALLY NEED IT?

Russell A. Doughty
William K. May

Office of Research and Development
U.S. Coast Guard
Washington, DC 20593

ABSTRACT

In recent years there has been increased discussion on implementing differential Loran-C in major U.S. harbors. Most of the discussion centers on the question, "To install or not to install differential Loran-C at all major U.S. harbors?" Typically the answer depends on the ability of differential Loran-C to meet the 8-20 meter accuracy requirement stated in the Federal Radionavigation Plan. However, the authors feel navigation system accuracy requirements are not well understood. We feel the real question should be, "In which harbors will differential Loran-C make a significant contribution to safe navigation?"

To answer this question, we must look at accuracy not in general terms like figures of merit (CEP or DRMS), but rather at specific requirements (like cross track error) for precise harbor navigation in each harbor of interest. This paper presents a realistic measure of accuracy needed for safe navigation of large ships in 32 major U.S. Harbor and Harbor Approach areas. We then examine the need for and ability of differential Loran-C to provide this accuracy. We conclude that only a small number of harbors would benefit significantly by having a real time differential Loran-C system.

INTRODUCTION

In 1974 the U.S. Department of Transportation selected Loran-C as the federally sponsored radionavigation system for the U.S. Coastal Confluence Zone (CCZ) and Harbor and Harbor Approach (HHA) applications. At that time it was known that Loran-C could be designed to meet the 1/4 NM, 2 drms accuracy requirement of the CCZ. This universal statement of requirements was possible because the CCZ doesn't involve physically restricted waterways. Unfortunately, this was not the case for the HHA. At the time of the Loran-C implementation decision there was no quantitative statement of the radionavigational requirements in the Harbor and Harbor Approach areas.

HHA Defined. There are five distinct phases of marine navigation in the US: ocean, coastal, harbor approach, harbor, and inland waterway. Ocean navigation is that phase which is beyond the continental shelf and more than

50 nm from land. In general, the coastal phase lies between the sea buoy and less than 50 nm from land. Harbor and harbor approach navigation is conducted in waters inland from the coastal phase. For large seagoing vessels, harbor navigation usually involves transiting well-defined channels from 200-600 meters in width which can narrow to as little as 120 meters farther inland. Inland waterways have the same general restrictions as harbor approach and harbor navigation. The primary distinction is the type of ship involved: the focus of inland waterways is non-seagoing vessels.

HHA Accuracy Requirements. There have been many attempts to define a universal radionavigation accuracy requirement for the HHA. Although the Federal Radionavigation Plan states a 8-20 meter, 2-drms requirement for the HHA, there is no known planned or operational Federal system which meets this requirement in all major U.S. harbors. This being the case, it is instructive to review some of the other stated HHA accuracy requirements:

o 1969: "...an all-weather accuracy of at least one-quarter channel width is required." (reference 1).

o 1972: "Quantitative statements of the needs for radionavigation services in this environment can be made in general terms and must reflect the uniqueness of the environment in each area." (reference 2).

o 1974: "The accuracy requirement (for HHA) ...varies from 1 nautical mile down to 50 feet." (reference 3).

o 1977: "An accuracy of 50 ft (2-drms) is considered generally to be the minimum accuracy of a system which could find broad application by major ships in the HHA." (reference 4).

o 1978: "The cross-track error of the navigation system should be 5 meters less than 20% of the channel width 99.9% of the time.", Saint Lawrence Seaway Navigation Aid Study, Vol I." (reference 5).

o 1981: "...a reliable 100 ft system..." (reference 6).

o 1983: "...channel half-width adjusted for vessel half-width..." (reference 7).

o 1984: "The required accuracy varies from one harbor to another. In the most restricted channels, predictable accuracy in the range 8 to 20 meters (2-drms) is needed." (reference 8).

The basic problem with the 8-20 meter, 2-drms accuracy requirements stated in the Federal Radionavigation Plan (FRP) is that HHA accuracy requirements are not universal, but must be established for each harbor and the largest typical user of that harbor...a difficult, but not impossible task. The requirements for radionavigation services in the HHA must be harbor specific and involve a consideration of:

o Acceptable level of safety risk to the user and the public
o Economic benefit to commerce and the public
o Cost impact to the Federal government

Large oceangoing vessels operating in the harbor approach and harbor areas have stringent navigation requirements. Here the vessel's pilot has a very limited ability to maneuver to avoid grounding or collision. As he is unable to turn around or stop to resolve a navigational problem, the pilot needs to be able to navigate his vessel within tens of feet. Thus to navigate safely, the pilot must have nearly continuous verification of his postion. This problem of safe navigation is further complicated by local weather conditions (direction/speed of wind and current, visibility, ice, rain) and ship-specific factors (vessel draft/beam/length, local knowledge/skill of the pilot). Another important consideration is that the pilot has many ways to get this information: fixed aids (lighthouses, daymarkers), floating aids (buoys), racons, radar, fathometer, and radioaids (Loran-C, GPS). In the final analysis, the question of whether differential Loran-C will be provided at all is an administrative decision dependent on the degree of benefits accruable in any particular harbor verses the cost to acquire and maintain it.

A realistic HHA accuracy requirement. With all this said, the question still remains, "What is a realistic precise positioning requirements for the HHA?" We believe this requirement can be met by a positioning system which provides 2-drms accuracy equal to 1/2 channel width minus 1/2 of the beam of the largest unescorted vessel typically using the HHA minus 10 meters for guidance error. Again it must be recognized that any requirement must be harbor specific and thus is not universal. In navigating the HHA, the most important considerations are position with respect to the sides of the channel (cross track) and position with respect to the next turn (along track). As it turns our for Loran-C, along track errors are not significantly worse than cross track errors. And, in most HHA areas, the bends are 35° or less. Further, the typical pilot of a large vessel will steer on the centerline of a channel to use existing ranges and to allow more room for navigational error. Hence, we conclude that cross track error is the most meaningful of the two.

Having established the pre-eminence of cross track error, channel width must next be addressed. After some careful thought, one concludes that if a vessel's cross track error is 1/2 channel width minus 1/2 of the vessel's maximum beam, it will be at the channel boundary. Due to the width of the locks, the St Marys River Signal Stability Study assumed the largest vessel had a beam of 32 meters (reference 6). All of the Loran-C Stability Studies to date have used this same assumptiom. As it turns out, it is a realistic assumption for the HHA since the largest vessel typically entering a US harbor unescorted by tugs is 50,000 DWT with a beam of 32 meters (references 9, 10). This means the maximum half-beam width is 16 meters. To this we must add an estimate of the pilots ability to follow a perfect Loran-C indication.

This is the essence of the guidance error problem which is caused by and depends on many variables: wind, current, channel characteristics, ice conditions, reduced visibility, ship's characteristics, approaching traffic, etc. There is no universal answer to this question. A 15 foot power boat can be steered to within several feet of a known track. Studies have shown that a ship with with length of under 650 feet and a beam of 90 feet or less can be steered to within 12 meters of channel centerline, while larger vessels average 31 meters off centerline (reference 9). The Loran-C Stability Studies assumed a 10 meter guidance error. One expert in the field stated that a good rule of thumb is that guidance error equals one half of the maximum beam of the ship (reference 10). Although a current Coast Guard R&D project is seeking more precise information on this problem, results won't be available for several years. Lacking more precise information, a 10 meter guidance error will be assumed.

Since we have defined a realistic HHA accuracy requirement, the question must be asked, "Can any positioning system, no matter how accurate, be the total solution to the problem of guiding large vessels safely through restricted waterways?" The answer is a resounding, "No!" The U.S. HHA areas contain many aids to navigation to assist the mariner: buoys, daymarks, light houses, racons, visual ranges, etc. It is a cardinal rule that the prudent navigator use all available aids to navigation and not rely exclusively on any one aid. In harbors where Loran-C is adequate except for a few narrow reaches, the mariner has other aids to safely guide him. Before implementing an expensive differential Loran-C system, each harbor should be examined closely to determine the adequacy of other aids in the areas where Loran-C service is inadequate. Next, we must examine Loran-C and how it does or does not meet HHA accuracy requirements.

USCG HHA R&D PROGRAM

As has been seen, no universal statement is possible for HHA accuracy requirements. With this in mind, the Coast Guard established a long-range research and develomment plan to show how Loran-C could (or couldn't) be used to meet HHA requirements. Note that this R&D program did not try to perform a cost-benefit analysis of possible HHA implementation. The program merely gathered and documented various Loran-C information on which to base the technical part of any administrative decision. For the past ten years the U.S. Coast Guard has been researching the suitability of Loran-C as an aid for precise navigation in the Harbor and Harbor Approach (HHA) areas of the continential U.S. The Coast Guard R&D Loran-C program can be broken down into four major categories:

- HHA guidance equipment
- HHA trackline surveys
- Loran-C chain augmentation techniques
- Loran-C signal stability

HHA guidance equipment. Although existing Loran-C receivers were adequate to meet CCZ requirements, they lacked the accuracy and automatic display capability needed in the HHA. Thus the first phase of the Coast Guard's R&D program explored ways to build and use accurate Loran-C receivers driving real-time graphic or digital displays. Two major projects made up this HHA guidance equipment program: Precision Intracoastal Loran Translocator (PILOT) and Portable Loran Assist Device (PLAD). The PILOT equipment presented the vessels position on a simple digital chart using Loran-C to determine that position...a real Loran-C navigator. It was used extensively in tests on the St Marys River, the St Lawrence River, and other areas. Although successful, PILOT failed to obtain widespread acceptance due to its lack of portability and the non-availability of a suitable source for digital charts.

PLAD is a portable waypoint Loran-C based navigation device. Its small hand-held digital display presents user selectable information as range/bearing to the next turn and along track/across track information. PLAD has proven to be a practical navigation device and, in fact, continues to be used in day-to-day piloting on the Delaware River/Bay by a member of the Delaware Pilot's Association. Further, many of today's Loran-C receivers now offer all of the capabilities of PLAD and more.

HHA trackline surveys. Once the equipment was in hand, the next task was to determine the best way to measure Loran-C time differences at precise geographic locations. After several unsuccessful attempts to use prediction techniques, the Coast Guard decided to use waypoints established by trackline surveys. Two methods of getting these measurements were developed: the visual approach where Loran-C time difference (TD) readings are taken at the intersection of two visual ranges, and; the electronic approach where a microwave positioning system is used to collect range measurements while Loran-C TD data is collected simultaneously, thus defining known trackline information. Note that the PILOT and PLAD equipments rely on local trackline surveys and are essentially useless outside their surveyed HHA area.

Loran-C chain augmentation techniques. Once the guidance equipment and its supporting trackline survey were available, the next task was to figure out what to do in those areas where the existing Loran-C system failed to meet user accuracy requirements. Three techniques were proposed and evaluated: supplemental lines of position (LOP), mini-chains, and differential Loran-C. The supplemental LOP approach adds a single Loran-C transmitting station to an existing chain to improve the geometry in a specific area. This concept was briefly tested on the St Marys River by using the Gordon Lake low power transmitter as a supplemental LOP for the Great Lakes Chain. The test didn't show any dramatic improvement in accuracy simply because the unaided Great Lakes chain geometry could not be improved upon by the addition of a supplemental LOP at Gordon Lake...this was a great idea tested in the wrong place! This technique is still considered a valid way to improve geometry problems in areas like Galveston/Houston.

The mini-chain concept can be used to meet high accuracy requirements in areas on the fringe/outside of existing Loran-C coverage areas. Although this technique was successfully demonstrated on the St Marys River, it did not substantially improve the accuracy provided by the Great Lakes Chain. Thus a mini-chain would have to be proven cost-effective before implementation.

The last augmentation technique considered was differential Loran-C. In this approach, TD variations are monitored at a surveyed site, compared to a reference TD, and the deviation broadcast to all users within a specific area. Differential Loran-C is the cheapest way to improve repeatable accuracy in areas which have good geometry and coverage, but lack TD stability. A demonstration real-time differential system is currently operating in New London, CT.

Loran-C signal stability. The last major area of Loran-C R&D study is to define the repeatable accuracy and stability characteristics of the signal itself. This, in turn, will allow us to determine whether some type of chain augmentation is necessary. The NEUS/SEUS and West Coast Signal Stability Reports analyized Loran-C stability at 32 major ports in the continental U.S. The ports were selected based on several criteria: heavy commercial traffic; heavy U.S. Navy/Coast Guard traffic; home port of Navy ocean minesweepers; and/or, home port of major Coast Guard buoy tenders. For data collection/analysis purposes, the continential U.S. was divided into four areas: U.S. East Coast, U.S. Gulf Coast, U.S. West Coast, and the Great Lakes. Remotely-controlled Loran-C monitors were established at critical locations in each of these areas, and data collected over a period of at least one year. The results of the first three studies are used extensively in this paper; the fourth study, the Great Lakes, should be completed in late 1986.

PROPAGATION MODEL

One goal of the signal stability studies was to gain an understanding of the repeatable accuracy available from Loran-C within the continental U.S. The approach was to take data samples at a number of key locations and then develop a method of predicting (or modeling) those areas where data was not taken. The key locations were chosen based on the characteristics and input parameters of the model developed. The Loran-C time difference model that was developed, known as the Double Range Difference (DRD) MOD 2 Model, is documented in references 6, 7, 11 and 12.

Modeling was necessary to be able to determine TD variations at locations within the HHA where actual measurements do not exist. By modeling the TD variations, one can compute data sigmas and cross correlation coefficients to generate error ellipses. Note that model parameters were adjusted to minimize the residual sigmas. Also, since certain quantities which change with time must be included, the the model accounts for changes in velocity of propagation as a function of distance and the propagation path itself (seawater, frozen/unfrozen land). The model also accounts for differences between Austron 5000 and LC 404 monitor receivers. Recall that Loran-C system control requires the time difference (TD) at the system area monitor (SAM) be held constant. In reality, there is an acceptable degree of variation at a SAM before any "out of tolerance" adjustment is made. Typically, the SAM's ability to keep the TD constant results in a sigma of 12 nanoseconds or less. Also, additional variations are caused by different types of monitor receivers. For example, the standard SAM monitor receiver, an Austron 5000 (wide band, linear) "sees" the world differentially than the HHA monitor receiver, an Internav LC-404 (narrow band, hard limiting). The DRD MOD 2 model accounts for a common error term between the Austron and the Internav. Obviously, different adjustments may be necessary if different monitor receivers are used.

LORAN-C REPEATABILITY

During the various Loran-C studies conducted since the mid-1970's, numerous factors have been discovered which affect the repeatable accuracy of Loran-C. Because these factors affect different receivers in different ways (e.g. monitor receivers are affected differently than navigation receivers), they tend to limit the repeatable accuracy of Loran-C. Even in its differential mode of operation, this uncertainty is estimated to be 25 nanoseconds.

Seasonal effects. The seasonal component is usually the primary source of TD variations. The stability studies found that the temperature and humidity of the air mass above the land, not the land itself, is the driving factor. A relatively simple scheme was devised to eliminate most of this error: classify land as either north or south, the dividing line being the contour where the mean annual number of days minimum temperature is 32 °F and below equals 90. Then modify the DRD prediction model to include a weighting factor corresponding to the land type. The practical limitation of the modeling was a TD standard deviation in the range of 11 to 35 nsec.

Chain control effects. Loran-C chain control is accomplished by adjusting the transmitted signal to maintain a constant TD number at a single control site (known as a System Area Monitor-"SAM"). System reliability is maintained through a system of back-up monitor sites. Unfortunately, problems with repeatable accuracy occur when the alternate monitor sites are used. Offsets of up to 300 nsec have been observed. Users who establish waypoints at positions when the chain is controlled by its primary monitor will probably experience errors when the primary SAM is relocated or a secondary SAM is temporarily used.

Transmitter switches. Many Loran-C stations have two transmitters to ensure reliable system operation and to perform routine maintenance. When these transmitters are routinely switched every 7 to 14 days, a 20-40 nanosecond offset is typically introduced into the system. This offset is removed by making a phase adjustment to the secondary transmitters emission delay. Since phase adjustments are made in 20 nanosecond steps, some residual error will be introduced into the system.

Other effects. There are several other factors which can cause considerable variation in the repeatable accuracy of Loran-C:

- Radio frequency interference
- Weather effects (severe cold weather or passing storm fronts)
- Diurnal effects

Unfortunately, there is no way our propagation model can account for these unpredictable variables.

STABILITY STUDY RESULTS

Ability to meet FRP HHA requirements. The NEUS/SEUS and West Coast Loran-C Stability Studies (references 7 and 12) identify and characterize Loran-C stability in 32 major HHA areas. Table 1 shows Loran-C repeatable performance in meters, 2-drms, as determined from the previously describe DRD MOD 2 model. Existing Loran-C does not meet Federal Radionavigation Plan requirements in any area. And, in over half of these HHA areas, even differential Loran-C fails to meet the 8-20 meter, 2-drms FRP requirement. Also, the Global Positioning System (GPS) accuracy planned to be released to the public, 100 meter, 2-drms, fails to meet FRP HHA requirements.

PORT	EXISTING (meters, 2-drms)	DIFFERENTIAL (meters, 2-drms)
U.S. EAST COAST		
Boston, MA	30	14
Providence, RI	39	19
New London, CT	49	16
New Haven, CT	33	15
Hudson River	106	22
New York, NY	32	14
Delaware River	47	15
Baltimore, MD	67	17
Chesapeake Bay	53	19
Norfolk, VA	43	20
Wilmington, NC	179	100
Charlestown, SC	45	18
Savannah, GA	36	16
Kings Bay, GA	26	14
Jacksonville, FL	31	14
Miami, FL	176	76
U.S. GULF COAST		
Tampa, FL	76	29
Mobile, LA	138	29
New Orleans, LA	58	22
Houston, TX	123	55
Post Arthur, TX	98	48
Corpus Christi, TX	179	111
U.S. WEST COAST		
San Diego, CA	194	73
Long Beach, CA	97	47
Los Angeles, CA	97	47
Port Hueneme, CA	82	40
Santa Barbara, CA	96	47
San Francisco, CA	46	27
Eureka, CA	75	28
Coos Bay, OR	82	33
Portland, OR	129	54
Seattle, WA	42	20

Table 1 - LORAN-C HHA PERFORMANCE

Ability to meet realistic HHA requirements. However, by using a realistic accuracy requirement and examining each HHA area individually, the results change dramatically. Table 2 shows the ability of existing Loran-C in the repeatable mode and differential Loran-C to meet the realistic HHA accuracy requirements defined earlier in this paper. Existing Loran-C in its repeatable mode, as predicted by the DRD MOD 2 model and updated with weekly or monthly seasonal corrections, can meet these requirements in over half of the HHA areas. Of the remaining HHA areas, there are only 5 which adding differential Loran-C will increase the performance sufficiently to meet our realistic requirement:

- o Upper Hudson River
- o Chesapeake Bay
- o Tampa, FL
- o Eureka, CA
- o Portland, OR

Figure 1 shows the half channel plots for these 5 areas indicating the results which can be achieved using Loran-C in its repeatable mode (left hand side) and by using differential Loran-C (right hand side). The differential Loran-C plots assume a 25 nanosecond uncertainty due to noise and differences between the monitor receiver and the users receiver. Cross track error data were computed for each reach point. The heavy solid line represents the half channel width minus 16 meters. The following notation is also used on the plots:

*** = cross track error exceeds 1/2 channel minus 16 meters

** = cross track error is within 1/2 channel minus 16 meters but within 5 meters of the channel boundary

* = cross track error is within 1/2 channel minus 16 meters but between 5 and 10 meters of the channel boundary

o = cross track error is within 1/2 channel minus 16 meters and better than 10 meters from the channel boundary

CONCLUSIONS

The Federal Radionavigation Plan HHA minimum performance requirement of 8-20 meters, 2-drms is unrealistic and cannot be met in all harbors by any existing or planned Federal radionavigation system. Any realistic HHA requirement must consider each harbor individually, and take into account such factors as channel width/depth, typical vessel size, and other available aids to navigation. Existing Loran-C has the stability required to meet realistic precise navigation requirements in about half of the HHA areas. Differential Loran-C can produce a meaningful improvement to safe navigation in only 5 HHA areas: Upper Hudson River, Chesapeake Bay, Tampa, Eureka, and Portland.

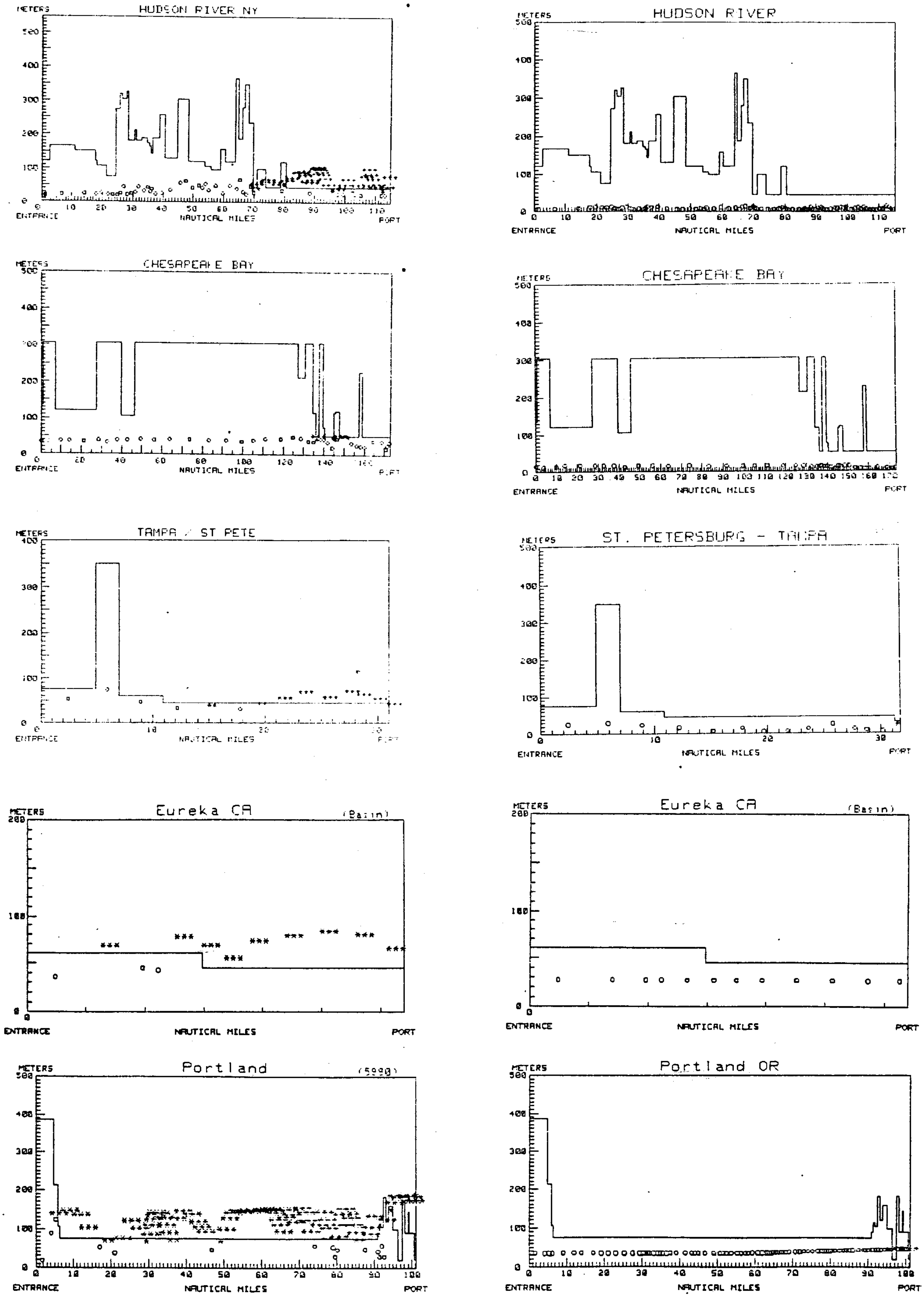
DISCLAIMER

The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Commandant or the Coast Guard at large.

PORT	EXISTING	DIFFERENTIAL
U.S. EAST COAST		
Boston, MA	PASS	PASS
Providence, RI	PASS	PASS
New London, CT	FAIL	FAIL
New Haven, CT	PASS	PASS
Hudson River (upper)	FAIL	PASS
Hudson River (lower)	PASS	PASS
New York, NY	PASS	PASS
Delaware River	PASS*	PASS*
Baltimore, MD	PASS*	PASS*
Chesapeake Bay	FAIL	PASS
Norfolk, VA	PASS*	PASS*
Wilmington, NC	FAIL	FAIL
Charlestown, SC	PASS*	PASS
Savannah, GA	PASS*	PASS
Kings Bay, GA	PASS*	PASS
Jacksonville, FL	PASS	PASS
Miami, FL	FAIL	FAIL
U.S. GULF COAST		
Tampa, FL	FAIL	PASS*
Mobile, LA	PASS*	PASS*
New Orleans, LA	PASS	PASS
Houston, TX	FAIL	FAIL
Post Arthur, TX	FAIL	FAIL
Corpus Christi, TX	FAIL	FAIL
U.S. WEST COAST		
San Diego, CA	FAIL	FAIL
Long Beach, CA	FAIL	FAIL
Los Angeles, CA	FAIL	FAIL
Port Hueneme, CA	PASS	PASS
Santa Barbara, CA	PASS	PASS
San Francisco, CA	PASS	PASS
Eureka, CA	FAIL	PASS
Coos Bay, OR	FAIL	FAIL
Portland, OR	FAIL	PASS*
Seattle, WA	PASS*	PASS*

* These ports Loran-C provides adequate performance in all but one or two reaches where the half-width of the channel at times approaches 30 meters. In these narrow areas, adequate alternatives to Loran-C exist.

Table 2 - LORAN-C ABILITY TO MEET REALISTIC HHA ACCURACY REQUIREMENTS



REPEATABLE LORAN-C

DIFFERENTIAL LORAN-C

Figure - AREAS RECOMMENDED FOR DIFFERENTIAL LORAN-C IMPLEMENTATION

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BIOGRAPHICAL DATA FORM

Full Name: Russell A. Doughty, Jr.

Current Position: Chief, Radio Aids to Navigation Team,
Navigation Systems Technology Branch,
Systems Technology Division,
U.S. Coast Guard Office of R&D

Affiliation: Member: IEEE Ocean Engineering Society
IEEE Computer Society

Professional Career Highlights: Mr. Doughty received a Bachelor of Science Degree in Electrical Engineering from Northeastern University in 1972. From 1970 to 1983 he served in the Ocean Engineering Division of Coast Guard Headquarters where he worked in the area of automated lighthouse systems design. In 1983, Mr. Doughty began his present job in the area of radionavigation sytems research and development.

BIOGRAPHY

Commander William K. May, U.S. Coast Guard

A 1966 graduate of the U.S. Coast Guard Academy, CDR MAY has served both on deck and in engineering on various High Endurance Coast Guard Cutters assigned to Ocean Stations BRAVO, CHARLIE, ECHO, DELTA, and NOVEMBER. He received his Masters in Electronics Engineering from the Air Force Institute of Technology in 1971.

His early electronics engineering assignments included the Coast Guard Electronics Engineering Laboratory and Coast Guard Headquarters Electronics Engineering Division where he was involved in communications and computer systems enginering. He served as Executive Officer on a Coast Guard Medium Endurance Cutter engaged in Search and Rescue and Maritime Law Enforcement.

From 1981 to 1984 he served as the commanding officer of the OMEGA Navigation System Operations Detail (ONSOD) in Washington, D.C. which provides operational control and engineering support for the entire worldwide OMEGA System. In August 1984, CDR MAY assumed his present post as Chief of the Navigation Systems Technology Branch, USCG Office of Research and Development, CG Headquarters where research into all maritime aids to navigation systems, including Loran-C, is conducted by the Coast Guard.

CDR MAY received his second Masters Degree (Human Resources Management) from Pepperdine University in 1981 during his free time. He is a member of Tau Beta Phi, ION, and the International OMEGA Association. He has received numerous commendations and service awards during his Coast Guard career.

DEPARTMENT OF ENGINEERING
COAST GUARD ACADEMY
NEW LONDON, CONNECTICUT 06320
(203) 444-8547

Differential Loran-C: Estimator Improvement and Local System Implementation

Dean C. BRUCKNER, ENS, USCG, graduated from the U. S. Coast Guard Academy with Highest Honors in Electrical Engineering in 1985. He is now a Deck Watch Officer on the USCG Cutter VIGILANT based in New Bedford, MA.

Gary R. WESTLING, P.E., LCDR, USCG, has served tours as project manager at the USCG Electronics Engineering, Wildwood, NJ and as Coordinator of Chain Operations, Mediterranean Sea Chain, Sellia Marina, Italy. LCDR WESTLING is presently an Assistant Professor of Electrical Engineering at the U. S. Coast Guard Academy, New London, CT.

This report is condensed from the final report of Dean BRUCKNER's U. S. Coast Guard Academy Scholars Project titled "Differential Loran-C: Fine Tuning the Loran System".

Copies of the complete report are available from the Librarian, c/o Superintendent (dl), U. S. Coast Guard Academy, New London, CT 06320-4195. Or from the USCG Research and Development Center, Avery Point, Groton, CT 06340.

ABSTRACT

Three methods of predicting Loran-C time difference offsets are presented for use in differential Loran. These are the method of Least Squared Error, and Alpha-Beta Filter, and a Linear Regression method. Evaluated against the Sample Mean Method that the USCG Research and Development Center now uses, they reduced the rms prediction error by 5.6, 4.6, and -2.3 per cent, respectively. Second, noise aspects are examined, and the need for a multi-station differential network is discussed. Third, a real-time differential Loran-C navigation system is examined. The system constructed generated real-time plots of the vessel's position on the Thames River in New London, Connecticut. Plots of vessel track using differentially corrected and uncorrected Loran are shown including bridge and pier approaches. Uncertainties in position are presented and explained, and underway test results are discussed. These tests indicate that a consistent accuracy within 10 meters is not an unreasonable goal for a differential Loran-C system on the Thames River.

I. Introduction

Loran-C is a long-range radio navigation system used in several places around the world. A Loran receiver works by measuring the difference in time of reception between a master station's signal and a secondary station's signal. A measured time difference (TD) of 14703.6 microseconds, for example, places the receiver on a hyperbolic line of position such that 14703.6 microseconds times the speed of light is the distance between the two stations. A chain of one master station and two to four secondary station lays out a grid of these hyperbolic lines of position.

In every chain, a system area monitor (SAM) removes time difference errors by adjusting the time of transmission of the stations in the chain. This effectively ties down the grid at the SAM position. In some areas away from the SAM the grid can stretch or warp due to seasonal and diurnal effects. These offsets in the grid do not matter much out at sea, in harbors and harbor entrances, accuracy is more critical and the offsets must be taken into account. In some harbors on the eastern U.S. Coast, Loran-C can be used as it is. In other harbors, though, a correction like differential Loran-C is needed before Loran-C can be used effectively in restricted waters (4).

The principle of differential Loran-C in harbors and harbor entrances is simple. Time difference offsets are measured at a shore station. Corrections or updates, based on the measured offsets, are broadcast to ships in the local area over VHF radio. Adding these updates to observed time differences removes the offsets and corrects the position of the grid for the local area. Differential Loran-C improves Loran by providing consistently accurate positions essentially free of TD offsets. Having these positions always available and knowing that they will be accurate one transit after another can be worth a great deal to the master of a vessel, especially when visbility is restricted.

Part 1: New Methods for Predicting Time Difference Offsets

In the differential system on the Thames River, new updates are broadcast every three to fifteen minutes. By necessity, every update is a prediction of what the Loran offset will be until the next update is broadcast. In order to keep the differential system performing well, these predictions need to be as accurate as possible. The goal of the research in Part 1 was to find a way to minimize the error of the offset predictions (also called updates or offset corrections) which are broadcast to ships in the local area.

Part 1 is an overview of the research into the new prediction methods. For a more in-depth treatment of this subject see Reference 12, Appendix A.

A. Solution and Procedure, Part 1

Differential Loran-C has been an on-going project at the USCG Research and Development Center at Avery Point, CT. Staff of the Electronics Branch at the USCG R&D Center operate a differential system in the Thames River/New London Harbor area.

Currently one monitor station at Avery Point broadcasts updates on VHF channel 83 at intervals of 3 to 15 minutes. To develop and test the navigation system a three-minute interval was used exclusively. A network of three stations will soon be in operation (7).

A.1 Current Method of Predicting TD Offsets. The prediction method that the USCG R&D Center now uses is a simple average. The mean of the last K samples is the prediction of what the offset will be over the next K data points. Since it is in use now, the sample mean method was used as the standard to evaluate the other three methods. **Fig. 1** is a plot of the rms error of the predictions vs. the number of samples, K, used in each averaging interval. The two curves represent the rms prediction error for two simultaneous 24-hour data sets of the 9960 MW Baseline. One of the two data sets used here was taken at the R&D Center at Avery Point; the other was taken across the Thames River at the U.S. Coast Guard Academy.

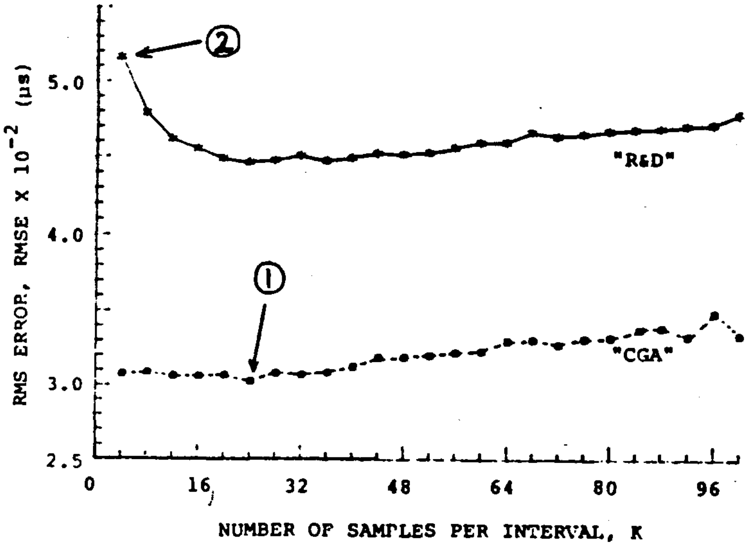

Fig. 1: Plots of RMS Error vs. Number of Samples Per Interval Sample Mean Method

For data set "R&D", 24 samples must be included in an averaging interval to minimize the variance of the measurement noise. At the quieter academy environment, not much variance reduction is seen as K increases. The upward trend in rms error as K increases beyond 24 occurs as the samples become too old to predict the movement of the offsets accurately.

Data set "CGA" was used to evaluate the three new prediction methods. The standard of performance is the lowest rms error of the sample mean method, 0.0303 microseconds, labeled point "1" in **Fig. 1.**

A.2 Least Squared Error Method. The first new method considered was a prediction by a linear combination of the past K samples:

$$P = a_0 + a_1x_1 + a_2x_2 + \dots + a_Kx_K$$

The problem here is to find the proper weights, a_0 through a_K. A multiple linear regression was used to find the **A** vector values that would minimize the squared prediction error. This method reduced the rms error below the standard of 0.0303 us by 0.017 us, or 5.6 percent.

A.3 Alpha-Beta Filter. The second method was an alpha-beta filter, which is a first-order low pass filter implemented in discrete time. The difference equation is:

$$P(I) = \alpha D(I) + \beta P(I - 1); \beta = 1 - \alpha.$$

where P(1) is the vector of predictions and D(1) is the vector of samples. By varying alpha, one can change the amount of filtering being done. This method reduced the rms prediction error by 0.014 us, or 4.6 percent for an alpha equal to 0.10.

A.4 Linear Regression Method. The third method predicts TD offsets by projecting the slope of the last K samples to the midpoint of the next interval. This method was designed to pick out any short-term trends in the offsets. This method fell short of the sample mean method by 0.007 us, or -2.3 percent. This indicates that for predictions of less than an hour or two, trends in the data are so small that they can be ignored. Over the short-term, the mean of the offset variations is essentially zero.

B. Results and Discussion, Part I

B.1 Summary of Results. This a summary of the results of these three new methods' performances on the 24-hour data set "CGA" for one Baseline, 9960-MW. At the Coast Guard Academy, 1 us of the 9960-MW time difference is equivalent to 203.1 meters. The rms errors in the predictions are equivalent to one standard deviation.

B.2 Evaluation of Sample Mean Method. For each data set tested, an optimum number of samples per interval exists: For samples taken at two different times at CGA the number of samples were twenty four (see fig. 2) and twelve, corresponding to update intervals of 8 and 16 minutes, respectively. This minimum probably signifies a trade-off between minimizing measurement noise and using the most recent data available. Averaging a large number of samples reduces the variance of measurement noise, but predicting ahead for longer periods of time renders the prediction less effective because it is not current enough. As the prediction grows older, the chance of it being in error increases. The reduction of noise by increasing K is much more apparent in the noisy data set "R&D" than in the quieter data set "CGA" (see fig. 4). In both sets, though, using a prediction for too long a period increases the error.

B.3 Evaluation of Least Squares Method. The method of least squares works the best for most set sizes between 200 and 1100 when K = 4. Ideally a large K should be able to model a waveform better than a smaller K. And when the coefficients are applied only in the set in which they are calculated, increasing K well beyond 4 does in fact reduce RMS error.

This application is impossible in real time since matrix Y is not known in advance. The coefficients must be calculated from a previous set. Essentially the same trade-off occurs here as in the previous method: predictions made for long intervals soon become too old to predict offset movements. For most set sizes, this trade-off occurs at K = 4.

For small set sizes the optimum K value is even less. Using K=1 and recalculating the coefficients every 13 minutes produces the smallest error found in all of the least squares tests performed, 2.86 x 10^{-2} us. This result shows that using the most recent data to make predictions is important, and also seems to confirm the presupposition that measurement noise is fairly small relative to the measurements themselves. In an ideal system without any measurement noise, the best prediction for the next sample is the most recent sample. Essentially K=1 represents this case.

A decrease in error is seen in the LSE method as the set size approaches 1100 samples, representing about 12 hours. At this point the error decreases to 2.97 x 10^{-2} us, 1.98% lower than by the sample mean method and almost as low as when K = 1 with 13 minutes per set. This is due to the diurnal frequency components in the offsets. The following power spectral density plot shows frequency components at 0.04 and 0.08 hour^{-1}, corresponding to 24 and 12 hour periods.

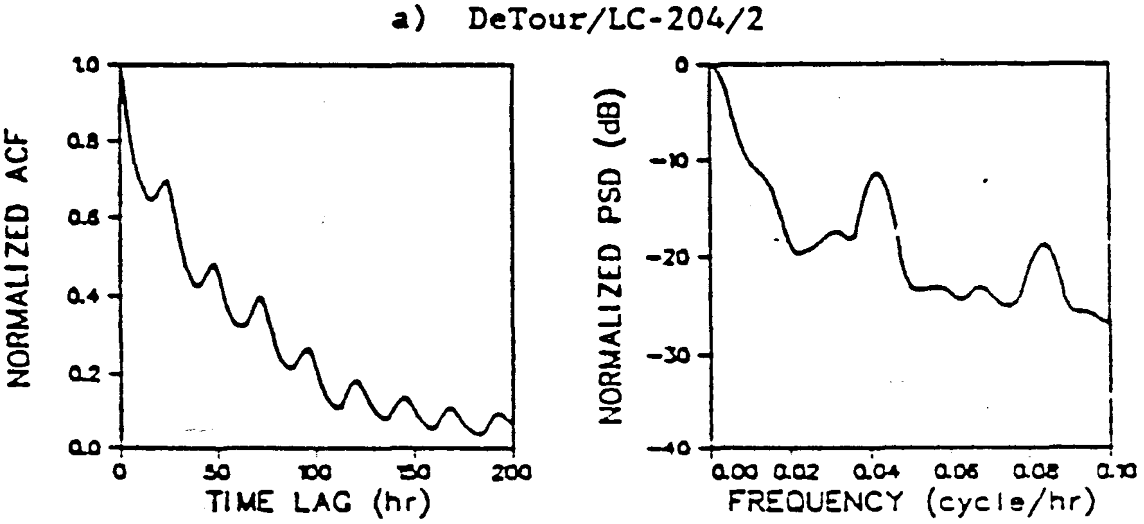

Fig. 2 . ACF and PSD plots
(Used with author's permission, ref. (4))

Higher harmonics also exist, but they seem to have little effect here. The 12 and 24-hour cycles may allow the LSE method to be used more efficiently than with the extremely small set sizes used with K=1. Computing coefficients every 12 hours uses significantly less computer time than calculating them every 13 minutes does. Because the 24-hour component is larger than the 12-hour component, it is likely that computing coefficients every 12 hours will yield smaller errors than computing them every 12 hours. Due to the limited memory of the HP85 (32K RAM.), no investigation of sets longer than 14 hours was conducted. Another variation may work even better: Compute several coefficient matrices over a 24-hour period, say one every four hours, and apply them to the corresponding times during the next day. This may produce the smallest error of all.

B.4 Evaluation of Alpha-Beta Filter. For values of alpha around 0.05 to 0.1 this method predicts with less error than does the sample mean method. With one data set, an improvement of 4.62% is obtained. These small values of alpha indicate that noise is being filtered out, but by themselves they do not support a conclusion that measurement noise is a large problem.

Like the sample mean method, the software needed for this method is extremely simple. But unlike the sample mean and least squares methods, a new update must be broadcast after every sample instead of after every K samples.

This type of continuous updating brings to light another potential problem. Occasionally due to measurement noise a measurement will contain an ususually large error. With a time constant of $1/(1 - \alpha)$, using small values of alpha means that the prediction can be influenced for some time by a sample with a large error. In the sample mean method, every sample is averaged only once, and so the effect of a bad sample point can influence only on update of K samples. To avoid including samples with unusually large errors, a tolerance interval can be implemented to reject any samples differing too greatly in magnitude from the most recent prediction.

A similar problem with this method is that a step change in the offset could cause predictions to be in error for a long period of time. In most of the the LORAN chains, harbor monitors observe steps when transmitters are switched every two weeks. One may not expect a prediction model to foresee these steps, but the model should be able to converge on the new offsets quickly. Intuitively, the sample mean method should work the best during a step. In an ideal situation the predictions would not be affected by the step after one prediction interval. Actually, a period of transient behavior would accompany such a step, lasting perhaps much longer than many intervals. But either way, the sample mean method should be able to deal with this type of step without much difficulty. On the other hand, the long time constant of the alpha-beta filter might be a handicap both in the initial step and in the transient period as well. The performance of the least squares method would probably fall somewhere in between these two.

METHOD	RMS PREDICT. ERROR	DIFFERENCE FROM BEST SAMPLE MEAN METHOD	PERCENT REDUC- TION
	METERS	METERS	
BEST SAMPLE MEAN METH. K=24, CGA	6.15	0	0
LSE	5.81	.346	5.61
ALPHA BETA FILTER	5.87	.285	4.62
LINEAR REGRESSION METHOD	6.30	-.142	-2.31

Fig. 3: Summary of Results of New Prediction Methods

B.5 The Argument for a Differential Network. The results above are based on the assumption that the sample mean method is being used to its fullest potential. Actually, for the last three months, the USCG R&D Center has been broadcasting 3-minute updates, with K=4 samples per interval. For the data set "R&D", this set of parameters had an rms error of 0.0516 microseconds, much greater than the best performance of the sample mean method, which had an rms error of .0303 us for K=24 on data set "CGA". See point "2" in **Fig. 1.** If 0.0516 us is picked as the standard of evaluation instead of 0.0303 us, then a much greater improvement is seen by switching to data taken in the Coast Guard Academy's quieter environment and by implementing the new methods. All of the methods work much better in a quieter environment. In a noisy environment, the sample mean method performs better with more points per averaging interval.

Having a network of, say, three harbor monitors receivers providing information for offest prediction gives the advantage of redundancy and error checking, in addition to the noise reduction accomplished by a filtered combination of the three input sources. A further advantage is the ability to test prediction algorithms on two of the stations' data against the observed at the third station. The network of harbor monitor stations thus providing their own model of a differential system including a user. This could be done in real time to provide an optimal prediction that adapts to changing conditions.

Part II: Real-Time Navigation System

The goal of this part of the project was to design, implement and test a computer-controlled system that would compute and plot a vessel's position based on differential Loran-C. This system is described in the following Procedure and Solution section, and its performance is presented and analyzed in the subsequent Results and Discussion section.

METHOD	RMS PREDICT. ERROR	DIFFERENCE FROM BEST SAMPLE MEAN METHOD	PERCENT REDUC-TION	DIFFERENCE FROM SAMPLE MEAN METHOD K=4,"R&D"	PERCENT REDUC-TION
	METERS	METERS		METERS	
SAMPLE MEAN K=4, "R&D"	10.48	———	——	0	0
BEST SAMPLE MEAN METH. K=24, CGA	6.15	0	0	4.33	41.28
LSE	5.81	.346	5.61	4.67	44.60
ALPHA BETA FILTER	5.87	.285	4.62	4.61	44.00
LINEAR REGRESSION METHOD	6.30	-.142	-2.31	4.18	39.90

Fig. 4: Improvement Seen by Switching to a Quiet Environment to Calculate Offset Predictions

A. Procedure and Solution, Part II

A.1 System hardware. The system here computes and plots a vessel's position from three Loran-C time differences and differential Loran-C updates:

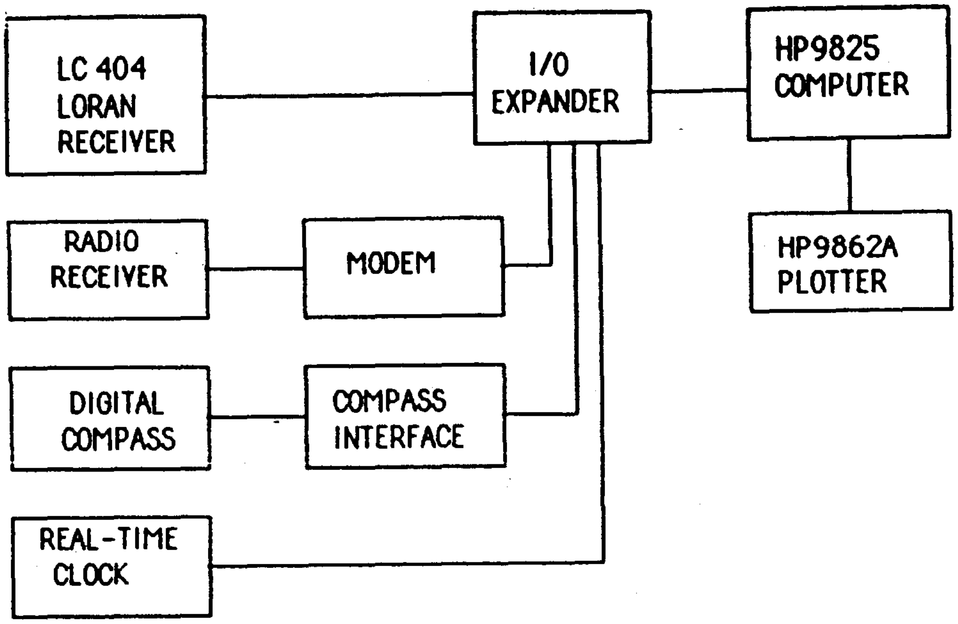

Fig. 5: Block Diagram of Real-Time Navigation System

The HP-9825 desktop computer is the system controller. Reading the real-time clock to keep track of elapsed time, the computer polls the Loran receiver, corrects the TD's using the updates, computes the vessel's position, and sends the position out to the plotter. To obtain differential corrections, the computer fills a 1600-character input buffer with the stream of characters it receives from the modem and searches for the update message. When it finds the update message, the computer interrupts the program and stores the current updates for the main program to use. The computer communicates with the Loran receiver and with the modem through RS232C serial ports. The compass interface converts a string of TTL pulses generated by the Digicourse Model 101 electronic compass to a 12-bit parallel Binary-Coded Decimal (BCD) output bus, which the computer reads through a Hewlett-Packard BCD interface. The Loran receiver is the Internav LC404 survey grade receiver, and has a resolution of 10 nanoseconds.

A.2 Converting Loran TD's to an X-Y Position. Calculating geographical coordinates from Loran time differences, while perhaps straight forward, is computationally time consuming. To save time we used a more simple conversion accurate over a small area, typically less than 5 square kilometers, where one can approximate the hyperbolic time difference lines with straight lines. Knowing the azimuths of each TD line, a conversion matrix can be calculated and used to convert observed TD's to a position on a cartesian coordinate system. The units are meters, and the position X direction is east while the position Y direction is north. Latitude and longitude could be obtained easily through a simple conversion from X-Y coordinates. Computing the 2 X 3 conversion matrix **G** is explained in reference (5). Here is the simple conversion process using a pre-computer G matrix:

$$\begin{bmatrix} Y \\ X \end{bmatrix} = \begin{bmatrix} G_{1,1} & G_{1,2} & G_{1,3} \\ G_{2,1} & G_{2,2} & G_{2,3} \end{bmatrix} X \begin{bmatrix} TD_{W\,OBS} - TD_{W\,REF} \\ TD_{X\,OBS} - TD_{X\,REF} \\ TD_{Y\,OBS} - TD_{Y\,REF} \end{bmatrix}$$

Y and X are the Cartesian coordinates in meters, G is the conversion matrix in meters/microseconds, and the TD matrix is the difference between the observed TD's from the receiver and the TD's of the appropriate waypoint in microseconds.

The USCG Research and Development Center surveyed the Loran TD's of 25 waypoints on the Thames River, from the sea buoys inland, and supplied the conversion method. Every point on the river has its own unique **G** matrix, but using an infinite number of waypoints is impractical. Little accuracy is sacrificed by using the G matrix of the nearest waypoint in the area around that waypoint. The accuracy of this approximation is addressed more fully in the next section.

A.3 Plotting the X-Y Position. The plotter plots the vessel's position on a 10 X 15 inch chartlet cut from NOAA/NOS Chart 13213, "New London Harbor and Vicinity." The dimensions match the 10 X 15 inch plotting surface of the HP 9862A Plotter. The chartlet covers a two-mile-long section of the Thames River from the U.S. Navy Submarine Base to Electric Boat, both in Groton, CT. With the conversion of 1852 meters = 1 minute of latitude, the cartesian grid of meters was scaled to cover this charted area and an X-Y position was assigned to each of the 5 waypoints on the chartlet.

In its operation the computer gives the grid scale to the plotter, calculates the vessel's position with respect to one of the grid's waypoints, and sends the vessel's current X-Y coordinates to the plotter.

The system was placed on one of the Coast Guard Academy's 65-foot training tugs, nicknamed "T-Boats", for underway tests in Thames River. With a generator on board, this was an ideal platform for testing.

B. Results and Discussion, Part II

This section is the analysis of the underway test plots. First, two plots are included to give the reader an idea of where the results come from. Second, the accuracy of the plotted positions relative to the actual observed positions is presented and discussed. Third, the performance of the G matrix conversions of 5 waypoints is analyzed. Fourth, other factors that decrease the accuracy of the plots are discussed.

B.1 Selected Plots. Here are two underway test plots. The first shows the T-boat leaving the T-boat pier (the southernmost pier at the academy), making a loop down to the bridge, up around buoy 7, and back to the larger pier where USCGC EAGLE ties up. This chart has been reduced to fit on this page. No discernable error in the plotted position was observed when the T-boat was at either of the docks. The measurement uncertainty of the observed position at the piers is about ± 5 meters.

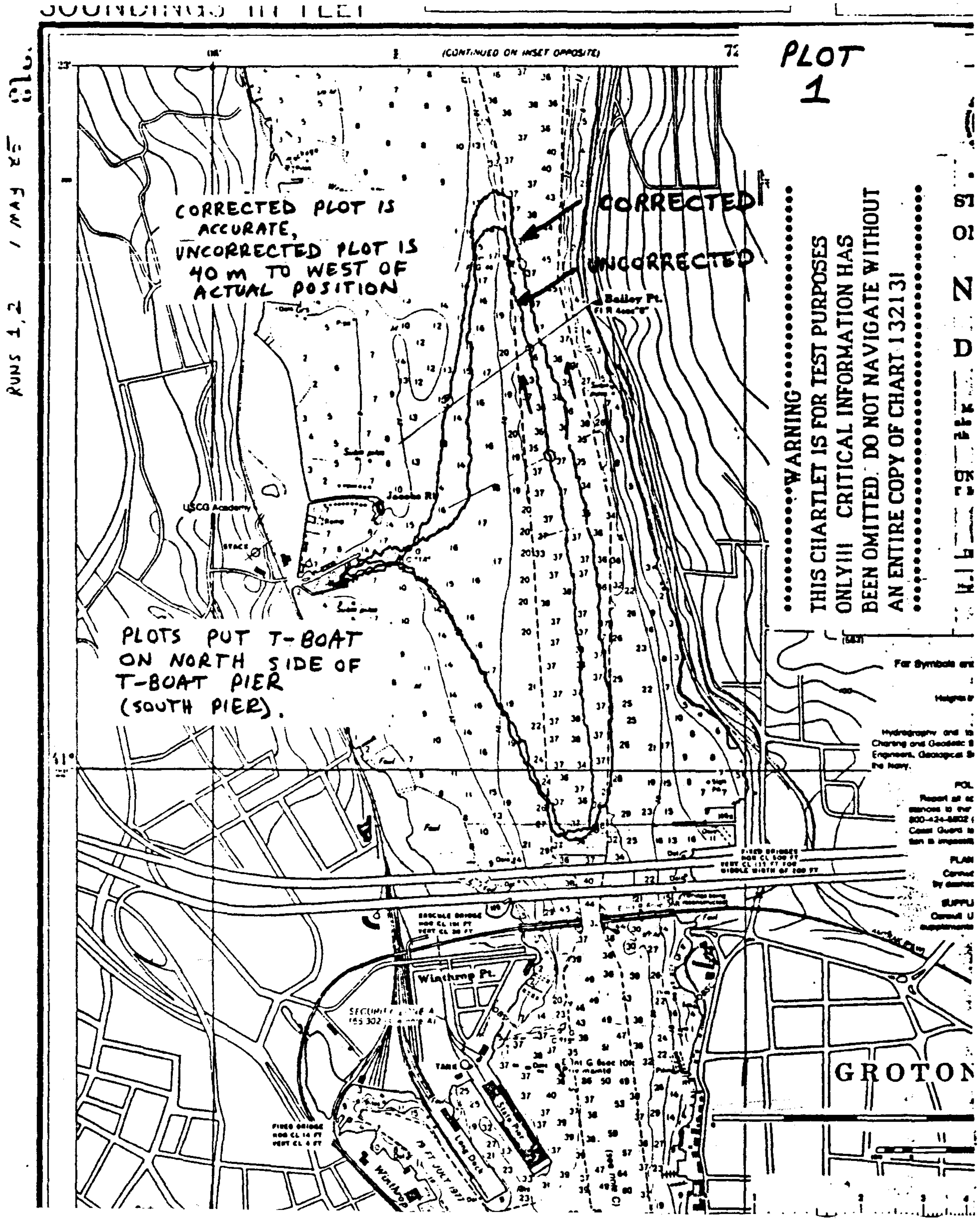

Fig. 7: Plot of Underway Test in Thames River Differential Corrections Applied

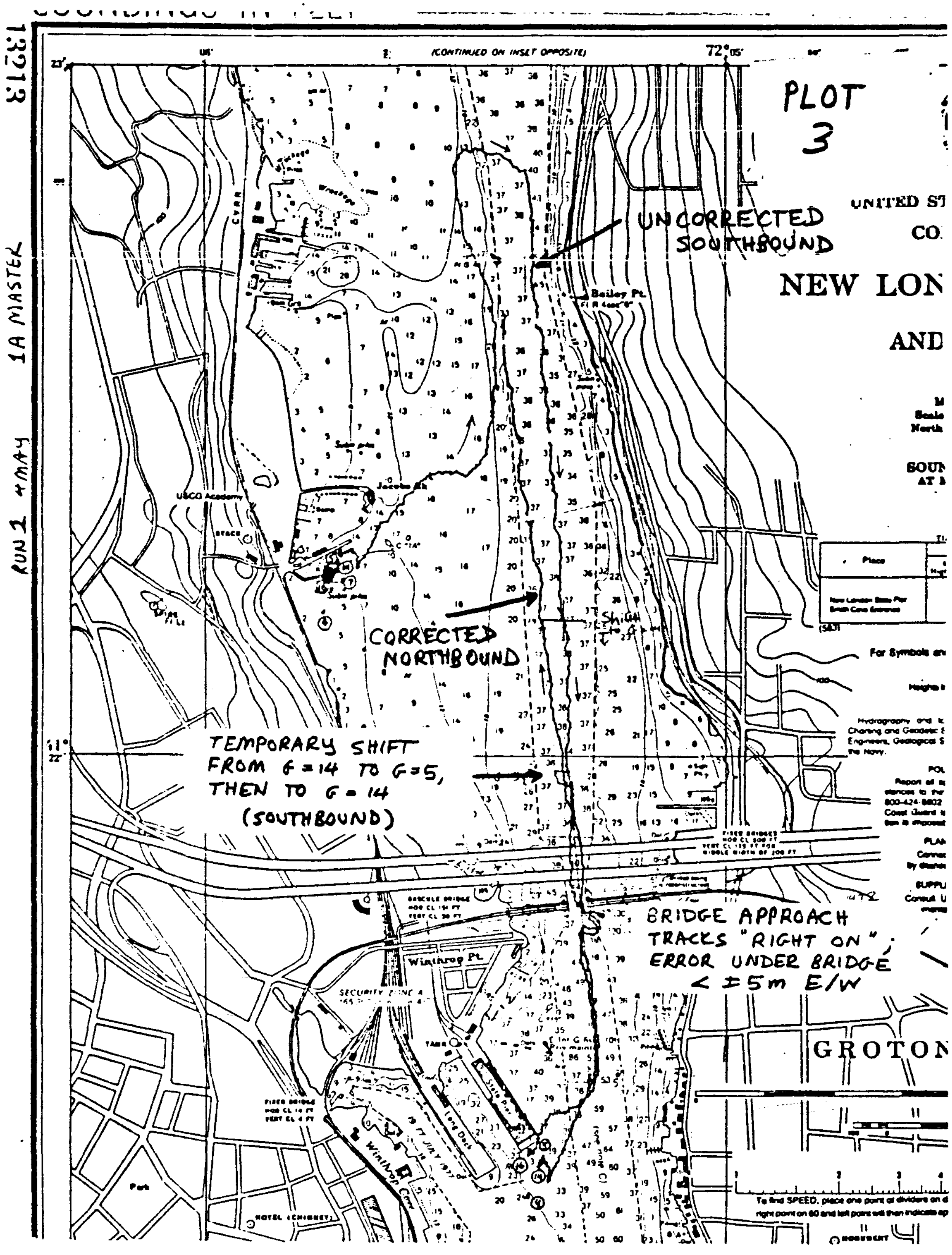

Fig. 8: Plots of Transits through Thames River Railroad Bridge Opening

LOCATION	DIST OF PLOTTED POSITION FROM OBSERVED POSIT (METERS)	MEASUREMENT UNCERTAINTY (METERS)	WAYPOINT
T-BOAT PIER NORTH SIDE	0 N/S 0 E/W	5 5	16
EAGLE PIER SOUTH SIDE	0 N/S 0 E/W	5 5	16
BUOY "7"	20 N/S 0 E/W	20 20	16
STATE PIER	25 S 35 E	15 15	5
RR BRIDGE	0 E/W	5	14

Fig. 9: Accuracy of Plotted Position Relative to Observed Position

The second plot shows two transits through the opening of the Thames River Railroad Bridge. The track to the right is a southbound uncorrected Loran-C plot, and the track to the left is a northbound corrected Loran plot. The error of the plotted position compared to the observed position was less than 5 meters. The measurement uncertainty of the observed position under the bridge is about ± 3 meters.

<u>B.2 Accuracy of the Plots Relative to Observed Positions.</u> Navigators will note on these plots how close the plotted position was to the actual position of the T-boat at the time. The following table shows the best accuracies seen in the underway tests at five locations. When the T-boat was alongside each of the 5 objects, the pen's position was noted and the T-boat's actual position was recorded. More confidence should be placed in the distances from the fixed objects than in the distance from the buoy "7". Buoys move, piers don't.

In all the plots random measurement noise is apparent. The peak magnitude of the noise is roughly ± 7 meters in the north-south direction and ±4 meters in the east/west direction. When the T-boat remained in one spot for any length of time, this measurement noise plotted as an ellipse. Considering the noise to have a mean equal to zero, the accuracy measurements were made from the centers of these ellipses whenever they occurred. In practice, if the plot is updated every few seconds, the random noise does not affect the performance of this navigation system. On an approach track to the bridge, for example, noise can be seen, but the direction of the approach track is quite clear. Looking at the plot, one can easily project ahead the future track of the vessel in spite of the noise. The measurement noise can be filtered out effectively either by eye or by further smoothing.

B.4 Difference Between Uncorrected and Corrected Loran. In the late spring when this research was done, Loran is on its best behavior on this part of the coast. The offsets are small, and they do not vary much from one day to the next. As a result, there is not much difference between the differential plot and the uncorrected plot. Here are the average uncorrected Loran positions with respect to the corrected positions for plots 3, 4 and 5. All three runs were on 4 May 1985 within three hours. TD offset measurements were taken at the USCG R&D Center and converted to X-Y positions using the **G** matrix for waypoint 16.

RUN	DISTANCE NORTH (METERS)	DISTANCE EAST (METERS)
1	21.2	1.6
2	21.2	3.0
3	19.3	3.5
AVERAGE	20.5	2.7

Fig. 6: Distance of Uncorrected Loran Position from Differential Loran Position at T-Boat Pier, 4 May 1985

The differences shown are fairly small, but during the winter months, the uncorrected position may be a hundred meters or more from the differentially corrected position. The offsets tend to fluctuate more also, in winter, and the advantage of differential Loran-C is much more apparent, than in the spring or summer.

B.5 Other Inaccuracies Unique to Plotting on a Chart. Three other sources of plot inaccuracies which should be considered are plotter nonlinearity, chart inaccuracies, and mercator distortion.

The Hewlett-Packard 9862A Digital Plotter performed very well for this project. Linearity tests completed before the plotter was placed on the boat showed that the plotter was able to plot a square grid with no discernable distortion. After the plotter was left on the boat in the humid, salty air for a couple of weeks, the plotter's square grid became slightly distorted. The plotter determines its position by the resistance along a slidewire which is exposed to the air, and so the salt and moisture affected the resistance measurements and hence the plotted positions. This factor could cause errors in plotted position of ± 20 meters or even more if the slidewires become very dirty. To counteract the effect of the salt air, the slidewires should be cleaned regularly.

No information was found concerning the inaccuracies in the charted positions of piers, bridges, etc for NOAA/NOS chart 13213. Based on the traditionally high quality of NOAA/NOS charts, the chart is assumed to be without error.

A mercator chart is slightly distorted both in the latitude and longitude scales. Distortion is not practicably measurable in the small 10 X 15 inch chartlet used here, but on the whole 29 X 45 inch chart (13213) the distortions are measurable. The distortion in longitude at the top of the chart relative to the bottom of the chart was found to be 0.6 meters distortion per minute of longitude, or 1.2 meters for the width of the chartlet. The latitude distortion, found by comparing the north/south distance between 41 -17'-00.0"N and 41 -18'00.0"N and between 41 -22'-00.0"N, and 41 -22'-00.0"N, was found to be approximately 3 meters.

Here is a summary of the uncertainties unique to plotting on a chart:

FACTOR	UNCERTAINTIES OF PLOTTED POSITION	
	IN X DIRECTION (METERS)	IN Y DIRECTION (METERS)
PLOTTER NONLINEARITY	± 3 TO ± 20	± 3 TO ± 20
CHARTING INACCURACIES	———	———
MERCATOR DISTORTIONS	± 1.2	± 3

Fig: 7: Summary of Uncertainties Unique to Plotting on a Chart

From previous sections, here are other uncertainties seen on plots but not originating within the plotting process.

FACTOR	UNCERTAINTIES OF PLOTTED POSITION	
	IN X DIRECTION (METERS)	IN Y DIRECTION (METERS)
SYSTEM NOISE	± 4 *	± 7 *
WAYPOINT SURVEY	± 5	± 5

Fig. 8: Other Uncertainties ***Approximation**

Staff of the Electronics Branch at the USCG R&D Center used microwave mini-rangers to survey the waypoints. The mini-rangers have an accuracy of about 1 meter, and the R&D Center staff feel that the accuracies of the waypoint locations are certainly within 5 meters of the stated positions. The other factors which affect the accuracies of the plot are errors in the G-matrix approximation and any error in the updates.

These uncertainties are included to demonstrate that a total differential Loran-C system must be designed to minimize all of these uncertainties. The system now in operation does a good job of minimizing these, as the results show.

IV. Conclusions and Recommendations

Conclusions

1. The Sample Mean method for offset prediction can work well with an appropriate number of samples per interval.

2. The Least Squared Error method and the Alpha-Beta filter can reduce the rms prediction error by at least four to five percent more than the Sample Mean method.

3. The use of a differential network should reduce prediction error significantly possibly by as much as 40 to 50 percent.

4. Short-term trends less than 2 to 3 hours in duration are not significant and can be ignored in predicting time difference offsets.

5. A real-time differential Loran navigation system can be consistently accurate and highly useful as an aid in piloting restricted waters.

6. Differential Loran works well for approaches to bridges, but experiences some storage effects under or very close to them.

7. A differential Loran system in the Thames River should be able to perform consistently with an accuracy of ± 10 meters.

Recommendations

1. The USCG R&D Center's offset prediction algorithm should be changed or modified to take advantage of the reduction in prediction error described in Reference 12, Appendix A. One very simple course of action would be to use more samples per interval when computing updates by the current method.

2. The differential Loran system should be implemented as scheduled to minimize the effects of environmental noise and to ensure system redundancy.

3. The staff at the USCG R&D Center should use the program(s) in Reference 12, Appendix B periodically to check the performance of their offset prediction method.

Acknowledgements

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NEW DEVELOPMENTS IN LORAN-C INTERFERENCE CONTROL

John F. Honey, CEO
MARINE TECHNOLOGY, INC.
2722 Temple Avenue
Long Beach, CA 90806

ABSTRACT

The Loran-C problem with on-board sources of interference is discussed, and we review the conventional use of low-pass filters to suppress such interference at its various sources. It is shown that, because of the tremendous difference between the level of local interference sources and the desired signal level, these measures alone may sometimes not be enough. The vessel's power system might thus be regarded as a noisy ground, and means of isolating the Loran receiver from this ground are proposed. A seawater ground filter-isolated from the bonding system and the counterpoise ground are proposed as means for providing a comparatively quiet ground for the Loran-C antenna system.

NEW DEVELOPMENTS IN LORAN-C INTERFERENCE CONTROL

Nature and Effects of On-board Interference.

The performance of marine Loran-C installations is frequently compromised by various on-board sources of electrical interference. The equipment is particularly susceptible to short high-energy, high-prf pulses such as are produced by the diode bridges in alternators, the dc-to-dc converters used in fluorescent lights, electronic ignition systems and so forth. The Loran receiver is also susceptible to interference produced by the fast-switching transistors in some solid-state voltage regulators, digital instrumentation, computers and the like. Older TV receivers often produce both electric-field and magnetic-field interference which is very difficult to control.

The effect of such interference on the Loran receiver may be to increase position error, cause cycle-jump with its consequent large position error, lengthen acquisition time or prevent acquisition altogether, or cause complete loss of lock. The interference adds to other received noise, and since the received Loran signal stays the same, the addition of the interference is indicated by a decrease in the signal-to-noise ratio (SNR).

Most Loran receivers provide a means for indicating the SNR or a number related to the SNR, and the owner's manual indicates the ranges of these numbers representing good reception and the ranges representing degraded or poor performance as applied to the weakest station in the chain. Reference to this measurement before and after a possible source of interference is turned on is an excellent indication whether or not a significant interference problem exists.

Installation Factors.

The basic Loran receiver antenna circuit is shown in Fig. 1. It's actually a resonant loop, in which the capacitance Ca between the antenna and nearby seawater is resonated by the loading coil L in the coupler. The resistance R1

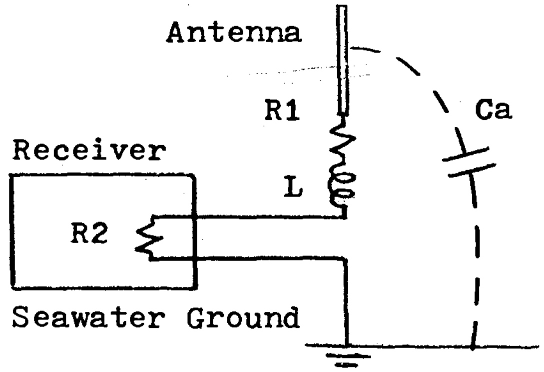

Fig. 1. Basic Antenna Circuit

is added intentionally to broaden the bandwidth of the resonant circuit wide enough for the Loran signal. The resistor R2 represents the receiver load to which the antenna delivers the signal and atmospheric noise it picks up.

The typical receiving antenna is very small, certainly as compared to the giant structures required at the transmitting stations, and its efficiency is correspondingly microscopic, on the order of a millionth of a percent. Nevertheless, it is high enough to deliver far more atmospheric noise to the receiver than the level of the noise generated in the receiver itself. The transmitting station in turn must be designed to deliver enough Loran signal in the area to comfortably override the atmospheric noise level. Now it's plain why such a small antenna can be used: a bigger one would pick up more signal, but it would also pick up more atmospheric noise. The signal-to-noise ratio would be unaffected, and the SNR is the well-known bottom line.

But atmospheric noise isn't the whole story. Fig. 1 shows that the antenna circuit involves not just the antenna itself but a big loop including the capacitance Ca from antenna to seawater, the connection to the receiver, the receiver ground connection and the connection between that ground and nearby seawater. If noise is introduced in any part of this loop from local sources, the SNR will be degraded. If this interference is comparable with the picowatt signal the antenna delivers from the weakest station in the chain, we may be in trouble.

Would a bigger antenna help? Theoretically, one four times as long would deliver 16 times as much signal power (and atmospheric noise power), a gain of some 12 dB in SNR if **local noise** were louder than the atmospheric noise and were **not** entering via the antenna or its ground system but at some other point in the receiver. Not bad. The preamplifier in the coupler helps in the same way as long as the local interference enters **after** the preamp and not at the antenna or its ground. But local interference usually does enter the receiver via the antenna and especially via its ground system, so it gets amplified right along with the signal and the atmospheric noise, and the SNR isn't improved. Now let's consider some ways to reduce local noise pickup by the antenna and ground system.

The obvious, oldest and best approach is to suppress the interference at its source or sources. A low-pass filter (1)* on the alternator is a must, since it's the strongest source around. Except maybe for those small 12-volt dc fluorescent fixtures which yield to a low-pass filter (2) in their power line plus a bit of electric-field shielding. Certain solid-state voltage regulators can give trouble unless an appropriate low-pass filter (3) is used in the excitation lead. Digital instruments -- tachometers, wind indicators, microcomputers and the like -- behave themselves if a low-pass filter (2) is used in their power leads. We still can't think of a better cure for a TV than to turn it off.

But even good filters are only good for 30 to 60 dB attenuation at Loran frequencies. That is, they're very good, but they still leak a little. And the associated wiring may couple out a good deal more than the filters leak. The atmospheric noise current in the antenna may run about 0.3 microamperes, whereas the line current rf component near 100 KHz in a fluorescent fixture measures 5 milliamps, 16,700 times or 84 dB stronger. We're not out of the woods yet!

The Battery

There's an old wives' tale around to the effect that a battery is close to zero impedance in series with its 12 to 14 volts dc, and that all you have to do to keep any unit from talking to any other unit over its power lines is to wire everything separately straight to the battery. The fact is that when a battery is charged and 'floating' on the line, even when the alternator is picking up a substantial connected load, it's closer to an open circuit than a zero-impedance source. It's little or no help in holding down either rf or af noise in the power system.

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* The numbers in parens refer to the MAR-LINE family of filters designed specifically for Loran-C noise control in marine installations. They are manufactured by Marine Technology, Inc. of Long Beach, California.
(1) MAR-70A 70-amp or the MAR-120A 120-amp alternator filter.
(2) MAR-P5 5-amp powerline filter; also 10, 20 and 35-amp models.
(3) MAR-10A 5-amp accessory filter.

The Antenna Ground

Fig. 1 emphasizes the point that the antenna circuit is a big loop. The antenna ground connection is as important a part of this loop as is the antenna or any other component. If the ground is "noisy" for any reason, that noise voltage will "shunt excite" the antenna; the coupler will act as a transmitting antenna matching network, and the resulting antenna current will be coupled right into the receiver just like any other signal source.

How can we have a noisy ground? Let us count the ways.

The Power System Ground

Most Loran receivers provide a connection on either the coupler or the receiver itself for use in grounding the system. But it is common practice for manufacturers to connect the radio ground in the set to the power ground within the set either through a capacitor or with a direct connection. Thus, like it or not, the vessel's power system becomes a part of the receiver antenna ground (Fig. 2). And you can bet that the vessel's power system is noisy, even if every single device connected to it is using the best low-pass powerline filter money can buy. Remember that 84 dB we're aiming for?

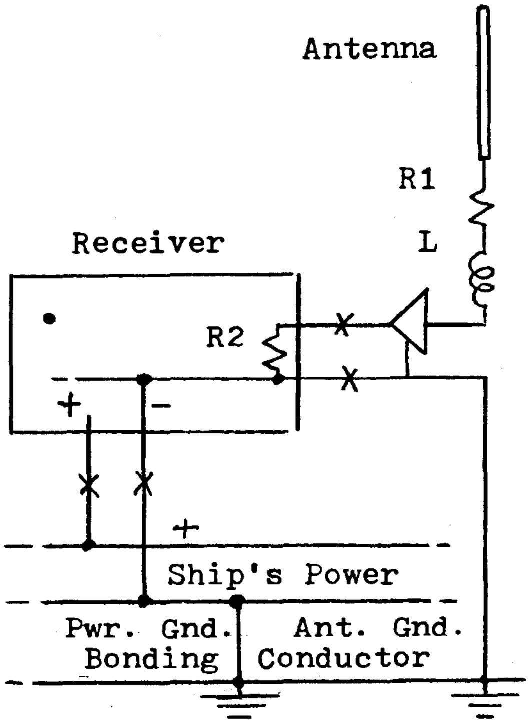

Fig. 2. Typical Antenna Circuit

The cure here is a special filter which will provide rf common-mode isolation in <u>both</u> the positive and negative power leads to the Loran receiver*. Now we have two filters working for us: 30 to 60 dB in the accessory filter plus perhaps 40 dB in the isolation filter. We're gaining on it!

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* You guessed it. That's the Mar-Line MAR-LC. We even make the MAR-DS for a similar problem with depth sounders and the MAR-HF powerline rf isolator for seagoing hams.

One manufacturer we've worked with puts the common-mode isolation in his antenna coupling circuit, where it serves the same purpose in isolating the antenna ground from the power system. This is a good idea because there's no problem in subsequently connecting an autopilot, plotter and the like. But we don't have a universal antenna isolator for all sets, and the MAR-LC at least gets the show on the road.

A Separate Loran Ground

Now that we've quieted the several noise sources and avoided using the vessel's electrical system with its residual noise as our antenna system ground, where can we find a nice quiet place to connect that enigmatic ground wire?

Almost all vessels have a ground plate of some sort in the water, plus struts, propellers, rudders, trim tabs, zinc plates, etc., and a number of smaller metal through-hull fittings, all securely bonded together by heavy copper tape or wire. A simplified system is diagrammed in Fig. 3. There is a small but significant resistance (R1, R2, R3,..., Rn) to the seawater in the immediate vicinity of each ground which is a function of the area of each ground, plus a mutual resistance Rm common to all grounds which is a function of the area over which the grounds are distributed.

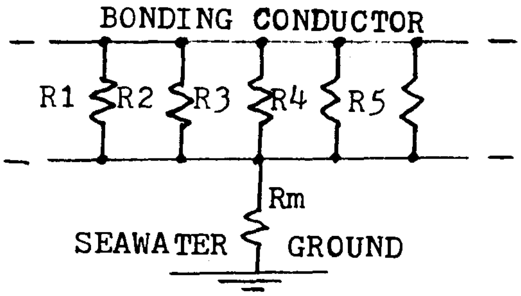

Fig. 3. Ground System

Now if all vessel electrical systems were turned off, any point in the system would be as good a ground for the Loran as any other. But when they're running, small rf voltages are induced into the many loops of the ground system by magnetic coupling between the bonding wires and the vessel's electrical wiring. Not very big voltages, to be sure, but it doesn't take much. And it's a no-no to have more than one common point or junction between the power system and the ground bonding system. But we do it anyway. Power currents with accompanying noise thus enter the bonding network by direct conduction. Noise currents flowing around the various ground loops result in a composite voltage at each of the ground points. So our big ground system has some noise in it after all.

While the bonding system actually contributes to the ground noise problem, it is necessary for the control of galvanic corrosion. So, with the aim of eating our cake and having it too, we are pleased to introduce a new product -- the MAR-GI, for "ground isolator". This is simply a special rf choke which passes the dc corrosion protection current with negligible drop, yet offers a high impedance to the flow of rf current. It can be used in the bonding connections to one or more grounds or groups of grounds, and one of these may then be used as a quiet ground for the antenna system. For example, we've had very good results using the metal rudder as ground for the Loran system.

The ground lead itself from the seawater ground to the receiver or coupler need not be very heavy, but it should be dressed well clear of other vessel wiring. This is frequently inconvenient as the dickens, and this requirement figures largely in the selection of the Loran ground.

While we're on the subject, it's a good idea to keep the coax cable from the set to the coupler away from other wiring as well. Coax cable leaks, especially at these low frequencies. The bigger RG-8 cable is much better from this standpoint, as well as being huskier.

Counterpoise Ground.

Every boat is different from every other, and sometimes circumstances prevail which make a quiet ground a hard thing to come by. Additionally, it is sometimes desirable to effect a temporary Loran installation for demonstration or whatever. We've had excellent luck using a **counterpoise ground** in such circumstances.

For example, the antenna and its coupler might be mounted to the metal railing on a flybridge. The coupler ground connection is then connected to the railing with a hose clamp. If the coupler doesn't have a ground connection, we make one by baring a short portion of the coax outer conductor and fastening it to the rail. Then the ground connection at the set is not used. A powerline isolation filter should be used on the receiver. The railing may or may not be otherwise grounded, but if it's a sizeable structure it won't matter.

Marine Technology, Inc. has conducted extensive tests on the interference control measures discussed here. They work. And it is our experience that marine Loran-C installations need suffer no signicant performance degradation due to on-board sources of interference typically encountered.

BIOGRAPHICAL SKETCH

John F. Honey (Jack) is a native of Portland, Oregon. He attended Reed College in 1942 and after three years in the armed services received the B.Sc. in 1947 and the degree of Engineer in 1948 from Stanford. He has been employed at Stanford Research Institute, Hoffman Laboratories, J. F. Honey Associates, Teledyne Systems and Ryan Aeronautical, specializing in military and space communications. He founded Marine Technology, Inc. in 1969.

LORAN-C Grid Measurements in Coastal New Hampshire
A NOAA Sea-Grant Student Project

Albert D. Frost
Department of Electrical and Computer Engineering
University of New Hampshire, Durham New Hampshire 03824

Jill Belon, Thomas Schmottlach and Steven Rossi
College of Engineering and Physical Sciences
University of New Hampshire, Durham New Hampshire 03824

An extended program of TD measurements (Northeast Chain; Caribou and Nantucket secondaries) was carried out during the period January - April 1985 by a three member team of senior engineering students. The survey covered coastal New Hampshire from Newburyport MA to Kittery ME. Sites were selected distributed over six USGS maps,7.5 quadrangles, at identifiable map locations. Results were analyzed to provide a best-fit to TD offset values,grid gradient and orientation. These estimates were then used to prepare LORAN-C grid overlays for each quadrangle. Subsequent navigation tests using the charts provided position identification and/or navigation errors under 300 feet in all test quads.

INTRODUCTION

For over fifteen years the University of New Hampshire has been supported in a wide range of marine related research efforts as a Sea Grant institution under NOAA , the National Ocean and Atmospheric Administration. These research projects have included each year a specially administered Undergraduate Student Project Course designed to provide research experiences under appropriate faculty guidance. Projects, proposed each year by faculty , are designed to be accomplished by a student team ranging in size from three to eight during the Fall and Spring terms. The proposals are first evaluated by the Project Adminstrator suitability to the UNH Sea Grant mission and with respect to the budget required. An important aspect of these projects operating under Sea Grant support is the provision of modest funds for equipment supplies and transportation.

The approved projects list for the year is then presented at a first meeting in early September to all qualified students who have expressed an interest in possible participation. Each faculty member presents a background review of his project problem, its technical or economic significance and the technical inputs that will probably be involved in its solution. Students backgrounds are in engineering,physical sciences,mathematics and life sciences (in particular ocean biology). In terms of the goals of the program those problems which require a combination of skill areas are the most desirable and which tend to attract students by their interdisciplinary content.

In the following weeks , teams are created on the basis of student choices, with some adjustment by the course administrator to provide a good skills mix where necessary. Some proposed projects are dropped for lack of interest and some students do not continue (also for lack of interest). By the third week teams have been formed,and after in-depth briefing by the faculty advisor prepare a project budget estimate, assign initial work tasks and prepare a tentative work time line. Budget approval is generally prompt and by mid- October most projects are under-way.

An important facet of the program is the required monthly meeting of all groups in which each team must advise its peer groups of its project progress,explain their understanding of its purpose and how they are working toward that goal.

The first author of this paper proposed in the summer of 1984 that a Sea Grant Student Team be organized to take measurements of LORAN-C TD values along the New Hampshire coastline and to create locally corrected maps for precision position determination in the Seacoast area. Accepted for presentation in September this proposed project was elected by three students. None had any previous experience in navigation or had even heard of LORAN-C prior to the class meeting in September. This is often true of these projects in that by their nature they introduce the team members involved to techniques or concepts which are outside the normal range of instruction and accordingly provide an excellent challenge for self-education. The student team for the LORAN-C Map Project were majors in Computer Science,Mechanical and Electrical Engineering. This was a mix of background,specialization and resources which proved to be an excellent match for the needs of the task they assumed.

EXPERIMENTAL PROCEDURES

Plans were made to take measurements of local TD values along the coast of New Hampshire and as far inland as available time and conditions would permit. After consultation with those at the Center for Navigation,U.S. Department of Transportation, Transportation Systems Center , Cambridge MA a MICROLOGIC ML 7500 receiver was selected for the survey on the basis of size,technical performance,weight and cost. It functioned satisfactorily using a light weight storage battery (four hours of operation). The antenna coupler was mounted on a twelve foot tripod erected over each test site point.

Tests sites were selected (a) to be free from any near powerlines or metallic obstacles(fences,tanks,building) (b) at a site which could be easily revisited for check tests (c) at a location where it was possible for the team to remain for at least a half hour if necessary for set-up and stability checks and (d) at points which were positively identifiable on USGS maps such as bridges, road intersections and rail grade crossings. Prior to the delivery of the receiver the team found candidate sites distributed over the six USGS maps shown in Figure 1 and listed in Table 1.

A3	York Harbor	43 7'30"	-	43 15'	N
		70 45'		70 37'30"	W
B1	Newmarket	43 0 0	-	43 7'30"	N
		71 0 0		70 52'30"	W
B2	Portsmouth	43 0 0		43 7'30"	N
		70 52'30"		70 45' 0	W
B3	Kittery	43 0 0		43 7'03"	N
		70 45'		70 37'30"	W
C2	Hampton	42 52'30"		43 0 0	N
		70 52'30"		70 45'	W
D2	Newburyport	42 45'		42 52'30"	N
		70 52'30"		70 45'	W

Table 1 USCG map areas covered by survey.

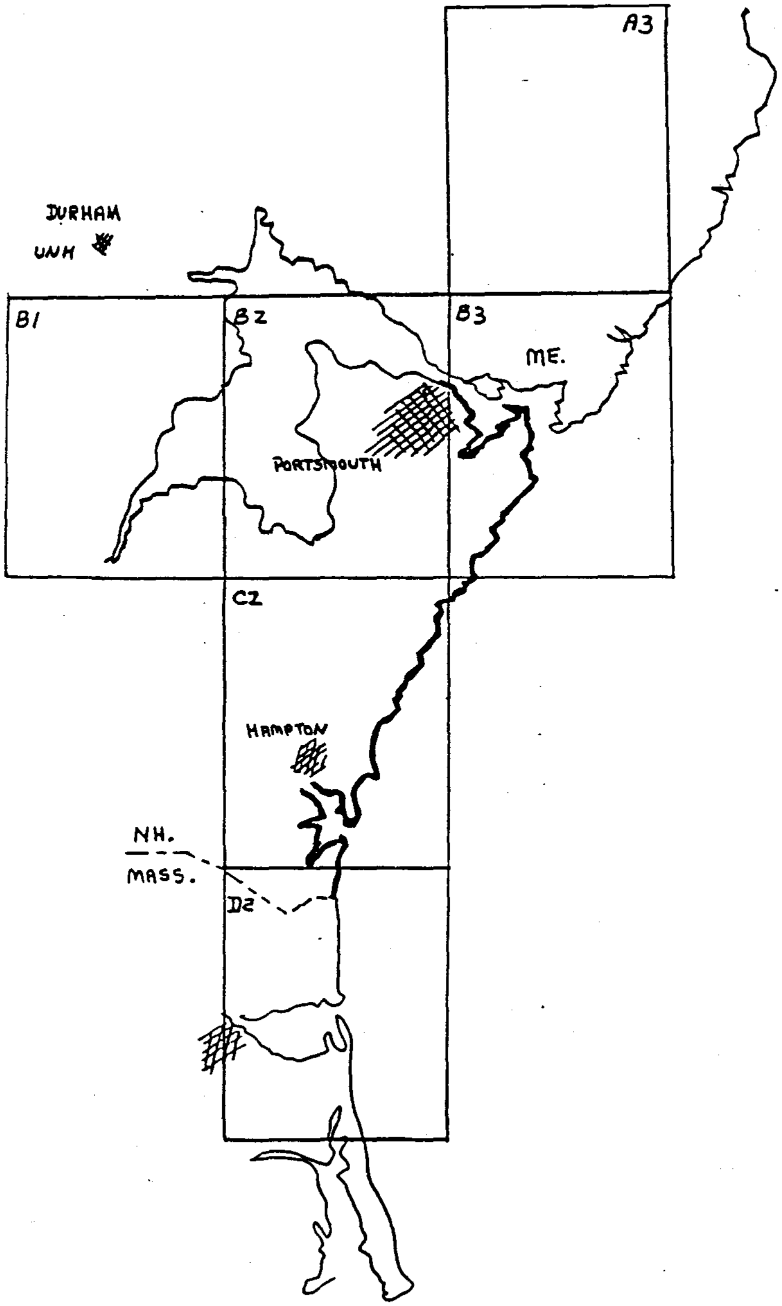

Figure 1 Coast of New Hampshire showing USGS 7.5 quadrangles mapped during survey.

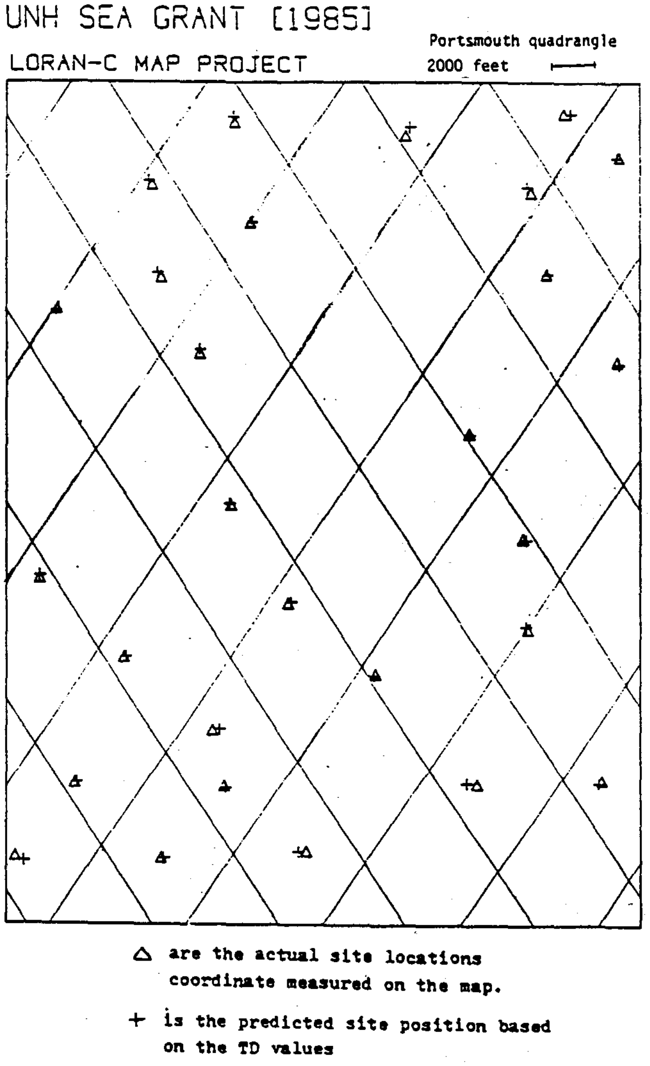

Figure 2. LORAN-C grid, Portsmouth quadrangle showing actual and predicted site locations based on estimated grid parameters.

During the months of January,February and March the team visited over 150 sites at least once, revisited over a dozen sites twice and several for three times. Lacking an automatic data collection system the team spent one afternoon recording data at one site for over three hours to observe short term variability and noise. Measurements were confined to the Northeast Chain GRI 9960 using secondaries Caribou and Nantucket. Signal strength was good and LOP crossing angle is approximately 68 degrees.

Assuming that over the extent of one 7.5 minute chart the gradient and orientation of the W and X LOP were approximately constant , collected data for each map area was subjected to a least squares best-fit analysis for gradient and TD values. Initial values were then readjusted for a best fit to orientation angle. LORAN-C overlay grids for each USCG chart were prepared. Figure 2 is a plot of the Portsmouth quad grid showing map sites at which measurements were taken and computed site locations based on TD values and new grid constants.

A comparison of TD values for the center of each quad and the EE10A predictions are shown in Table 2

		UNH estimate	EE10A
A3	York	13641.343	13778.618
		25988.865	25992.265
B1	Newmarket	13785.079	13786.099
		26077.049	26080.421
B2	Portsmouth	13735.116	13737.223
		26031.161	26033.432
B3	Kittery	13685.297	13646.086
		25986.356	25993.030
C2	Hampton	13777.343	13778.618
		25988.865	25992.265
D2	Newburyprt	13816.488	13820.117
		25945.553	25949.105

Table 2 Estimated TD coordinates for each quad center based on UNH field tests and EE10A computed TD values

The results in each map area show a scatter in data points which in most cases were well within the accuracy to be expected in the region. On the completion of the chart overlays " blindfold" navigation tests were made at sites not previously visited. Tests were made on both the prediction of TD values to be observed at selected sites and on navigation to a point with a designated TD. In all cases the position finding or predictions were within 300 feet and in several cases better than 100 feet.

CONCLUSION

IN the monthly reporting and critique session the LORAN-C Map team was able to introduce the entire project class and their faculty advisors to the capabilities and the potential of LORAN-C as an adjunct tool to ocean investigations of all kinds; sea bed studies of marine life habitats , archaeological site identification, return to instrument and traps. The reports on the accuracy of the results obtained in the later months of the term , supported the initial estimates and provided specific numerical data to many possible users in the UNH Marine community. It was evident from the questions that arose during the life of the project and since its completion in May 1985 that the Map Project achieved its goal of determining local grid values for the New Hampshire coast and also contributed to the education of a wide spectrum of engineers and life scientists into the uses that LORAN-C might have in future experiments.

ACKNOWLEDGEMENTS

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Brief Resume

Albert D. Frost

Present employment: Professor of Electrical and Computer Engineering
University of New Hampshire
Durham NH 03824

Education: BA (Physics) Tufts University
AM (Engineering Science and Applied Physics) Harvard University
ScD (Physics) Massachusetts Institute of Technology.

Areas: Radio propagation,acoustics and instrumentation.

Previous positions held (while on leave from UNH)

Physicist;Institute for Defense Analyses,Washington DC

Visiting Professor: Nuffield Radio Astronomy Laboratory,Jodrell Bank
University of Manchester , England

Visiting Professor: University of Sheffield,Space Physics Laboratory
Meteor Wind Radar Group.

Visiting Scientist: Oxford University,Research Laboratory of Archaeometry
Oxford England.

University Faculty Fellow: Transportation Systems Center, Department of Transportation Cambridge MA.

Since 1981 active consultant with TSC in the areas of radionavigation, analysis of LORAN-C signal characteristics. VLF propagation and the application of LORAN-C to land navigation.

GULF COAST AND EASTERN SEABOARD LORAN-C CALIBRATION

Robert H. Miller
Kaman Tempo
816 State Street
Santa Barbara, CA 93102

ABSTRACT

In some geographical areas actual line-of-position (LOP) values differ from those shown on nautical charts published by the National Ocean Survey. The U.S. Coast Guard has instituted a program to obtain independent positioning data for the purpose of correcting navigation charts. As a part of that program, a calibration of the Loran-C coverage along the eastern sector of the Gulf of Mexico and the Southeast seaboard was conducted in January 1981.

For this calibration, the U.S. Coast Guard provided a defined vessel track of some 2250 nautical miles from Tampa Bay, Florida, around the Florida Keys, to the sea buoy at Norfolk, Virginia. All data were taken aboard the USCGC Ingham during a total elapsed time of 16 days, which included the diversions of the vessel to meet U.S. Coast Guard operational requirements enroute. Loran-C position fixes were obtained by Coast Guard Electronics Engineering Center (EECN) personnel using Coast Guard equipment. Independent position fixes were obtained by Kaman Tempo personnel using the Maxiran system in a range-range mode. The two systems were synchronized in time to record simultaneous position data at 3-minute intervals along the entire track. Four shore-based teams were involved in leap-frogging the Maxiran fixed-site transmitters through a total of 27 previously surveyed land sites to provide complete coverage of the data track.

This paper describes the planning procedures for the execution of this field test and the operational aspects of test execution. Included are land-site reconnaissance and survey, installation and calibration of Maxiran equipment, data acquisition techniques, and test control procedures to insure continuity of operations.

AUTHOR BIOGRAPHICAL SKETCH

Robert H. Miller is a retired officer from the U.S. Army and received his Bachelor of Science from the U.S. Military Academy in 1958. He attended the Pennsylvania State University receiving a Doctor of Philosophy in Chemistry in 1965. With Kaman Tempo since mid-January 1981, and General Electric Tempo since late 1979, Dr. Miller has been involved with Loran-C and other electronic positioning systems in airborne, land-based, and oceanic environments. For the past two years, Dr. Miller has been working on the position location methodology and error prediction techniques for the U.S. Air Force Precision Location Strike System (PLSS) presently undergoing combined Development and Operational Test Evaluation by the Air Force Operational Test and Evaluation Center (AFOTEC) at Kirtland Air Force Base, New Mexico. Dr. Miller is also the Manager of the Kaman Tempo Albuquerque field office.

BACKGROUND

The U.S. Coast Guard had earlier defined a vessel track of some 2250 nautical miles for this project. Beginning at Tampa Bay, Florida, this track covered a dynamically changing course around the Florida Keys and up the Southeast Coast to Norfolk, Virginia. Figure 1 is a sample of the data track covering the first day's planned effort. The U.S. Coast Guard provided the Cutter Ingham for the data collection effort. Coast Guard Electronics Engineering Center personnel installed the Loran-C data collection equipment aboard the Ingham while Kaman Tempo installed the Maxiran equipment to collect independent position data. The Kaman Tempo mission was to collect the independent positioning data in a format prescribed by the U.S. Coast Guard and upon completion of the calibration, to turn the data tapes over to the U.S. Coast Guard for analysis.

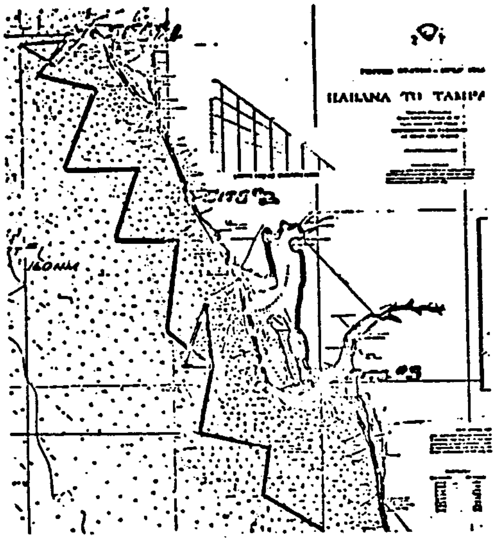

Figure 1. Data Track for Day 1*

*Florida coastline and vessel track enhanced; also showing shore sites #1, #2, and #3.

EQUIPMENT

The data collection systems used were totally independent of each other. Personnel from the U.S. Coast Guard EECN employed the Austin 5000 Loran receiver to collect Loran time difference (TD) data and Loran signal characteristics. They used a PDP-11 computer for control and a Texas Instruments TI-733 terminal for data recording. Kaman Tempo's independent positioning system was the Maxiran system having an accuracy of better than ±30 meters. Figure 2 shows the major components in block diagram format for both systems. At the start of each day's effort and at periodic intervals during the day, both systems were synchronized to Greenwich Mean Time to insure simultaneity in data recording.

Maxiran

The Maxiran system operates in the 400-MHz band. In standard form this system is comprised of

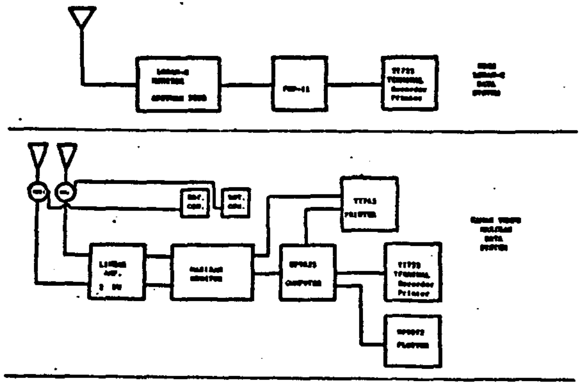

Figure 2. Data Collection Equipment For Gulf Coast and Eastern Seaboard Loran-C Calibration.

a display monitor and a transmitting/receiving station called an interrogator with two identical shorebased transmitting/receiving stations called beacons. The monitor and interrogators are carried aboard the ship. Some of the Maxiran system specifications are listed in Table 1.

Table 1. MAXIRAN Specifications

	Interrogator	Beacon
Transmitter	Solid-state, Xtal Oscillator	Solid-sate, Xtal Oscillator
Signal	Pulsed-phase-coded	Pulsed-phase-coded
Frequency	440 MHz	430 MHz
Peak Power	200 Watts minimum	200 Watts minimum
Bandwidth	±10 MHz (first null)	±10 MHz (first null)
Pulse Width	12.8 μsec	12.8 μsec
Phase Code	Pseudo-random	Pseudo-random
Repetition Rate	150 Hz	N/A
Receiver	Superheterodyne	Superheterodyne
Sensitivity	-105 dBm	-105 dBm

The monitor generates a two-pulse code that is fed to the cylindrical interrogators located on the antenna mast. The time interval between each of the pulses in the two-pulse group determines which of the two possible beacons will be interrogated. Intervals are selectable between 26 and 60 usec. The Maxiran monitor has the capability to use up to three beacons simultaneously, but for this effort only two beacons were used at a time.

At the interrogator, the pulse group is converted to a pair of 25-usec UHF pulses, transmitted at 440 MHz via a 4-pole filter incorporated in the transmitter output circuit to a vertically polarized high gain antenna. Each pulse represents a burst of continuous wave carrier with 127-bit code to serve as an identifying signal, recognizable by the receiver in any of the beacons. The modulation takes the form of a phase reversal of the RF carrier such that logical 1 is represented by a phase reversal condition and logical 0 by an in-phase condition. The clock rate for the code is 5.76 MHz.

Pulse groups are transmitted at the rate of 150 per second; the complete pulse train being time-shared between selected beacon codes. If three shore-based units, for example, Beacons A, B, and C are selected at the monitor, then each beacon would be interrogated 50 times per second in the sequence ABCABCA, . . . etc. If only Beacons B and C are selected, as was the case here, then each remote unit is interrogated 75 times per second in the sequence BCBCBC, . . . etc. Similarly, selection of only one remote would result in 150 interrogations of that unit per second.

At the shore-based beacon, the pulse train is received via its common transmit-receive antenna and 4-pole filter, amplified and mixed with a 320-MHz local oscillator to produce an IF of 120 MHz. After further amplification and filtering, the signal is routed through a surface-acoustic-wave (SAW) delay line in which the pulse components undergo a correlation and code recognition process. Signal enhancement in the SAW device amounts to an improvement in signal-to noise ratio of 21 dB and a width compression of the pulse from 25 μsec to 100 nsec.

The signal then passes through further acceptance tests wherein pulses below a predetermined signal strength are rejected. Finally, the signal reaches the beacon decoder section where the interval between the pair of pulses forming each group is measured. If the time interval matches the beacon code, which has been manually set on the thumbwheel code switch, a trigger pulse is sent to a transmitter section that in turn generates a responding pulse of 25 μsec duration at the beacon transmitting frequency of 430 MHz.

The time of arrival of the return pulse at the monitor is stored in a counter, using a clock of 150 MHz for measuring the interval between transmission and reception. This becomes a measure of the distance between the two locations. The contents of the clock counter are scaled in meters and fed to the data output circuits for parallel and serial formatting. The built-in, real-time clock and event counter provide reference information that may be included in the output data string if desired.

A shore-based station is essentially self-contained and consists of the following: Beacon Transmitter/Receiver; Antenna Tower; Log Periodic Antenna, dual 10 element; 12 VDC Battery; Control Box; and Thermoelectric Generator. Except for periodic requirements for antenna reorientation, each shore-based station requires little attendance.

Propagation

Research of electromagnetic wave propagation over water masses has established that frequencies between 50 and 500 MHz can be propagated along the air-sea interface. Under normal conditions, the refractive index of the atmosphere decreases with height so that the radio waves travel more slowly near the sea surface than at higher altitudes. This variation in velocity with height results in the bending of the radio rays. The decrease in the refractive index with height may be so great that the ray is bent downward with a radius nearly equal to that of the earth so that the ocean surface may be considered flat. A further increase in the refractive index gradient results in the radio ray being bent down sufficiently to be reflected from the surface and appearing to be "trapped," as if in a duct between the reflecting layers. Under these circumstances, the ray can be considered to be traveling in a manner analogous to microwaves - in a waveguide extending over the sea surface between transmitter and receiver antenna elements.

Therefore, when bending conditions are particularly favorable, a surface duct may be formed that can propagate radio waves over remarkable distances with very little attenuation. The height of the duct over the water's surface may be only 20 to 50 feet, or it may be 1,000 feet or more depending upon the local atmospheric conditions. Ducts exhibit a low-frequency cutoff characteristic similar to that encountered in a waveguide, which is determined by the strength of the discontinuity in refractive index at the upper surface of the duct.

These aspects tend to confirm the existence of worldwide, strong surface ducts, though with some degree of variability and subject to numerous influences.

Shore Site Selection

Using map reconnaissance techniques, approximate shore sites were selected based upon maintaining continuous coverage of the predetermined vessel track. Specific parameters used in the map reconnaissance phase entailed consideration of geometric dilution of precision (GDOP), unobstructed propagation paths, shoreline proximity and site accessibility. Preliminary shore sites were selected such that the crossing angle between two sites and the vessel position was always greater than 30° and less than 150°. Sites were also selected to insure that, to the maximum extent possible, propagation paths were over seawater with no obstructions such as land masses, trees, building, etc., over the full range of antenna orientations for each site.

Shore Site Positioning

Upon completion of the map reconnaissance phase, final sites were selected, surveyed, and identified. This was accomplished by physically visiting each of the pre-selected sites to determine its exact location. Each final site selection was surveyed using a Magnavox MX 1502 Satellite Surveyor or the coordinates were obtained from U.S. Geodetic Service (USGS) horizontal control point data. All coordinates were referenced to the World Geodetic Survey 1972 (WGS-72) datum. Figure 3 shows the locations for the 28 different shore sites used in this effort; Table 2 lists coordinate data for each site.

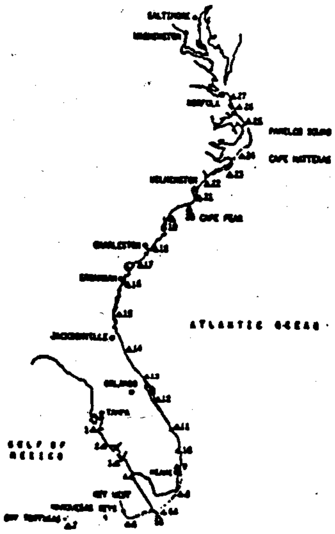

Figure 3. Maxiran Shore Sites for Gulf Coast and Eastern Seaboard Loran-C Calibration.

It is worthy to note that the map reconnaissance principles worked quite well. No final site selected deviated by more than a few meters from the pre-selected site. Since the vessel track passed between the Dry Tortugas and the Marquesas Keys off Southwest Florida, it is obvious that a "baseline" crossing would occur at that point but no alternatives were available in this area, however. Sites 5A and 5B were chosen at close proximity to each other in order to provide satisfactory coverage in the West (5B with sites 4 and 6) and in the East (5A with sites 6 and 8).

Table 2. Coordinates of Gulf Coast and Eastern Seaboard Sites

Site No.	Latitude	Longitude	Height (meters)
1	27°31'31.640"	82°44'14.846"	9.694
2	27°4'39.849"	82°27'8.448"	4.166
3	26°29'14.173"	82°11'6.925"	13.586
4	25°54'29.833"	81°43'43.261"	12.030
5A	24°43'50.978"	81°03'27.697"	2.544
5B	24°45'58.159"	80°54'44.583"	10.076
6	24°33'1.967"	81°48'3.680"	24.38
7	24°37'41.224"	82°52'20.630"	1.9
8	25°4'33.257"	80°26'36.094"	3.549
9	26°2'56.427"	80°6'45.890"	8.901
10	26°35'21.954"	80°2'15.571"	21.001
11	27°14'39.030"	80°11'26.536"	14.940
12	28°1'15.476"	80°32'5.739"	9.957
13	29°5'4.431"	80°55'31.604"	11.382
14	29°59'18.002"	81°18"54.338"	15.175
15	31°2'35.745"	81°24'42.605"	10.407
16	31°59'16.384"	80°51'0.187"	11.294
17	32°30'9.970"	80°17'47.157"	5.776
18	32°47'49.684"	79°45'28.894"	-2.357
19	33°32'23.839"	79°1'26.572"	5.186
20	33°52'46.946	78°27'47.285"	8.411
21	34°0'36.557"	77°54'5.471"	7.965
22	34°27'43.220"	77°28'56.554"	11.235
23	34°37'21.521"	76°31'25.856"	Sea Level
24	35°06'32.033"	75°59'10.344"	24.38
25	35°50'1.959"	75°33'28.850"	5.986
26	36°10'55.280"	75°45'4.779"	18.498
27	36°37'50.709"	75°53'30.699"	2.970

The MX 1502 satellite geoceiver consists of a portable antenna unit, a main unit, and a 12-volt battery. The MX 1502 is designed around a microprocessor that controls essentially every function of the instrument. The main unit combines the microprocessor, keyboard, display function, magnetic-tape cassette, dual-channel receiver, crystal oscillator, rechargeable backup batteries, and power supply in a single lightweight, rugged, field protable enclosure.

The MX 1502 computes and displays a three-dimensional (3-D) position fix. This result is accomplished in the field and verifies proper system operation, assuring the location has been determined to the desired accuracy. The results computed in the field provided an indication to the operator that sufficient data have been collected and a move to the next site can be made with assurance. The MX 1502 included a thorough self-test capability to assure proper operation. If the self-test function detects a problem, the specific module causing the problem is indicated. However, it should be noted that there were no malfunctions during the satellite survey. After each record was placed on magnetic tape, it was immediately read back to assure no recording mistakes. If an error had been detected, that portion of data would have been re-recorded.

The MX 1502 can acquire the orbital parameters of all Transit satellites by reading a previously recorded tape cassette (alert tape). Thereafter, it shifts automatically to a minimum power mode between satellite passes to reduce battery consumption.

INSTALLATION AND CALIBRATION

During the period 6-10 January 1981, the Maxiran equipment was prepared for the survey effort. Shore beacon stations were divided into four identical groups. All cables were marked and tagged to insure integrity when calibrated. After calibrating the interrogators and the four beacons, each beacon was dispatched to its initial shore-site and the Maxiran ship board equipment were installed per Figure 2.

Calibration

Sites 1 and 2 were used for the calibration. The monitor and interrogators were installed at site 1 while each beacon was installed in turn at site 2. Knowing the length of the propagation path between these two sites, calibration was relatively straightforward. The process is, however, somewhat tedious and time consuming since both of two interrogators must be calibrated with all four beacons.

Major calibration corrections are provided to the monitor via thumbwheel switches at the rear of the monitor. When calibrating the system, these are set to zero initially. Each interrogator is then used with each beacon to determine the differences in range measurements. For this step, the actual range is not important. The data sought here is the difference in readings between each interrogator and each beacon. This difference is then nulled to zero by adjusting trimpots in the interrogators and beacons such that the readings obtained from each beacon agree. Next each beacon is used in turn with each interrogator for actual range measurements. Adequate data samples are taken to insure a valid statistical set is obtained. From the statistical data set, a root mean square error is calculated which becomes the calibration constant for the beacon and interrogator pair. In operation, this calibration constant is entered via the appropriate thumbwheel switch at the rear of the monitor.

Ship Installation

Equipment installation aboard the Cutter *Ingham* was successfully accomplished in 1 day with the bulk of the effort going towards mounting the log periodic antennae atop the main mast and routing the RF cables through the mast tower. Operating space was at a premium in the ship's electronic repair room on the second deck aft of midship. All equipment was secured in preparation for any adverse weather at sea. Main power was taken from the ship's main power source for all equipment items.

OPERATIONS

Technique

The technique used was daily routine. Main control of the Maxiran was aboard the ship since the ship's position, heading, and speed was known at all times aboard the vessel. Communications existed between the vessel and the shore sites via voice HF/SSB transceivers. Instructions for each shore site were relayed from the vessel using these transceivers.

At the start of any given track day, each shore site was issued times and magnetic bearings for antenna orientations. The times and new antenna bearings were calculated aboard the ship based upon maintaining a shore based antenna fan coverage of 70° and a vessel speed of 12 knots. Thus, each day, each shore station had a schedule for antenna reorientation. Before each change was executed, the shore team would contact the vessel for verification. The vessel in turn would verify the change and/or issue a new schedule based upon the past progress.

Nominally, three shore stations were always operable during the data collection period. Two were in active use for data collection while a third was in operation waiting acquisition of its signal by the vessel. A fourth was generally enroute to the next site. When the vessel satisfactorily acquired the third station's signal, a release order was issued to the first station for disassembly and move to a new site. When the fourth station became operable, notification was passed to the vessel and its time table for antenna orientation was also provided by the vessel. In this manner, the stations were leap-frogged from site to site commensurate with the vessel's progress along the predetermined track.

Careful coordination aboard the vessel was mandatory. It was important to maintain very close cognizance of the beacon identity for each shore station.

DATA COLLECTION

The principal data recording device was the TI-733 terminal (Figure 2). Both hard copy printer output and magnetic tape cassettes were used. Data were recorded at 3-minute intervals using a serial port to the cassette recorder and a parallel port to the printer. Table 3 illustrates the data format recorded on the printer. The first column of data elements is the month, day, and time group (GMT). The next two columns are corrected range data in meters for the two beacons in active use while the following two columns always contain a zero because only two beacons were used at one time. The final two columns are latitude and longitude, respectively.

Table 3. Recorded Maxiran Operational Data

01:21:22:09:00	053245	084671	0	0	29 29 53.037	80 38 47.551
01:21:22:12:01	052257	085129	0	0	27 29 20.603	80 38 56.996
01:21:22:15:01	051263	085607	0	0	29 28 47.806	80 39 6.308
01:21:22:18:01	050263	086106	0	0	29 28 14.623	80 39 15.463
01:21:22:21:01	049264	086608	0	0	39 27 41.533	80 39 24.864

An auxillary TI-743 printer was also used to print Maxiran monitor data. Table 4 contains a sample of this data. The first data column contains month and day (numeral 1 is the true month but due to a minor difficulty numeral 0 was printed); the second column contains the time group (GMT). The third data column is meaningless and was not used. Sequential event numbers are in column 4 while the next three columns contain corrected range data. Columns 5 and 6 reflect corrected range data for the active beacons while column 7 contains range data for a third beacon. The latter was occasionally used to track the next beacon to be used or to track a previously used beacon for curiosity experiments such as persistence of the ducting effect.

Table 4. Maxiran Monitor Data

022	00:24:01	0000	2377	018605	104853	105404
022	00:27:03	0000	2378	019707	103788	103787
022	00:30:02	0000	2379	020819	103363	103101
022	00:33:01	0000	2380	021927	102194	102391
022	00:36:04	0000	2381	023063	101488	101677

An HP-9872 two-axis plotter was also used in the data collection effort. At a scale of 1:100000, the ship's track was plotted throughout the entire effort. Plotter points were generated every 3 seconds in addition to tick marks and event numbers at 3 minute intervals. The latter correspond to the printer outputs described earlier. Figure 4 is an illustration of one such plot.

SUMMARY

The survey effort commenced at 0900 hours on 11 January 1981 after an elapse of 3 hours for harbor clearance. At 2109 hours on 27 January the survey was completed. The last event number was 4,314 which represents nearly 9 full days of continuous operations. Included in the total elapsed time were interrupts for refueling, one search and resuce mission, and two law enforcement missions.

The total data return was better than 97%. The volume of data was accounted for on 34 magnetic tape cartridges, 86 pates of printer product, and 81 plotter charts. ducting effects were quire noticeable with range data frequently exceeding 100 kilometers. At other times, predominantly during period of precipitation, signal quality became seriously degraded at ranges just over 50 kilometers.

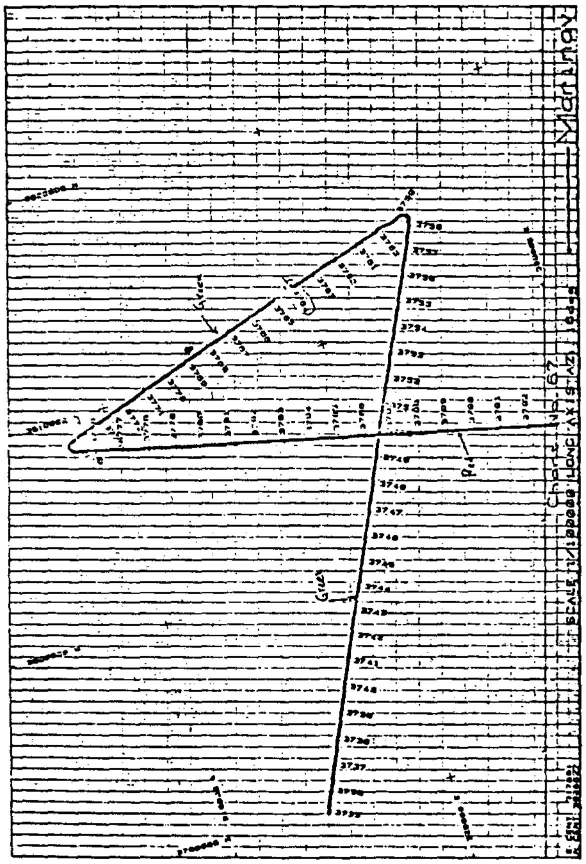

Figure 4. Vessel Track Recorded from Maxiran Data.

ACKNOWLEDGEMENTS

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LORAN DYNAMIC GRAPHICS POSITIONING SYSTEM

Kurtis L. Maynard
Supervisor of Special Projects
John E. Chance & Associates, Inc.

ABSTRACT

LORAN DYNAMIC GRAPHICS POSITIONING SYSTEM

Since the first semi-submersible anchor rigs started drilling offshore 25 years ago, the method used for marking proposed anchor locations and the location of the proposed drill site has been the placement of a pattern of buoys. This system worked quite well until recently when oil exploration moved into very deep waters which has made the placement of buoys difficult. A portable system was needed on the anchor boats and the rig that would continuously monitor placement of the anchors and initial positioning of the rig. The system uses Loran calibrated to the work area which plots the position of the rig on a graphics terminal in relation to the proposed drill site. At the same time, the position of the anchor boat is relayed to the graphics terminal on the rig via a radio modem so that its position can be determined allowing the boat to be directed to the correct anchor location. This system was used recently in Alaska (Navarin Basin) with a G.P.S. satellite receiver to calibrate the Loran to the work area. The combination of G.P.S. and Loran provided a dynamic accurate positioning tool.

I. History of Rig Positioning

As the oil industry moved offshore in the early 1950's the surveyors role changed from land surveying to offshore surveying. The first drilling rigs were positioned using triangulation techniques from survey control points on shore. As permanent drilling platforms were established offshore, survey control was carried along to these platforms, making it possible to meet the survey needs of the industry. Before the advent of modern electronic measuring equipment, visual sightings with a transit were the only means of positioning. It was concievable to hold a rig up for three or four days waiting for the fog to clear. With the advent of the dynamic microwave measuring equipment in the mid 60's, visibility no longer was a criteria in the positioning process.

Although the procession offshore in the Gulf of Mexico was orderly in the respect that new areas were usually within range of line-of-sight methods, a few places required long range radio positioning. Lorac, Raydist and Shoran were some of the first hyperbolic radio positioning services that allowed the oil industry to survey and navigate beyond the horizon with accuracies of 15 to 100 meters, depending upon the area, and ability to calibrate accurately.

Drilling off the East Coast of the United States began in the mid 70's but this time the first wells were 120 miles offshore which precluded use of line-of-sight techniques. Two new survey tools had been added to the surveyors tool box by now. The Transit satellite system, and range-range radio positioning. Buoys used as markers for the anchors and the proposed drill site were deployed with Argo (range-range positioning). Once the rig was positioned over the buoy, a final tie was accomplished using the transit satellite system in the translocation mode.

II. Using Loran To Position A Rig

Using radio positioning and deploying buoys to mark the proposed location worked well until the summer of 1983. Shell Oil Company decided to drill in 6,950' of water off the coast of New Jersey. The water depth precluded the use of buoys as a location marker.

To make matters worst, the Argo radio positioning could not be used on the rig due to its antenna tuning sensitivity to mass changes. Calibrated Loran-C seemed to be the answer. As a company, we had used calibrated Loran-C for a couple of years to re-establish lane count of our Argo after sky-wave periods, the Loran had proven a useful tool in this task, but there was some skepticism whether the calibrated Loran would prove accurate enough to position rigs.

The Discoverer Seven Seas was the rig to be used in this deep water. It is a dynamically positioned rig, using computer controlled thrusters that position over accoustic beacons.

The calibration of the Loran at the drill site was accomplished using Argo on a survey vessel. The Loran was calibrated to the Argo for 12 hours, prior to the arrival of the rig. The Loran and a computer were then placed on the rig, using the calibration values obtained the day before to drive the rig onto location. Once the rig began its drilling operation, a final position was determined using transit satellite translocation. The final satellite position and Loran position agreed within 15 meters.

III. Dynamic Graphics Positioning System

Our good experience on the East Coast with Loran to position a drilling rig started us thinking about ways we could use Loran to help us with rig positioning in the Gulf of Mexico.

The rigs in the Gulf of Mexico were by this time moving into water depths up to 2,000 feet. There was a need to not only position the rig but also the anchor boats used to deploy the rigs anchors, without the use of marker buoys.

The Dynamic Graphics Positioning System was assembled to meet this need. The system consists of Loran receivers with a modem and radio installed on the anchor handling vessels. A Loran, modem, radio and computer graphics terminal is installed on the rig. The Loran is first calibrated in the work area against any number of systems, depending upon the area. If the work area is within line-of-sight of survey control, microwave measuring devices are used to calibrate the Loran. If the area is beyond line-of-sight, radio positioning or satellite equipment is the calibration tool used.

Once the Loran is calibrated, the calibration is entered into the computer. Data shipped from the anchor boats via the radio is then corrected by the calibration factors and plotted on the graphics screen, showing the boats position, and the azimuth and distance it needs to go to place the anchor. At the same time the Loran on the rig is being read, the calibration factors applied and the rig is also plotted on the screen showing its present position, and the direction and distance it needs to go to the proposed drilling position. Besides plotting the rig and anchors boats positions, pipelines, shipwrecks, existing wells or any other hazards that might encumber the placement of anchors or the drilling operations are also plotted.

IV. Dynamic Graphics Positioning System in Alaska

The positioning of Amoco Production Company's rigs in the Navarin Basin of Alaska, was a perfect use for the Dynamic Graphics Positioning System because of Loran's long-range measuring capability. This area of the Bering Sea is about 300 nautical miles from the United States mainland, which would stretch the range of most commercial land based navigation systems. This area also was an ideal area to use the Global Positioning Satellite System to calibrate the Loran initially and also be a check for the final fix determined by transit satellite. We set up the Loran and G.P.S. satellite system on one of the anchor boats and proceded to location ahead of the drilling rig. Once at location we calibrated the Loran with the G.P.S. receiver. In this area of Alaska the G.P.S. constellation was available twice daily for approximately four hours. Once the Loran was calibrated we boarded the drilling rig, inserted our loran corrections into our computer program and proceded to drive the rig onto location. We positioned four rigs in the Navarin Basin this season, in all four cases, the final position determined by the Loran was within ten meters of the final position determined by the Transit and G.P.S. satellite systems.

V. Summary

In summary, the Dynamic Graphic positioning systems ability to position drilling rigs and anchor boats in deep water and remote areas has proven to be an ideal use of Loran-C.

BIOGRAPHY

Kurtis L. Maynard is employed by John E. Chance & Associates, Inc. in Lafayette, Louisiana. Kurt is a native of Indiana and is 33 years of age. He received his B.S. in Land Surveying Engineering from Purdue University in May of 1974. Kurt is a registered Land Surveyor in the State of Wisconsin and is a member of A.C.S.M. and The Wild Goose Association.

CONVERSION OF LORAN C DATA FOR THE HP 41

Ralph P. Anderson

Professional Engineer, Port Townsend, WA

ABSTRACT

The object of this effort was to provide within the HP 41 a program for reduction of TD's to LAT/LONG with display of several iterations so that progress of the operation can be observed in detail. Also, a program for preparation of data cards for different GRI groups was needed in the program memory for convenient preparation of this data.

This makes it possible for a user to make experimental modifications to the program for variations in speed of performance and accuracy.

CONVERSION OF LORAN C DATA FOR THE HP 41

The method used here for the HP 41 in computing LAT/LONG from TD's may be something different or, on the other hand, as old as the hills. This iteration method appears to be very simple and is essentially algebraic.

Charts for three different systems were used in developing the program as a working tool, these being GRI 5990, 7960 and 9960. Data cards to recover all the statistics can be prepared using the LOR DAT program included here.

Using any HP 41 machine with a quad memory one simply inserts the 12 card sides into the machine and calls for XEQ "LORAN."

There is a PROMPT for CARD and the appropriate GRI system card is passed through the card reader.

There follows a PROMPT for EST POS (estimated position), LAT/LONG, and then a prompt for ITD NOS. After inserting each data number when prompted the R/S key is pressed.

A simple overlay is shown per Fig. 1 makes it convenient to enter the ITD NOS in their proper sequence.

Data for the slave stations to be used is entered in a COUNTERCLOCKWISE manner.

In response to PROMPT for ITD NOS, the first SLAVE data is inserted by pressing the appropriate W,X,Y or Z in the top line of the machine. Next you press W,X,Y or Z in the second line. In each case inserting the correct ITD Number and pressing R/S to proceed.

As soon as the second ITD number is entered and R/S activated, the program is in operation.

If one is only interested in the final results of the LAT-LONG it will be displayed and then stored in registers 78 and 79 from which it can be recovered.

With the available data now in the machine, a new estimated position can be entered to start another run by simply pressing Key E. The program will start at that point and call for a revised estimated position.

Likewise, if new ITD NOS are to be entered you press key J and there will be a prompt for new ITD NOS. In each case after a run the most recent recorded position is stored in the machine as the current estimated position.

Interest was concentrated in getting a reliable working program; it has not been refined to take care of trespass into the Eastern Hemisphere. That can be done just as with any great circle program.

To establish a velocity correction, the program uses the base line data from the standard Loran C handbook compared to the great circle distance in nautical miles and the two data are averaged. This resulting average velocity figure is used in the calculation of position. This is perhaps somewhat better than an all seawater route, reflecting the type of terrain.

A typical "run" is illustrated by Fig. 2 and 3.

CANADA CHART 3461 was used. GRI #5990 and ZULU-YANKEE.

A start position was assumed first to the West and then the East of the U.S. Navy calibration buoy off of Port Angeles:

48.15N	123.30W
48.15N	123.00W

The actual printout is per Fig. 2 and iteration moving across the chart per Fig. 3.

Note that the progress follows the hyperbolic curve for system YANKEE and stops when ITD for system ZULU equals the computed value of ITD ZULU developed within the program.

METHOD OF ITERATION

A simple algebraic system of iteration is used based upon ITD = SP - MP + BL + CTD.

The several forms in which this can be represented are part of Fig. 4.

The coordinates for estimated position P are used to obtain distances to S1, S2 and M.

By combining the two basic equations it is obvious that all "proper" points which will satisfy equation 3 fall along the hyperbola which is common to both systems. This is marked S1P - S2P.

If the value of MP is computed from equation 3 and is compared with the value of MP calculated directly from the estimated position, there must be a discrepancy unless P is correctly at the proper spot.

Simply using this differential to compute new values of S1P and S2P using equations 4 and 5, makes it possible to obtain a new estimated position. This is done per Fig. 5.

The new estimated LAT/LONG data is run through again and again until we arrive at the correct position.

Meanwhile, the iterations carry our estimated position along the hyperbolic curve ITD2 = S2P - MP + BL2 + CTD2. Each time a comparison is made between the proper and the computed ITD 1. When they converge, we are on target.

Preceeding the actual program with documentation notes there is a BLOCK DIAGRAM.

Printer: Although the program is designed to illustrate the progressive iterations with a printer, it will run with the HP 41 and card reader only.

Program lines 385 and 579 show the ADJ correction and ITD correction respectively at each iteration.

MACHINE CAPACITY UTILIZED

With SIZE set at 084 there are some spare registers included. Both the LORAN and LOR DAT programs shown here can be in the machine memory at the same time. This makes it possible to conveniently prepare magnetic cards for different GRI groups.

BASE LINE EXTENSIONS

If the printout of line 585 (see Fig. 2) changes sign as from + to - and vice versa during the running of a problem, the position is very likely near a base line extension. Hunting is indicative of a severe base line extension situation.

ACKNOWLEDGEMENTS

Considerable information on the history of LORAN C was provided by D.H. Gray of Canada Hydrographic Service. The encouragement given by Messrs. George Eaton and A.R. (Tony) Mortimer of Ocean Sciences, Sidney, B.C. is much appreciated.

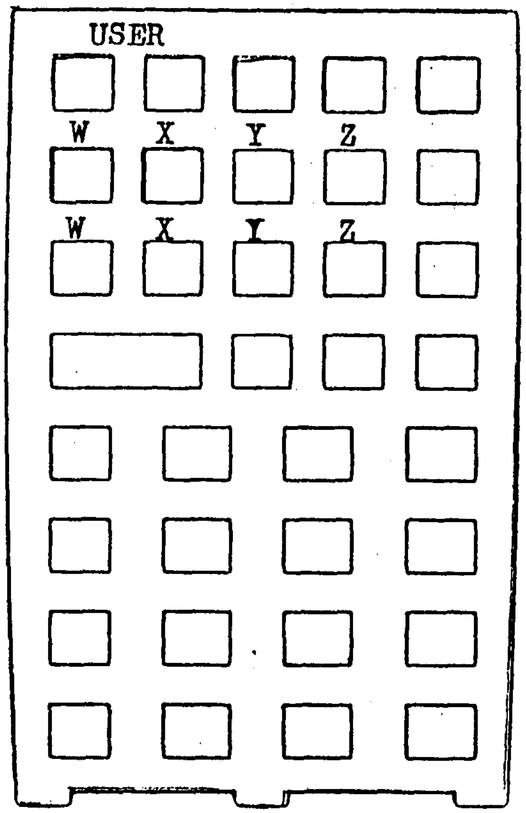
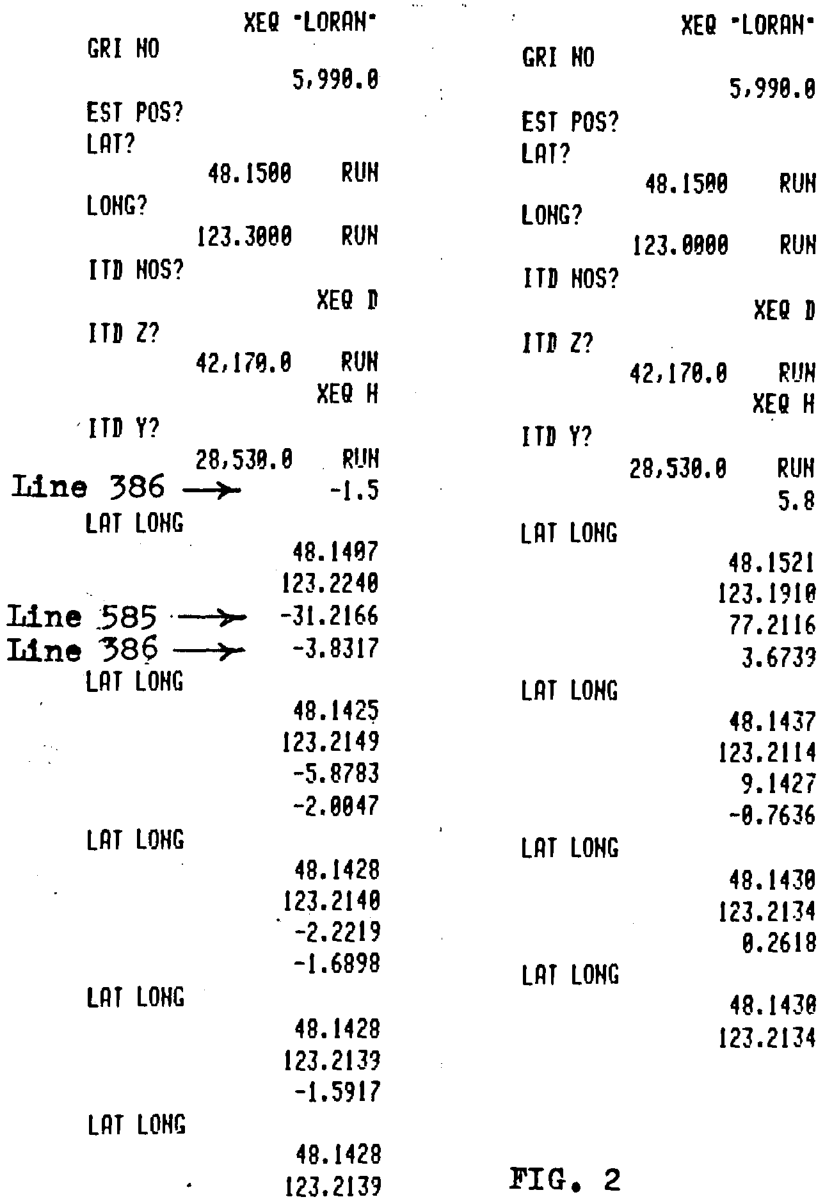


FIG. 1



```
                         XEQ "LORAN"
              GRI NO
                              5,990.0
              EST POS?
              LAT?
                       48.1500    RUN
              LONG?
                      123.3000    RUN
              ITD NOS?
                                XEQ D
              ITD Z?
                      42,170.0    RUN
                                XEQ H
              ITD Y?
                      28,530.0    RUN
Line 386 -->                     -1.5
              LAT LONG
                              48.1407
                             123.2240
Line 585 -->                 -31.2166
Line 386 -->                  -3.8317
              LAT LONG
                              48.1425
                             123.2149
                              -5.8783
                              -2.0047
              LAT LONG
                              48.1428
                             123.2140
                              -2.2219
                              -1.6898
              LAT LONG
                              48.1428
                             123.2139
                              -1.5917
              LAT LONG
                              48.1428
                             123.2139
```

```
                XEQ "LORAN"
GRI NO
                    5,990.0
EST POS?
LAT?
             48.1500    RUN
LONG?
            123.0000    RUN
ITD NOS?
                      XEQ D
ITD Z?
            42,170.0    RUN
                      XEQ H
ITD Y?
            28,530.0    RUN
                        5.8
LAT LONG
                    48.1521
                   123.1910
                    77.2116
                     3.6739
LAT LONG
                    48.1437
                   123.2114
                     9.1427
                    -0.7636
LAT LONG
                    48.1430
                   123.2134
                     0.2618
LAT LONG
                    48.1430
                   123.2134
```

FIG. 2

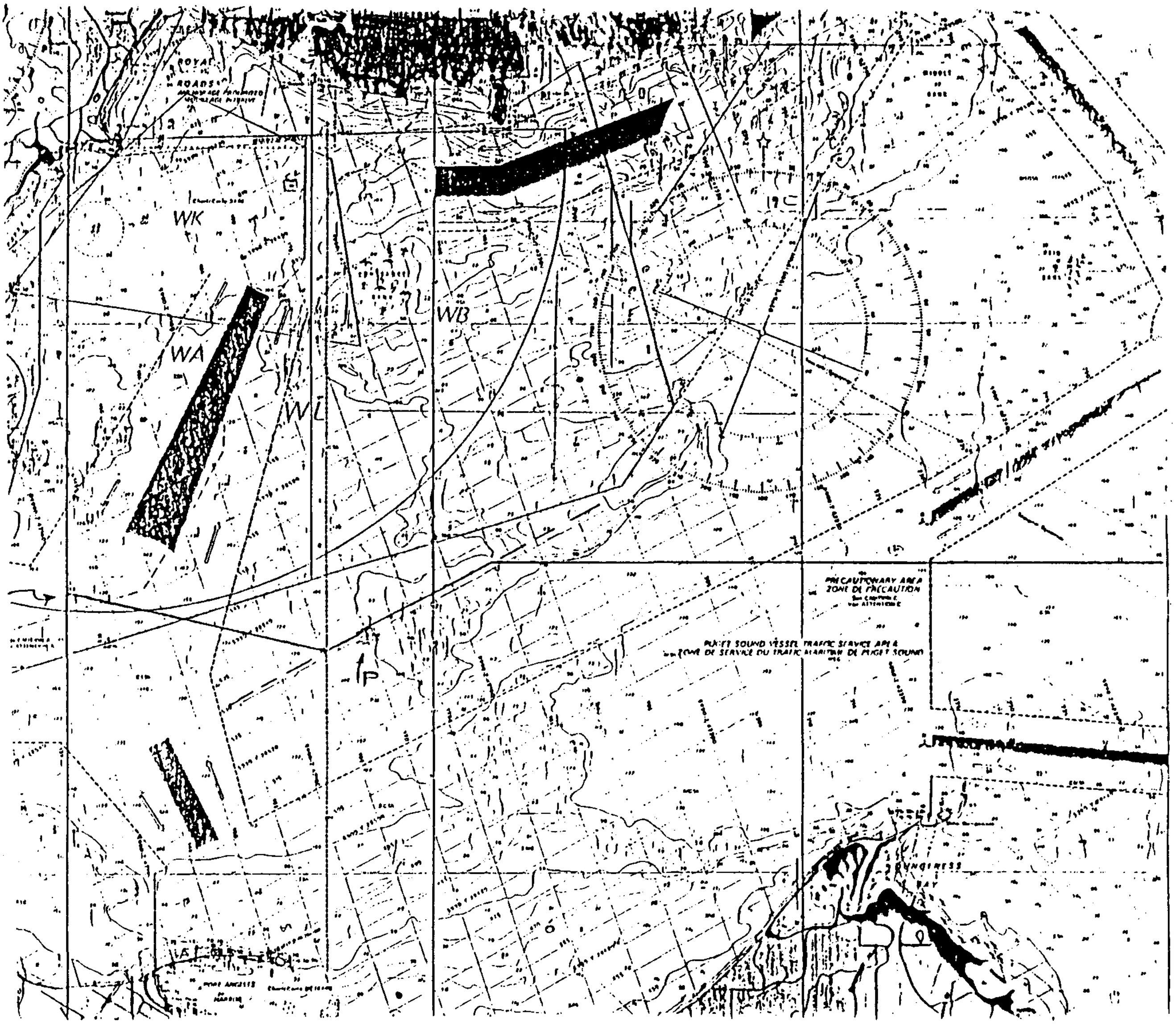
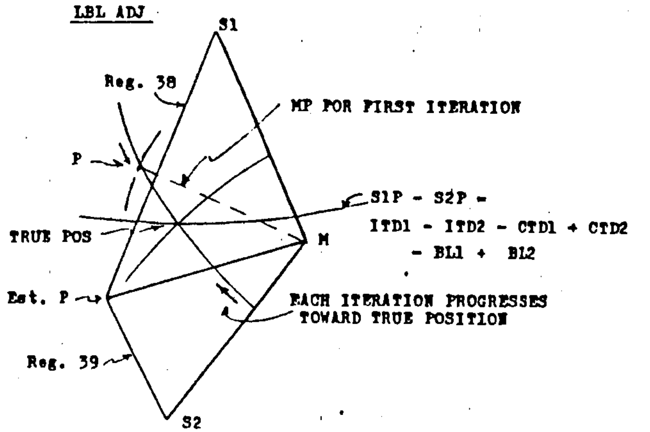

48°15'
123°30'
48°15'
123°00'
ROYAL ROADS
WK
WA
WB
WL
P
PRECAUTIONARY AREA
ZONE DE PRÉCAUTION
PUGET SOUND VESSEL TRAFFIC SERVICE AREA
ZONE DE SERVICE DU TRAFIC MARITIME DE PUGET SOUND
DUNGENESS BAY

FIG. 3



1. ITD1 = S1P - MP + BL1 + CTD1
2. ITD2 = S2P - MP + BL2 + CTD2
3. MP = [S1P + S2P + BL1 + BL2 + CTD1 + CTD2 - ITD1 - ITD2] / 2
4. S1P = ITD1 + MP - CTD1 - BL1
5. S2P = ITD2 + MP - CTD2 - BL2
6. S1P - S2P = ITD1 - ITD2 -CTD1 + CTD2 - BL1 + BL2

FIG. 4

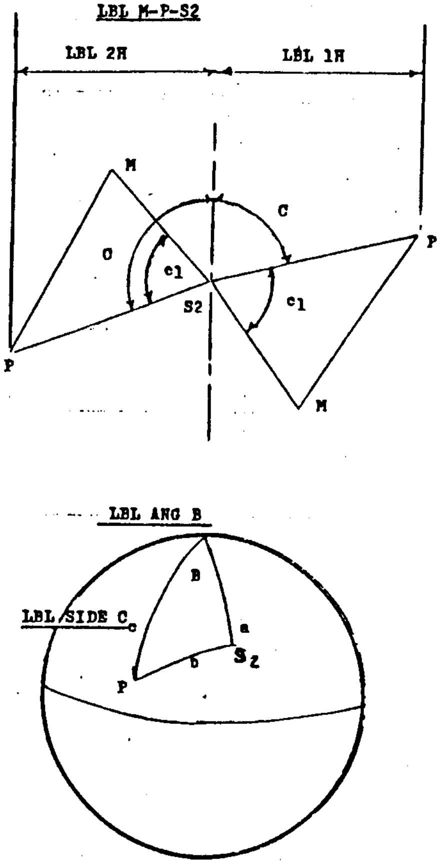
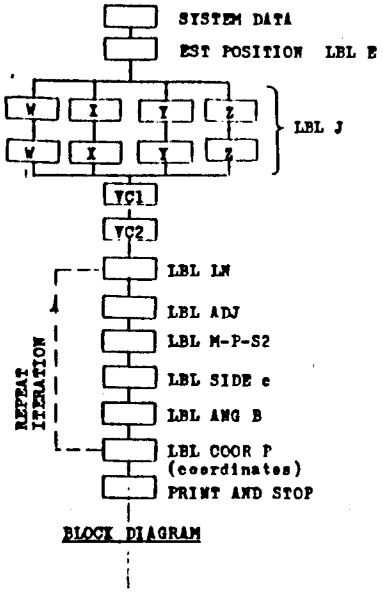


FIG. 5



BLOCK DIAGRAM

RECOVER GRI DATA FROM CARD

```
01♦LBL "LORAN"
02 CLST
03 CLRG
04 000.022
05 RDTAX
06 "GRI NO"
07 XEQ 06
08 FIX 1
09 CLA
10 VIEW 00
11 PSE
12 CLX
13 FIX 4
```

PROMPT FOR ESTIMATED POSITION

```
14♦LBL E
15 "EST POS?"
16 AVIEW
17 PSE
18 "LAT?"
19 PROMPT
20 HR
21 STO 19
22 STO 69
23 "LONG?"
24 PROMPT
25 HR
26 STO 20
27 STO 70
```

PROMPT ITD NOS

```
28♦LBL J
29 FIX 1
30 0
31 STO 68
32 "ITD NOS?"
33 AVIEW
34 PSE
35 FIX 1
36 STOP
```

TOP ROW W

```
37♦LBL A
38 "ITD W?" —
39 PROMPT
40 STO 22
41 CLX
42 CLA
43 RCL 03
44 STO 26
45 RCL 04
46 STO 27
47 RCL 11
48 STO 30
49 RCL 15
50 STO 32
51 CLX
52 CLD
53 STOP
```

TOP ROW X

```
54♦LBL B
55 "ITD X?" —
56 PROMPT
57 STO 22
58 CLX
59 CLA
60 RCL 05
61 STO 26
62 RCL 06
63 STO 27
64 RCL 12
65 STO 30
66 RCL 16
67 STO 32
68 CLX
69 CLD
70 STOP
```

TOP ROW Y

```
71♦LBL C
72 "ITD Y?" —
73 PROMPT
74 STO 22
75 CLX
76 CLA
77 RCL 07
78 STO 26
79 RCL 08
80 STO 27
81 RCL 13
82 STO 30
83 RCL 17
84 STO 32
85 CLX
86 CLD
87 STOP
```

TOP ROW Z

```
88♦LBL D
89 "ITD Z?" —
90 PROMPT
91 STO 22
92 CLX
93 CLA
94 RCL 09
95 STO 26
96 RCL 10
97 STO 27
98 RCL 14
99 STO 30
100 RCL 18
101 STO 32
102 CLX
103 CLD
104 STOP
```

BOTTOM ROW W

```
105♦LBL F
106 "ITD W?" —
107 PROMPT
108 STO 23
109 CLX
110 CLA
111 RCL 03
112 STO 28
113 RCL 04
114 STO 29
115 RCL 11
116 STO 31
117 RCL 15
118 STO 33
119 GTO "INCR"
```

BOTTOM ROW X

```
120♦LBL G
121 "ITD X?" —
122 PROMPT
123 STO 23
124 CLX
125 CLA
126 RCL 05
127 STO 28
128 RCL 06
129 STO 29
130 RCL 12
131 STO 31
132 RCL 16
133 STO 33
134 GTO "INCR"
```

BOTTOM ROW Y

```
135♦LBL H
136 "ITD Y?" —
137 PROMPT
138 STO 23
139 CLX
140 CLA
141 RCL 07
142 STO 28
143 RCL 08
144 STO 29
145 RCL 13
146 STO 31
147 RCL 17
148 STO 33
149 GTO "INCR"
```

BOTTOM ROW Z

```
150♦LBL I
151 "ITD Z?" —
152 PROMPT
153 STO 23
154 CLX
155 CLA
156 RCL 09
157 STO 28
158 RCL 10
159 STO 29
160 RCL 14
161 STO 31
162 RCL 18
163 STO 33
164 GTO "INCR"
```

COMPUTES VELOCITY FACTOR FOR SLAVE S1
AND BEARING S1 TO M
LINE 165 THROUGH 256

```
165♦LBL "INCR"
166 CLX
167 CLA
168 XEQ "CONST 1"
169 XEQ "CONST 2"
170 RCL 41
171 STO 51
172 RCL 42
173 STO 52
174 RCL 69
175 STO 19
176 RCL 70
177 STO 20
178 XEQ "LN"
179♦LBL "CONST 1"
180 RCL 01
181 STO 19
182 RCL 02
183 STO 20
184 RCL 30
185 STO 40
186 RCL 27
187 RCL 20
188 -
189 XEQ 07
190 COS
191 RCL 19
192 COS
193 *
194 RCL 26
195 COS
196 *
197 RCL 19
198 SIN
199 RCL 26
200 SIN
201 *
202 +
203 ACOS
204 60
205 *
206 STO 57
207 RCL 40
208 X<>Y
209 /
210 STO 41
211 RCL 26
212 SIN
213 RCL 57
214 60
215 /
216 COS
217 *
218 CHS
219 RCL 19
220 SIN
221 +
222 RCL 26
223 COS
224 RCL 57
225 60
226 /
227 SIN
228 *
229 1/X
230 *
231 1
232 X<>Y
233 X>Y?
234 GTO 02
235 GTO 03
236♦LBL 02
237 1
238♦LBL 03
239 ACOS
240 STO 54
241 RCL 27
242 RCL 20
243 -
244 0
245 X<>Y
246 X<=Y?
247 GTO 02
248 RCL 54
249 GTO 03
250♦LBL 02
251 360
252 RCL 54
253 -
254 STO 54
255♦LBL 03
256 RTN
```

COMPUTES VELOCITY FACTOR FOR S2
AND BEARING S2 TO M AS WELL AS
AVERAGE VELOCITY FACTOR

LINES 257 THROUGH 340

```
257♦LBL "CONST 2"
258 RCL 01
259 STO 19
260 RCL 02
261 STO 20
262 RCL 31
263 STO 40
264 RCL 29
265 RCL 20
266 -
267 XEQ 07
268 COS
269 RCL 19
270 COS
271 *
272 RCL 28
273 COS
274 *
275 RCL 19
276 SIN
277 RCL 28
278 SIN
279 *
280 +
281 ACOS
282 60
283 *
284 STO 58
285 RCL 40
286 X<>Y
287 /
288 STO 42
289 RCL 28
290 SIN
291 RCL 58
292 60
293 /
294 COS
295 *
296 CHS
297 RCL 19
298 SIN
299 +
300 RCL 28
301 COS
302 RCL 58
303 60
304 /
305 SIN
306 *
307 1/X
308 *
309 1
310 X<>Y
311 X>Y?
312 GTO 02
313 GTO 03
314♦LBL 02
315 1
316♦LBL 03
317 ACOS
318 STO 55
319 RCL 29
320 RCL 20
321 -
322 0
323 X<>Y
324 X<=Y?
325 GTO 02
326 RCL 55
327 GTO 03
328♦LBL 02
329 360
330 RCL 55
331 -
332 STO 55
333♦LBL 03
334 RCL 41
335 RCL 42
336 +
```

```
337 2
338 /
339 STO 03
340 RTN
341◆LBL "LN"
342 XEQ "MP"
343 XEQ "S1P"
344 XEQ "S2P"
345 RCL 32
346 RCL 30
347 +
348 RCL 37
349 -
350 RCL 38
351 +
352 STO 45
353 RCL 33
354 RCL 31
355 +
356 RCL 37
357 -
358 RCL 39
359 +
360 STO 46
361 GTO "ADJ"
```

COMPUTES DISTANCES IN ws
FROM EST. POS. TO S1 S2 AND M

```
362◆LBL "ADJ"
363 RCL 37
364 STO 60
365 RCL 38
366 RCL 39
367 +
368 RCL 30
369 +
370 RCL 31
371 +
372 RCL 32
373 +
374 RCL 33
375 +
376 RCL 22
377 -
378 RCL 23
379 -
380 2
381 /
382 STO 61
383 RCL 60
384 -
385 STO 66
386 VIEW X
387 PSE
388 CLD
389 RCL 68
390 XEQ 07
391 .1
392 X>Y?
393 GTO "M P S2"
394 RCL 68
395 1.1
396 *
397 RCL 60
398 +
399 STO 63
400 RCL 63
401 RCL 22
402 +
403 RCL 30
404 -
405 RCL 32
406 -
407 STO 64
408 RCL 63
409 RCL 23
410 +
411 RCL 31
412 -
413 RCL 33
414 -
415 STO 65
416 RCL 64
417 STO 38
418 RCL 65
419 STO 39
420 RCL 63
421 STO 37
```

ITERATION CORRECTION AS DESCRIBED
ON LBL ADJ

```
422◆LBL "M P S2"
423 RCL 37
424 RCL 63
425 /
426 60
427 /
428 STO 53
429 RCL 39
430 RCL 03
431 /
432 60
433 /
434 STO 50
435 RCL 31
436 RCL 03
437 /
438 60
439 /
440 STO 48
441 RCL 50
442 COS
443 RCL 48
444 COS
445 *
446 CHS
447 RCL 53
448 COS
449 +
450 RCL 50
451 SIN
452 RCL 48
453 SIN
454 *
455 1/X
456 *
457 1
458 X<>Y
459 X>Y?
460 GTO 02
461 GTO 03
462◆LBL 02
463 1
464◆LBL 03
465 ACOS
466 STO 51
467 RCL 55
468 RCL 51
469 -
470 STO 56
471 0
472 X<>Y
473 X<=Y?
474 GTO 02
475 GTO 03
476◆LBL 02
477 360
478 RCL 56
479 +
480 STO 56
481◆LBL 03
482 180
483 RCL 56
484 X<=Y?
485 GTO "1H"
486 180
487 RCL 56
488 X>Y?
489 GTO "2H"
490◆LBL "2H"
491 1
492 STO 44
493 360
494 RCL 56
495 -
496 STO 52
497 GTO "SIDE C"
498◆LBL "1H"
499 -1
500 STO 44
501 RCL 56
502 STO 52
503 GTO "SIDE C"
```

DETERMINE DIMENSIONS AND ANGLES
FOR THE M-P-S2 TRIANGLE
SKETCH 2a

$$\cos C = \frac{\cos MP - \cos S_2P \cos BL_2}{\sin S_2P \sin BL_2}$$

```
504◆LBL "SIDE C"
505 90
506 RCL 28
507 -
508 STO 49
509 RCL 52
510 COS
511 RCL 50
512 SIN
513 *
514 RCL 49
515 SIN
516 *
517 RCL 50
518 COS
519 RCL 49
520 COS
521 *
522 +
523 ACOS
524 STO 64
```

DETERMINE SIDE C

$c = \cos^{-1}\left[\cos \angle C \sin S_2P \sin a + \cos S_2P \cos a\right]$

```
525◆LBL "ANG B"
526 RCL 49
527 COS
528 RCL 64
529 COS
530 *
531 CHS
532 RCL 50
533 COS
534 +
535 RCL 49
536 SIN
537 RCL 64
538 SIN
539 *
540 1/X
541 *
542 1
543 X<>Y
544 X>Y?
545 GTO 02
546 GTO 03
547◆LBL 02
548 1
549◆LBL 03
550 ACOS
551 STO 63
```

DETERMINE ANGLE B

$\angle B = \cos^{-1} \frac{\cos S_2P - \cos a \cos c}{\sin a \sin c}$

```
552◆LBL "COOP P"
553 RCL 63
554 RCL 44
555 *
556 RCL 29
557 +
558 STO 66
559 90
560 RCL 64
561 -
562 STO 65
563 RCL 65
564 STO 19
565 STO 69
566 RCL 66
567 STO 20
568 STO 70
569 FIX 4
570 "LAT LONG"
571 XEQ 06
572 RCL 19
573 HMS
574 VIEW X
575 PSE
576 CLD
577 RCL 20
578 HMS
579 VIEW X
580 PSE
581 CLD
582 RCL 45
583 RCL 22
584 -
585 VIEW X
586 PSE
587 CLD
588 XEQ 07
589 2
590 X<>Y
591 X<=Y?
592 GTO 02
593 GTO "LN"
594 GTO 03
595◆LBL 02
596 FIX 4
597 "LAT LONG"
598 XEQ 06
599 RCL 65
600 HMS
601 STO 78
602 VIEW 78
603 PSE
604 PSE
605 RCL 66
606 HMS
607 STO 79
608 VIEW 79
609 PSE
610 PSE
611 STOP
612◆LBL 03
613 STOP
```

TESTS TO DETERMINE IF ITD1
MATCHES ITD1 AS CALCULATED

IF TEST IS SATISFACTORY RESULT IS PRINTED
IF UNSATISFACTORY RETURN TO LBL LN

```
614◆LBL "S1P"
615 RCL 27
616 RCL 20
617 -
618 XEQ 07
619 COS
620 RCL 19
621 COS
622 *
623 RCL 26
624 COS
625 *
626 RCL 19
627 SIN
628 RCL 26
629 SIN
630 *
631 +
632 ACOS
633 60
634 *
635 RCL 03
636 *
637 STO 38
638 RTN
639◆LBL "S2P"
640 RCL 29
641 RCL 20
642 -
643 XEQ 07
644 COS
645 RCL 19
646 COS
647 *
648 RCL 28
649 COS
650 *
651 RCL 19
652 SIN
653 RCL 26
654 SIN
655 *
656 +
657 ACOS
658 60
659 *
660 RCL 03
661 *
662 STO 39
663 RTN
664◆LBL "MP"
665 RCL 02
666 RCL 20
667 -
668 XEQ 07
669 COS
670 RCL 01
671 COS
672 *
```

```
673 RCL 19
674 COS
675 *
676 RCL 01
677 SIN
678 RCL 19
679 SIN
680 *
681 +
682 ACOS
683 60
684 *
685 RCL 03
686 *
687 STO 37
688 RTN
689♦LBL 07
690 0
691 X<>Y
692 X<=Y?
693 GTO 02
694 GTO 03
695♦LBL 02
696 CHS
697♦LBL 03
698 RTN
699♦LBL 06
700 AVIEW
701 PSE
702 RTN
703 END
```

LBL 07 : IF NEG CHANGE SIGN

AVIEW PSE

```
01♦LBL "LOR DAT"
02 CLST
03 CLRG
04 "GRI NO?"
05 PROMPT
06 STO 00
07 "LAT M?"
08 PROMPT
09 HR
10 STO 01
11 "LONG M?"
12 PROMPT
13 HR
14 STO 02
15 "LAT W?"
16 PROMPT
17 HR
18 STO 03
19 "LONG W?"
20 PROMPT
21 HR
22 STO 04
23 "LAT X?"
24 PROMPT
25 HR
26 STO 05
27 "LONG X?"
28 PROMPT
29 HR
30 STO 06
31 "LAT Y?"
32 PROMPT
33 HR
34 STO 07
35 "LONG Y?"
36 PROMPT
37 HR
38 STO 08
39 "LAT Z?"
40 PROMPT
41 HR
42 STO 09
43 "LONG Z?"
44 PROMPT
45 HR
46 STO 10
47 "BLW?"
48 PROMPT
49 STO 11
50 "BLX?"
51 PROMPT
52 STO 12
53 "BLY?"
54 PROMPT
55 STO 13
56 "BLZ?"
57 PROMPT
58 STO 14
59 "CTD W?"
60 PROMPT
61 STO 15
62 "CTD X?"
63 PROMPT
64 STO 16
65 "CTD Y?"
66 PROMPT
67 STO 17
68 "CTD Z?"
69 PROMPT
70 STO 18
71 000.022
72 WDTAX
73 END
```

DATA REGISTERS

00	GRI No		50	S_2P-DEGREES
01	LAT M		51	$\angle C_1$
02		LONG M	52	$\angle C$
03	" W		53	MP-DEGREES
04		" W	54	BRG S_1M
05	" X		55	BRG S_2M
06		" X	56	BRG S_2P
07	" Y		57	
08		" Y	58	
09	" Z		59	
10		" Z	60	ADJ ROUTINE
11	BL W		61	" " "
12	" X		62	
13	" Y		63	USE LBLADJ9∠B
14	" Z		64	ADJ ROUTINE
15	CTD W		65	S1P & S2P
16	" X		66	
17	" Y		67	
18	" Z		68	ADJ ROUTINE
19	LAT P		69	TEMPORARY
20		LONG P	70	LAT/LONG
21			71	
22	ITD 1		72	
23	" 2		73	
24			74	
25			75	
26	LAT S_1		76	
27		LONG S_1	77	
28	" S_2		78	LAT P FINAL
29		" S_2	79	LONG P
30	BL 1		80	
31	BL 2		81	
32	CTD 1		82	
33	" 2		83	AVERAGE
34				VELOCITY FACTOR
35				
36				
37	CALCULATED MP			
38	" S_1P			
39	" S_2P			
40				
41	VELOCITY CONST.			
42	SEE REG 83			
43				
44	1H & 2H ROUTINE			
45	CALCULATED ITD1			
46	" ITD2			
47				
48	BL2-DEGREES			
49	SIDE a (90-LAT S_2)			

ADDENDUM

FOR MOST GRI CHAINS, CONVERGENCE TO A FINAL LAT/LONG SOLUTION CAN BE OBTAINED IN THREE TO FOUR ITERATIONS WITH CONSIDERABLE CONSISTENCY. THIS BY MAKING THE PROGRAM SENSITIVE TO THE CONSIDERABLE VARIATION IN RATES OF CHANGE. THIS IS PARTICULARLY EVIDENT WHEN COMPARING GRI 7960, FOR EXAMPLE, WITH GRI 5990.

IF INTERMEDIATE DISPLAYS ARE ELIMINATED (AT THE OPTION OF THE USER BY EDITING THEM OUT) THE TIME CAN BE CONSIDERABLY REDUCED.

```
29 SF 00   ──→   28♦LBL J
                 29 FIX 1
```

NEW LINE 29 IS ADDED

```
395 FS? 00
396 GTO "CC"
397 RCL 68
398 XEQ 07
399 30
400 X<>Y
401 X>Y?
402 GTO 02
403 XEQ 15
404 GTO 03
405♦LBL 02
406 1.1
407 STO 74
408♦LBL 03
409 GTO "AA"
410♦LBL 15
411 RCL 68
412 XEQ 07
413 15
414 X<>Y
415 X>Y?
416 GTO 02
417 XEQ 18
418 GTO 03
419♦LBL 02
420 1.2
421 STO 74
422♦LBL 03
423 GTO "AA"
424♦LBL 18
425 RCL 68
426 7.5
427 X<>Y
428 X>Y?
429 GTO 02
430 XEQ 19
431 GTO 03
432♦LBL 02
433 1.3
434 STO 74
435♦LBL 03
436 GTO "AA"
437♦LBL 19
438 RCL 68
439 3.75
440 X<>Y
441 X>Y?
442 GTO 02
443 XEQ 20
444 GTO 03
445♦LBL 02
446 1.4
447 STO 74
448♦LBL 03
449 GTO "AA"
450♦LBL 20
451 RCL 68
452 1.88
453 X<>Y
454 X>Y?
455 GTO 02
456 XEQ 21
457 GTO 03
458♦LBL 02
459 1.5
460 STO 74
461♦LBL 03
462 GTO "AA"
463♦LBL 21
464 RCL 68
465 1
466 X<>Y
467 X>Y?
468 GTO 02
469 1.6
470 STO 74
471 GTO 03
472♦LBL 02
473 2
474 STO 74
475♦LBL 03
476 GTO "AA"
477♦LBL "AA"
478 RCL 68
479 RCL 74
```

OMIT ORIGINAL LINES 394 AND 395
SUBSTITUTE NEW LINES 395 THRU 479

```
394 RCL 68
395 1.1
```

INSERT NEW LINES 787 THRU 791

```
787♦LBL "CC"
788 1.1
789 STO 74     ──→   792 RTN
790 CF 00            793 END
791 GTO "AA"
```

ADDENDUM
CONVERSION OF LORAN C DATA FOR THE HP 41

The following minor modification to the original program appears to reduce the number of iterations in some instances. This is particularly where great distances are involved and rapid rates of change.

```
394 RCL 68
395 RCL 73
396 *
397 RCL 60
```

LINE CHANGE

```
587 CLD
588 XEQ 07
589 STO 76
590 80
591 X<>Y
592 X>Y?
593 GTO 02
594 1.1
595 STO 73
596 GTO 03
597•LBL 02
598 .8
599 STO 73
600•LBL 03
601 RCL 76
602 2
```

LINES ADDED

Biography

The author is a native of Marquette, Michigan and an E.E. graduate of Michigan Tech. Most of his professional life has been spent in the electrical machinery and steel mill machinery business. Sailing and amateur radio have led to the present interest in LORAN. He is a licensed P.E. in Ohio and Washington.

TECHNICAL SESSION No. 4 - AVIATION TECHNOLOGY

Session Chairman - Robert D. Bronson
II Morrow, Inc.

SESSION CHAIRMAN

Mr. Bob Bronson

SPEAKERS

(l to r) Bob Bronson, Frank MacKenzie, Bill Polhemus (back)
Larry Cortland, Bob Erikson, Bob Lilley, Walt Dean

NASA TECHNICAL MEMORANDUM 97

OPERATIONAL CONSIDERATIONS FOR LORAN-C IN THE NON-PRECISION APPROACH PHASE OF FLIGHT

Ground monitor data collected at Galion and Athens, Ohio is presented, with assessment of correlation over the 90 nm between the two sites. Flight data collected on runways 7 and 25 at Ohio University airport is discussed in terms of nonprecision approach requirements; effects of waypoint resolution and receiver cycle-slip are noted. Comments are included on data collection methods.

by

Robert W. Lilley
Daryl L. McCall

Avionics Engineering Center
Department of Electrical and Computer Engineering
Ohio University
Athens, Ohio 45701

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NASA Langley Research Center
Hampton, Virginia 23665

and

Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591

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I. INTRODUCTION

There appear at this writing to be no major obstacles in the path toward public-use non-precision approaches (NPA) based on Loran-C signals. Much hard work remains, and a few key decisions, but any early mysteries in this area are gone.

The users, separately and through the various associations, have driven this evolution, and continue to provide assistance to USCG and FAA in development of criteria and procedures to take the best safe advantage of Loran-C capabilities. Past studies and measurements have established the accuracy of Loran-C; its suitability for accurate NPAs is not questioned from the standpoint of signal in space. The assurance of system performance from transmitter to cockpit display during the approach phase of flight does, however, require hardware and procedures changes related only indirectly to the 100 kHz pulses.

Initial approach experience will be obtained at, or very near, locations where Loran-C monitors are operating in an executive, "go/no-go" mode. Long- and short-term monitor data are now being collected by several organizations; final placement of ground monitors will be affected by the results obtained and correlated.

A determination must soon be made as to the specifications for the minimum Loran-C receiver which can be approved for IFR approach use. Such characteristics as waypoint and TD correction entry methods, error-detection delays, CDI scale factors, triad and station selection, waypoint resolution, propagation correction methods and receiver contribution to total error given a specified SNR are examples. It is highly unlikely that multiple "categories" of Loran-C approaches will appear, based on receiver design. Therefore, the approach minima which become available depend upon the performance of the minimum receiver.

Air Traffic Control (ATC) procedures will impact, and be impacted by, Loran-C approach use. Transition from a primary navigation system to the supplemental Loran-C system will require an integrity check of the receiver prior to approach initiation. This receiver check must reliably tie the Loran-C navigation outputs to the primary system as a reference.

A variety of ancillary requirements for approach establishment must be considered, lest the availability of Loran-C approaches be oversold. Basic TERPS [2] criteria for obstacle clearance, runway markings and lighting, altimeter setting information and ATC communications may not be met at many small airports without some additional expense. These criteria relate to all types of instrument approaches, not just Loran-C.

This paper presents interim results on monitor data correlation, comments on waypoint resolution and receiver integrity checks, flight data-collection methods, and identification of several ancillary issues which must be faced in selection of runways appropriate for Loran-C approaches.

II. GROUND MONITORING

The Ohio University Avionics Engineering Center is operating Loran-C ground monitors at Galion, OH Municipal Airport and at Ohio University Airport, Athens/Albany, OH. The Galion monitor is a Northstar 6000 receiver, while the ARNAV-1000 is used at Athens. It is intended to operate both monitors for a full year; approximately three months' data are in hand. The summer months are characteristically quiet, as regards large, proper TD variations; localized thunderstorm activity appears, however.

Figures 1 through 6 show one week's interim data from both monitors. Note that the TD baseline is arbitrary here, to keep the TD trace on the chart. Later analysis will, of course, apply a similarly-modeled baseline to both monitor TD outputs. The MYZ triad for chain 9960 is shown, since this is the primary triad for both airports. Expected diurnal SNR reductions are seen; processing differences in the dissimilar receivers account for the characteristic difference in TD traces.

The significant observation to date is the relative immunity of TD quality to momentary or diurnal changes in SNR. It is anticipated that convincing arguments may be made for future relaxation of the initial zero-dB criterion for approach use of Loran-C.

The FAA Airport Screening Model [1] was run for each monitor site to obtain 'standard' TD values, for comparison with measured values. Table I gives the results for Galion and Athens.

Table I: Sample Monitor Data for June, 1985
(ASM - Airport Screening Model)

Monitor	Survey Location	ASM TDs	Monitor TDs	Diff
Galion	40 45 06.758	43285.54	43287.30	+1.76 us (1287.1 ft)
	82 43 41.863	56760.04	56760.60	+0.56 us (277.3 ft)
Athens	39 12 43.688	42526.07	42526.63	+0.56 us (367.9 ft)
	82 13 37.750	56693.32	56691.75	-1.57 us (862.4 ft)

Given the angles of the TD-Y and TD-Z lines of position at Galion and Athens, these differences correspond to position bias values (considering only the two receivers used) of 0.18 nm, bearing 030.1 degrees at Galion, and 0.13 nm, bearing 284.5 degrees at Athens.

These bias values, while dissimilar at these two points some 90 nm apart, are stable. This is shown by the monitor data collected thus far, and indicates that the Athens value could be predicted by the Galion value, or vice versa. It remains to be seen whether this relation holds throughout the year, and to what degree, statistically, the prediction is valid.

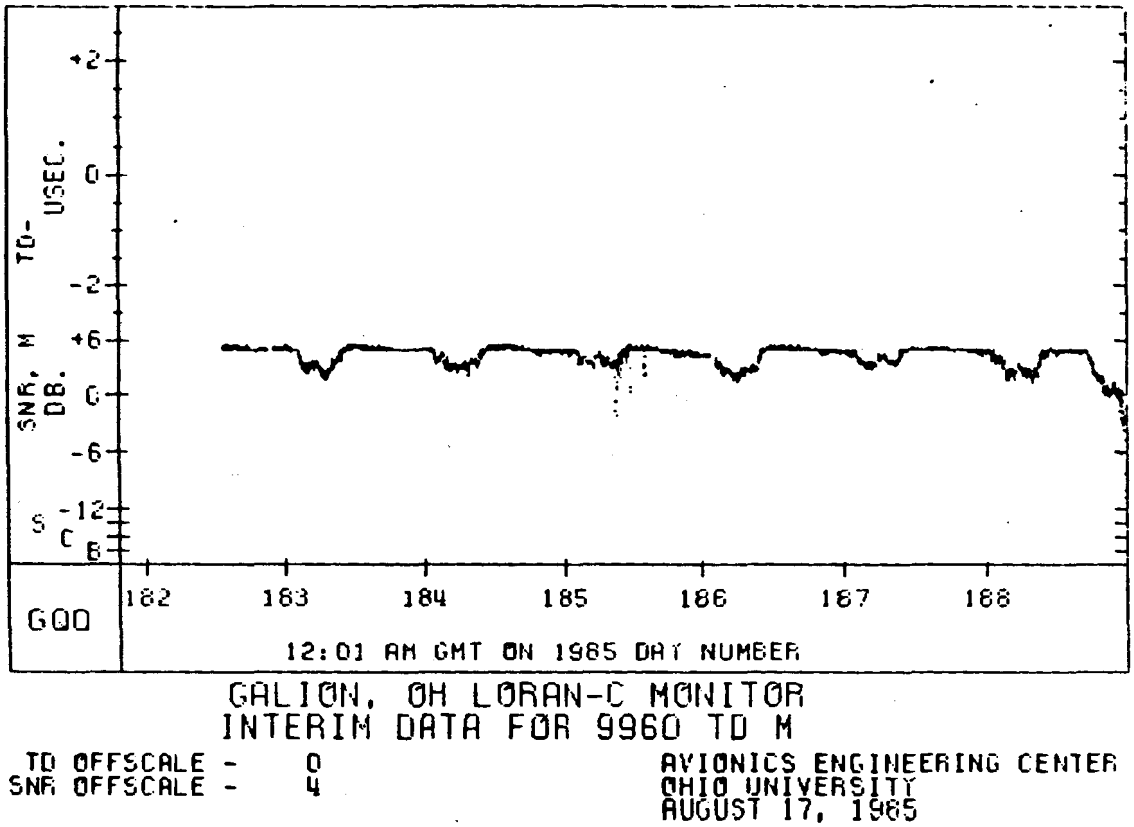


Figure 1. Galion, Ohio Loran-C Monitor Interim Data for 9960 TD M; August 17, 1985.

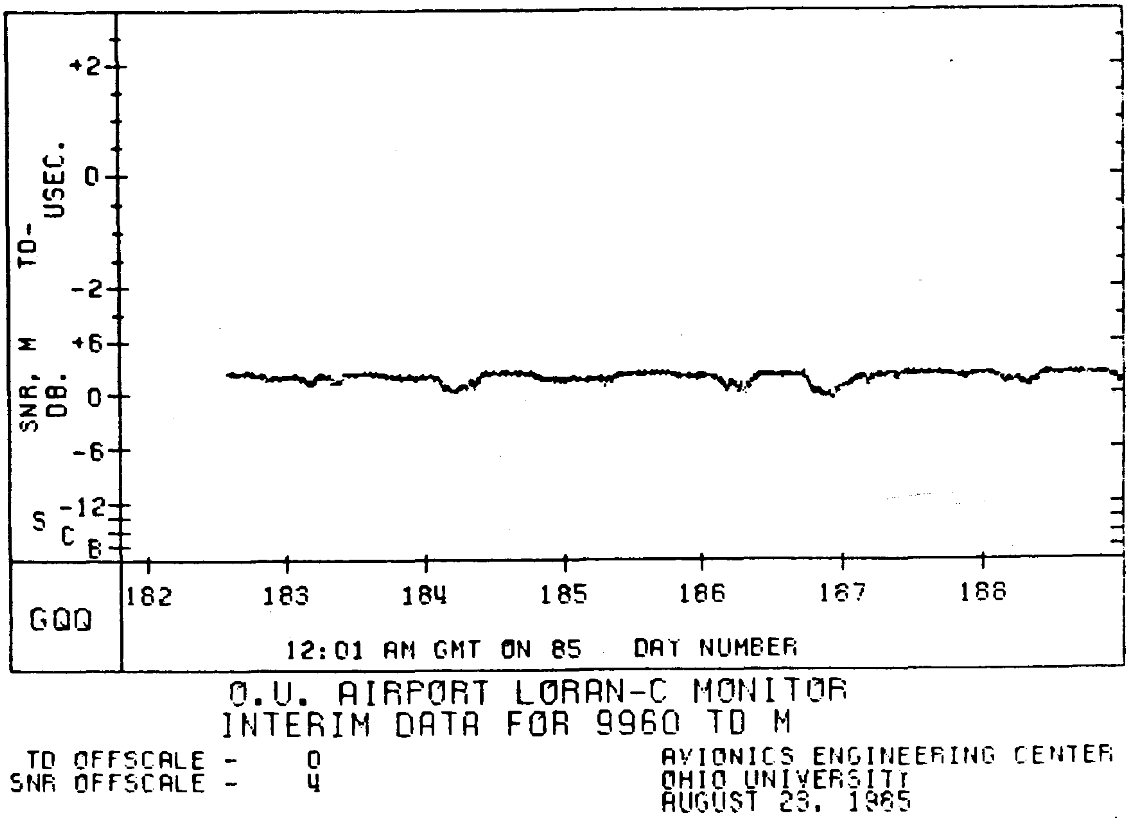


Figure 2. O. U. Airport Loran-C Monitor Interim Data for 9960 TD M; August 23, 1985.

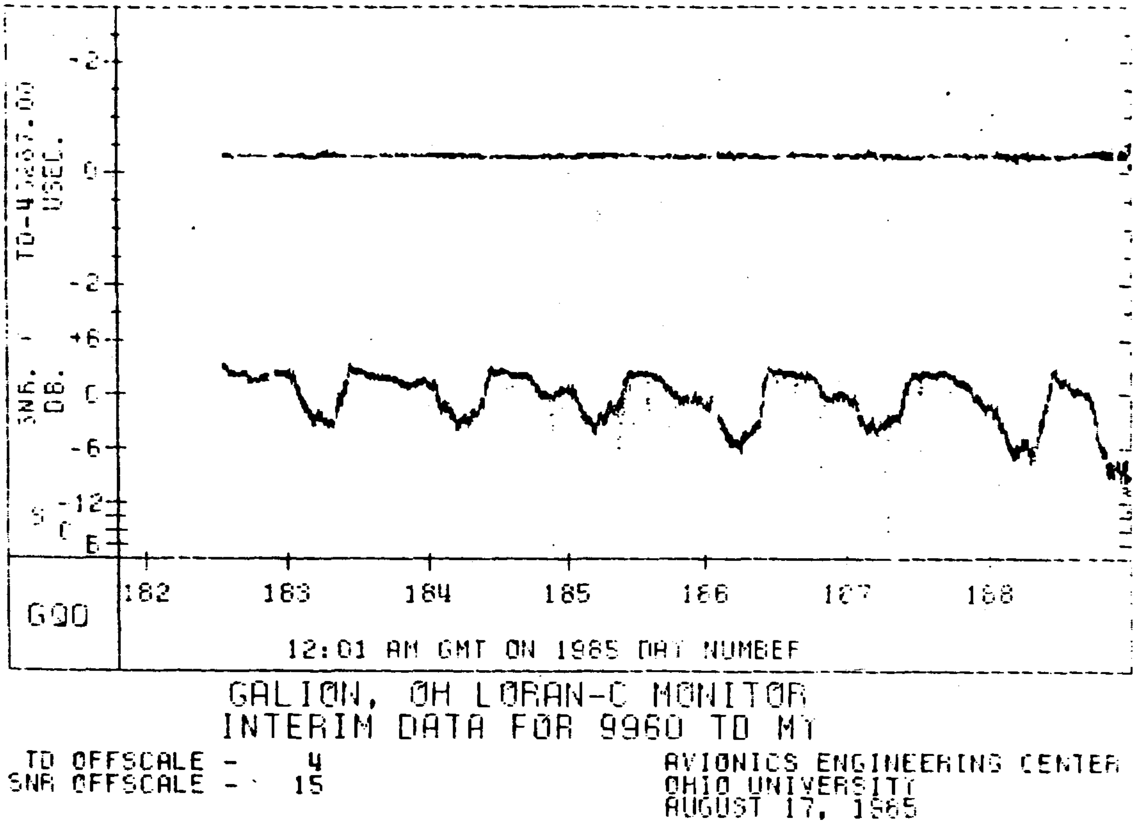


Figure 3. Galion, Ohio Loran-C Monitor Interim Data for 9960 TD MY; August 17, 1985.

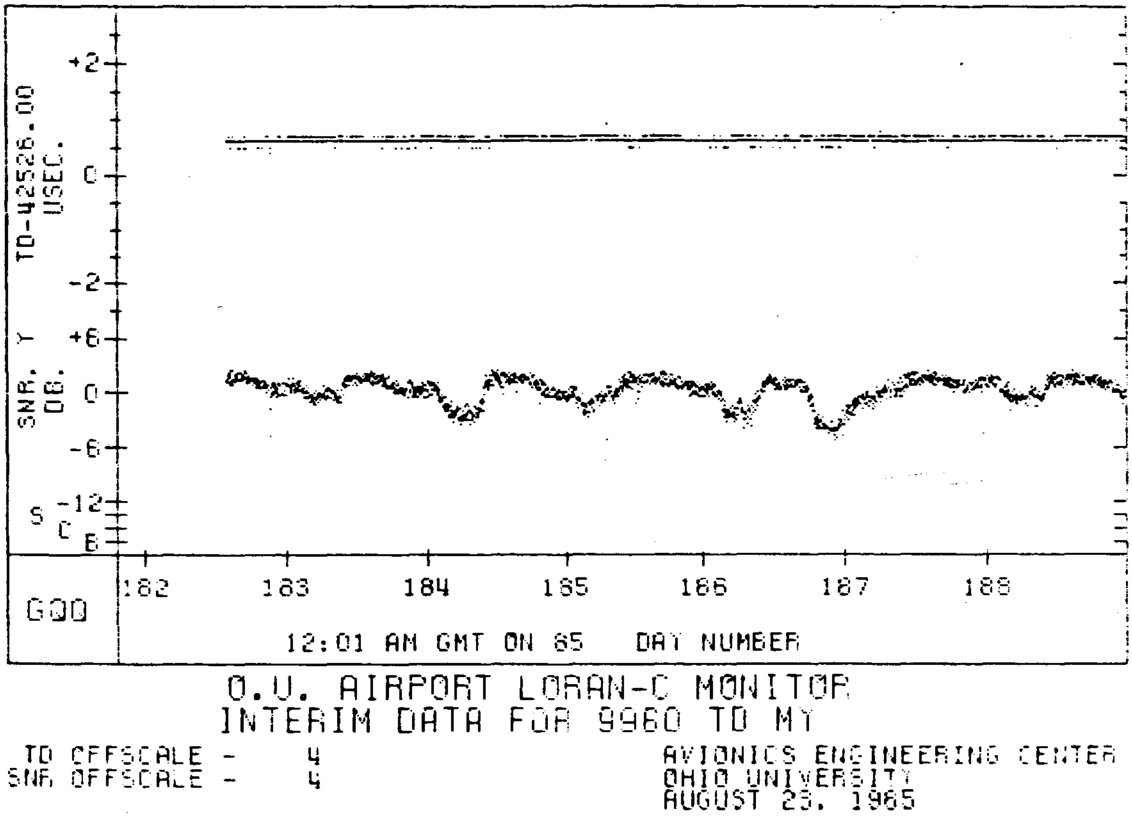


Figure 4. O. U. Airport Loran-C Monitor Interim Data for 9960 TD MY; August 23, 1985.

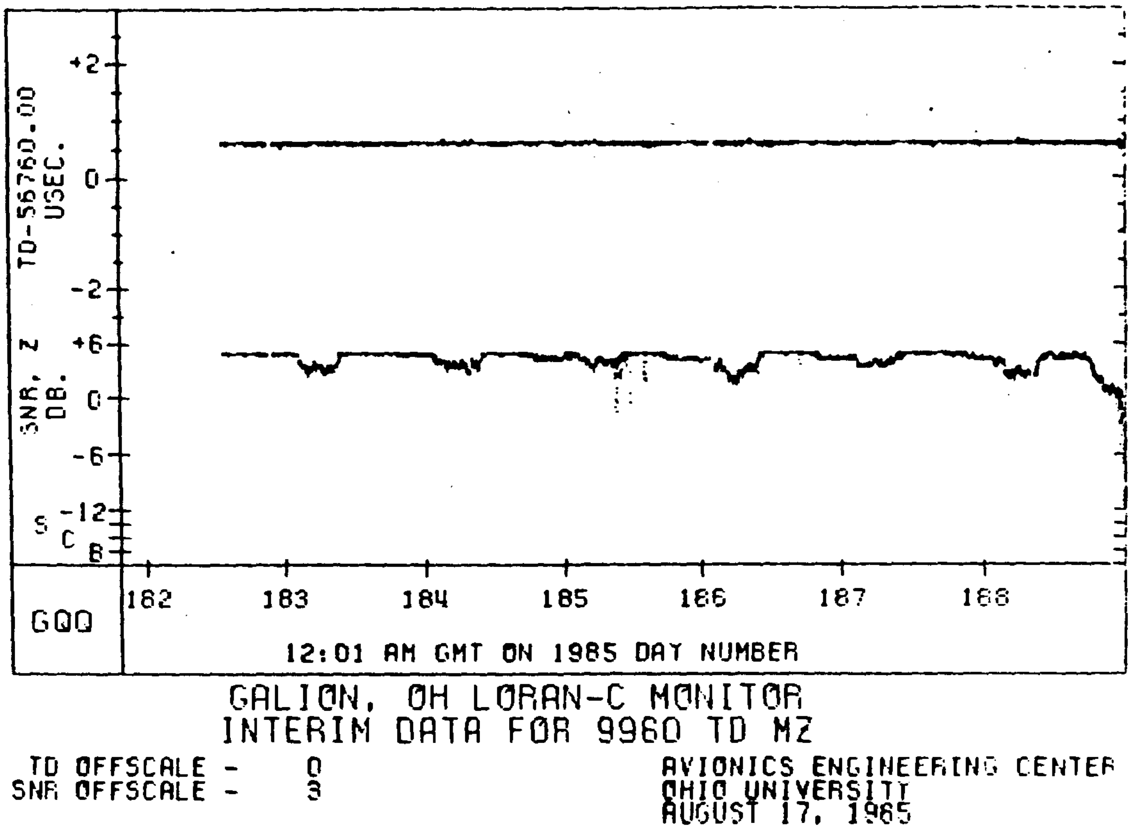


Figure 5. Galion, Ohio Loran-C Monitor Interim Data for 9960 TD MZ; August 17, 1985.

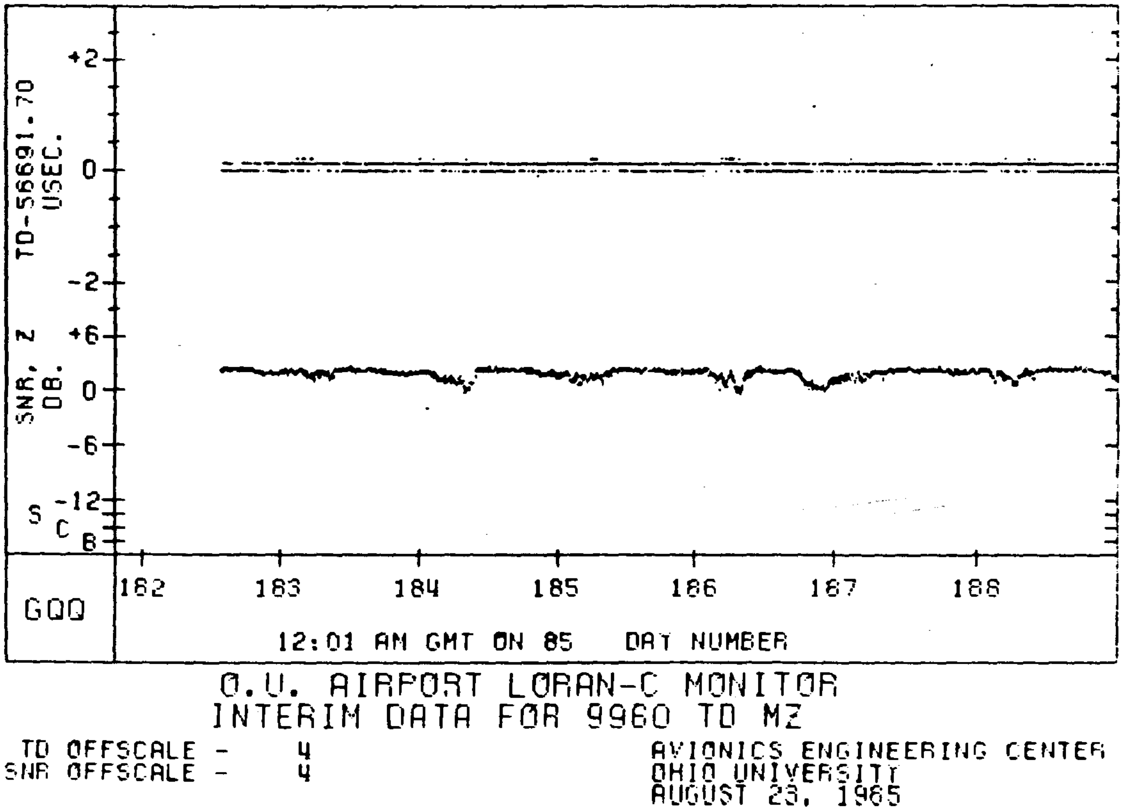


Figure 6. O. U. Airport Loran-C Monitor Interim Data for 9960 TD MZ; August 23, 1985.

Monitors are being installed by FAA at Mansfield, OH and at Columbus. These monitor units will be identical, and correlation of data will take place over a distance similar to the Athens-Galion monitors. Comparison among monitors will provide additional insight into the degree of co-variation observed over such distances, as fall and winter approach and variations increase.

III. SUMMARY OF GROUND AND FLIGHT MEASUREMENTS

Flight evaluations have been carried out at Galion and Athens, to assess the degree to which monitors at both locations predict the actual bias errors observed on approach. At Athens, flights to a waypoint at the runway 25 threshold consistently show the uncorrected Loran-C approach path to be 0.13 nm to the left of runway centerline, and 0.1 nm outside threshold, along centerline. The Athens monitor, using the Airport Screening Model as a reference, generated data which would result in corrections of -1.57 us to the Z TD, and 0.56 us in Y. Applying the correction to the flight data, the resulting Loran-C corrected approach waypoint moved to a point exactly abeam threshold, offset 0.047 nm or 285.6 feet to the left of centerline.

Galion monitor data vs. flight data have not yet been completely analyzed, but preliminary results appear similar to those just described for Athens.

A. Receivers: Waypoint Resolution

Waypoint resolution, once determined either by FAA published coordinates or by receiver manufacturers, obviously causes predictable error at any specified waypoint location. In Ohio, for example, the earth's geometry results in slightly less than 0.1 nm position error for each 0.1 minute error in waypoint specification.

Waypoint resolution of 0.1 minute in latitude and longitude results in error of ^{0}.05 minute, maximum. For the 9960-MYZ triad in Ohio, position errors compared with a first-order survey position can be on the order of 300 feet north-south and 230 feet east-west. Ohio enjoys good Loran-C geometry, however, and resolution errors can increase significantly at larger distances from the Loran-C baselines.

The resolution issue is tightly associated with cockpit workload concerns related to waypoint data entry. Receiver data bases ease this workload considerably, and permit additional precision to be introduced into waypoint definitions.

B. Receivers: Pre-Approach Integrity Check

Loran-C approaches will likely be commissioned with an operational requirement that the pilot conduct a receiver integrity check prior to beginning the approach. This check must provide assurance that no receiver-related inaccuracies are present, due to cycle-slip or other problems.

Primary navigation systems against which the Loran-C receiver must be checked are include VOR, VOR/DME, Radar, or Nondirectional Beacons. Each primary system has unique characteristics which affect the result, or the workload associated with the result.

Effects of cycle slip are predictable; tests run at Ohio University showed at least a 1.0-mile offset for each 10-us slip on any one station in the 9960-MYZ triad. In the best Loran-C case, where the aircraft is on a baseline, the minimum position offset for a 10-usec slip on one of the stations forming the baseline, is approximately 0.8 nautical mile.

Radar fixes are considered to be accurate to 500 feet or 3% of the distance between the radar and the aircraft. Geometry suggests that a radar fix more than 17 miles from the radar site would result in 0.5 nm detectable error. A pilot within this range could request a position verification from the controller. The controller does not presently see the target latitude and longitude, so his fix information must be a relative bearing and distance from a primary navaid, or two bearings from such navaids. The pilot must then compare these numbers with the Loran-C receiver outputs of bearing or bearing and distance to waypoints laid over those same primary navaids. Much communications time and cockpit workload result.

A Loran-C receiver check by overflying a VOR or VORTAC station requires the pilot to overfly the station with a miss distance of less than 0.5 nm, and to judge the time between VOR and Loran-C to-from flag motion as a measure of along-track error. Cockpit workload and distraction are factors.

The most direct methods for obtaining an integrity check appear to be comparison of Loran-C output with bearing and distance outputs from the VOR and DME equipment aboard the aircraft. Alternatively, two VOR radials may be used, with the two VOR positions entered as Loran-C waypoints.

DME provides an accuracy of 1/2 nm or 3% of the distance from DME to aircraft, and VOR radials are considered accurate to 3.6 degrees when used as a cross-fix, and 4.5 degrees along-track. Using these figures, a pilot would be required to integrity-check his Loran-C receiver within 6.4 nm of a VOR used for VOR/DME reference or along-track angle reference, and within 10 nm of a VOR used as a cross-fix angular reference.

IV. FLIGHT DATA-COLLECTION METHODS

Loran-C approaches require the same design and maintenance activities as other types of instrument approach. Pre-commissioning flight data are necessary, as are periodic flight inspections, measuring signal quality and freedom from interference, as well as correct alignment of the approach path, with respect to obstacle clearance.

The Avionics Engineering Center routinely conducts flight measurement missions, evaluating a variety of navigation aids for engineering studies. It has been found, over a period of two decades, that traditional ground-truth systems are less critical to accurate and repeatable results in some applications. The azimuth-only guidance regime is one of these cases. Anticipating a large number of Loran-C approach applications, some reliable method for accepting user-input data prior to the initial FAA flight inspection can save time and cost.

Visual cues alone can result in accurate flight paths, evidencing less than 0.2 degree errors during a five-mile approach or level pass along the extended centerline. Figure 7 shows a portion of a typical centerline flight, made during Loran-C evaluations. The pass was tracked by an optical theodolite located on centerline, 75 feet beyond the stop end of a 4200-foot runway. Raw tracker azimuth values indicate the flight path, and GXTE (column 7) gives the resulting flight-technical cross-track error (FTE). This is a typical run, showing that FTE cross-track values can be controlled to 0.01 nm or below.

Other data columns in figure 7 include raw tracker elevation and range in meters, a go/no-go flag, and the raw Loran-C cross-track and distance-to-go to the threshold. Computed values include cross-track error and distance to go computed from ground tracker data. Residual values are the along-track and cross-track error values for the Loran-C approach-guidance signal. Flags include cross-track error sign, distance sign, and data flag, all generated by the Loran-C receiver.

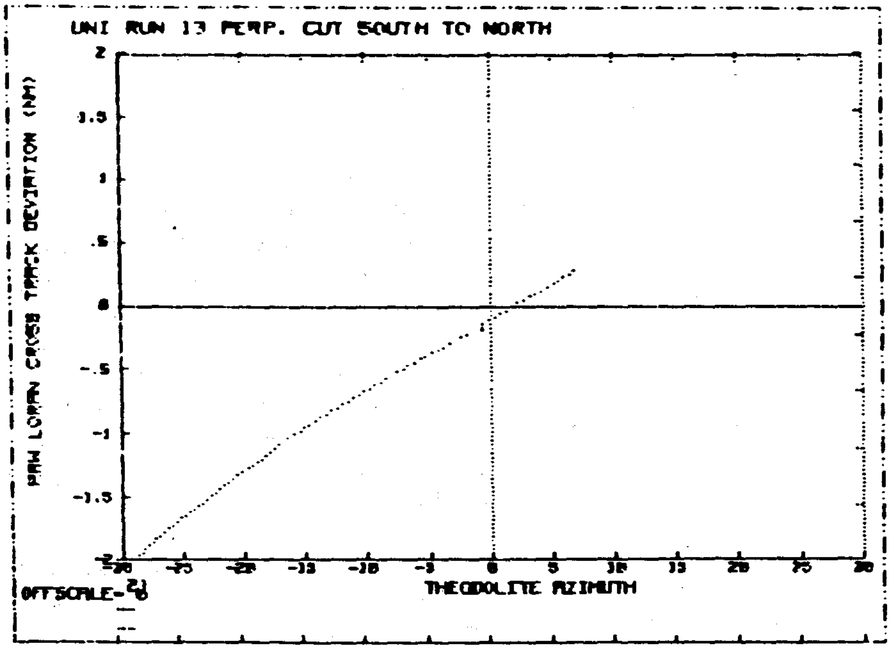
Figure 8 illustrates a flight perpendicular to centerline, made to verify lateral coverage of the Loran-C signal. In this case, it is obvious that no 'false paths' will be found to the left side of the approach path. A similar run to the right showed similar results, on a separate graph. Two passes were required due to aircraft data-link antenna pattern restrictions, since corrected by use of a less directional airborne antenna.

```
FILE: 3
DATE: 07-MAY-85
AIRPORT: UNI RUN 7 HIGH GAIN 15 INCHES
RUNWAY: 25
THEODOLITE OFFSET    75
RUNWAY LENGTH        4200.9

--------GROUND-------- ----AIR----  --COMPUTED--     --RESIDUAL-- --FLAGS--
 AZIM  ELEV  RANGE G/N XTEA   DTGA  GXTE    GRNG      ATED     XTED XF DF DAF

  .02  2.37 13670 1   .04    6.70   .003   6.671      .029     .037 3  0  0
  .02  2.33 13354 1  -.08    6.50   .003   6.501    -.001    -.083 0  0  0
  .03  2.31 13298 1  -.10    6.50   .004   6.471      .029   -.104 0  0  0
  .08  1.98 12886 1  -.15    6.20   .010   6.250    -.050    -.160 0  0  0
  .07  1.98 12829 1  -.15    6.20   .008   6.219    -.019    -.158 0  0  0
  .09  1.95 12411 1  -.13    5.90   .011   5.994    -.094    -.141 0  0  0
  .09  1.95 12351 1  -.12    5.90   .010   5.961    -.061    -.130 0  0  0
  .11  2.02 11644 1  -.09    5.50   .012   5.579    -.079    -.102 0  0  0
  .10  2.09 11157 1  -.09    5.20   .011   5.316    -.116    -.101 0  0  0
  .06  2.17 10724 1  -.09    5.00   .006   5.082    -.082    -.096 0  0  0
  .06  2.19 10663 1  -.09    5.00   .006   5.049    -.049    -.096 0  0  0
  .06  2.20 10598 1  -.09    4.90   .006   5.014    -.114    -.096 0  0  0
  .07  2.25 10225 1  -.09    4.70   .007   4.813    -.113    -.097 0  0  0
  .07  2.26 10161 1  -.09    4.70   .007   4.778    -.078    -.097 0  0  0
  .07  2.28 10098 1  -.09    4.70   .007   4.744    -.044    -.097 0  0  0
  .10  2.32  9715 1  -.09    4.40   .009   4.537    -.137    -.099 0  0  0
  .10  2.34  9650 1  -.09    4.40   .009   4.502    -.102    -.099 0  0  0
  .10  2.36  9586 1  -.09    4.40   .009   4.468    -.068    -.099 0  0  0
  .10  2.37  9523 1  -.08    4.30   .009   4.434    -.134    -.089 0  0  0
  .10  2.37  9455 1  -.08    4.30   .009   4.397    -.097    -.089 0  0  0
  .10  2.38  9391 1  -.08    4.30   .009   4.362    -.062    -.089 0  0  0
  .10  2.39  9326 1  -.08    4.20   .009   4.327    -.127    -.089 0  0  0
  .10  2.39  9259 1  -.08    4.20   .009   4.291    -.091    -.089 0  0  0
  .10  2.39  9195 1  -.08    4.20   .009   4.257    -.057    -.089 0  0  0
  .11  2.39  9127 1  -.09    4.10   .009   4.220    -.120    -.099 0  0  0
  .11  2.39  9061 1  -.09    4.10   .009   4.184    -.084    -.099 0  0  0
  .12  2.39  8995 1  -.09    4.10   .010   4.149    -.049    -.100 0  0  0
  .12  2.40  8928 1  -.09    4.00   .010   4.113    -.113    -.100 0  0  0
  .12  2.41  8863 1  -.09    4.00   .010   4.077    -.078    -.100 0  0  0
  .12  2.41  8798 1  -.09    4.00   .010   4.042    -.042    -.100 0  0  0
  .13  2.41  8732 1  -.09    3.90   .011   4.007    -.107    -.101 0  0  0
  .13  2.41  8664 1  -.09    3.90   .011   3.970    -.070    -.101 0  0  0
  .12  2.41  8598 1  -.09    3.80   .010   3.935    -.135    -.100 0  0  0
  .12  2.40  8534 1  -.09    3.80   .010   3.900    -.100    -.100 0  0  0
  .08  2.33  8137 1  -.11    3.60   .006   3.686    -.086    -.116 0  0  0
  .06  2.32  8070 1  -.11    3.60   .005   3.650    -.050    -.115 0  0  0
 -.02  2.44  7599 1  -.12    3.30  -.001   3.396    -.096    -.119 0  0  0
 -.04  2.46  7533 1  -.12    3.30  -.003   3.360    -.060    -.117 0  0  0
 -.06  2.53  7064 1  -.12    3.00  -.004   3.107    -.107    -.116 0  0  0
 -.04  2.56  6754 1  -.13    2.80  -.003   2.939    -.139    -.127 0  0  0
 -.04  2.49  6530 1  -.13    2.70  -.002   2.819    -.119    -.128 0  0  0
 -.02  2.41  6213 1  -.12    2.60  -.001   2.648    -.048    -.119 0  0  0
  .01  2.32  5940 1  -.12    2.40   .001   2.501    -.101    -.121 0  0  0
  .04  2.21  5593 1  -.12    2.20   .002   2.314    -.114    -.122 0  0  0
  .04  2.20  5522 1  -.12    2.20   .002   2.276    -.076    -.122 0  0  0
  .04  2.19  5455 1  -.12    2.20   .002   2.239    -.039    -.122 0  0  0
  .04  2.18  5383 1  -.12    2.10   .002   2.201    -.101    -.122 0  0  0
  .03  2.18  5313 1  -.12    2.10   .002   2.163    -.063    -.122 0  0  0
  .03  2.17  5245 1  -.12    2.00   .001   2.126    -.126    -.121 0  0  0
  .02  2.17  5174 1  -.12    2.00   .001   2.088    -.088    -.121 0  0  0
  .03  2.15  4965 1  -.12    1.90   .001   1.975    -.075    -.121 0  0  0
  .03  2.14  4894 1  -.12    1.90   .001   1.937    -.037    -.121 0  0  0
  .02  2.13  4822 1  -.12    1.80   .001   1.898    -.098    -.121 0  0  0
 -.02  2.01  4402 1  -.13    1.60  -.001   1.672    -.072    -.129 0  0  0
 -.02  2.00  4333 1  -.13    1.60  -.001   1.634    -.034    -.129 0  0  0
 -.02  1.98  4264 1  -.13    1.50  -.001   1.597    -.097    -.129 0  0  0
  .03  1.86  3849 1  -.13    1.30   .001   1.373    -.073    -.131 0  0  0
  .05  1.82  3780 1  -.13    1.30   .002   1.336    -.036    -.132 0  0  0
  .01  1.67  3296 1  -.13    1.00  0.000   1.075    -.075    -.130 0  0  0
  .01  1.66  3225 1  -.13    1.00  0.000   1.037    -.037    -.130 0  0  0
  .01  1.50  2744 1  -.13     .70  0.000    .777    -.077    -.130 0  0  0
  .02  1.50  2676 1  -.13     .70   .001    .741    -.041    -.131 0  0  0
 0.00  1.55  2540 1  -.13     .60  0.000    .667    -.067    -.130 0  0  0
 -.03  1.45  2132 1  -.13     .40  -.001    .447    -.047    -.129 0  0  0
 -.03  1.38  2064 1  -.13     .40  -.001    .410    -.010    -.129 0  0  0
  .01   .93  1583 1  -.14     .20  0.000    .151      .049   -.140 0  0  0
  .01   .81  1515 1  -.14     .10  0.000    .114    -.014    -.140 0  0  0
  .09   .23  1031 1  -.14    -.30   .001   -.147      .153   -.141 0  3  0
  .08   .14   715 1  -.15    -.40   .001   -.318      .082   -.151 0  3  0
  .12   .40   493 1  -.15    -.50   .001   -.438      .062   -.151 0  3  0
  .10  1.57   183 1  -.15    -.70  0.000   -.605      .095   -.150 0  3  0
```

Figure 7. Portion of a Typical Centerline Flight Made During Loran-C Evaluations.



```
FILE: 9
DATE: 07-MAY-85
AIRPORT: UNI RUN 13 PERP. CUT SOUTH TO NORTH
RUNWAY: 25
THEODOLITE OFFSET      75
RUNWAY LENGTH          4200.9

 --------GROUND--------  ----AIR----   --COMPUTED--       --RESIDUAL--  --FLAGS--
 AZIM   ELEV  RANGE G/N  XTEA    DTGA  GXTE     GRNG      ATED     XTED  XF  DF  DAF

  6.93   3.86  5848  1    .27    2.30   .380    2.424     -.153    -.110 3   0   0
  6.62   3.85  5840  1    .24    2.30   .363    2.421     -.148    -.123 3   0   0
  6.14   3.85  5832  1    .22    2.30   .336    2.420     -.143    -.116 3   0   0
  3.43   3.92  5804  1    .07    2.30   .187    2.417     -.124    -.117 3   0   0
  2.96   3.92  5800  1    .04    2.30   .161    2.416     -.122    -.121 3   0   0
  2.47   3.93  5798  1    .02    2.30   .135    2.417     -.120    -.115 3   0   0
  2.02   3.94  5799  1   -.01    2.30   .110    2.418     -.120    -.120 0   0   0
  1.54   3.95  5797  1   -.04    2.30   .084    2.418     -.119    -.124 0   0   0
  1.09   3.95  5798  1   -.06    2.30   .059    2.419     -.119    -.119 0   0   0
   .63   3.90  5796  1   -.09    2.30   .034    2.418     -.118    -.124 0   0   0
   .14   3.89  5796  1   -.11    2.30   .008    2.418     -.118    -.118 0   0   0
  -.32   3.86  5800  1   -.14    2.30  -.017    2.421     -.121    -.123 0   0   0
 -1.71   3.81  5804  1   -.22    2.30  -.093    2.422     -.123    -.127 0   0   0
 -2.18   3.79  5811  1   -.24    2.30  -.119    2.425     -.128    -.121 0   0   0
 -2.64   3.75  5814  1   -.27    2.30  -.144    2.425     -.130    -.126 0   0   0
 -3.10   3.72  5819  1   -.29    2.30  -.170    2.427     -.133    -.120 0   0   0
 -3.56   3.70  5824  1   -.32    2.30  -.195    2.428     -.136    -.125 0   0   0
 -4.52   3.66  5833  1   -.36    2.40  -.248    2.429     -.042    -.112 0   0   0
 -4.96   3.66  5840  1   -.39    2.40  -.272    2.431     -.046    -.118 0   0   0
 -5.41   3.66  5849  1   -.41    2.40  -.297    2.434     -.052    -.113 0   0   0
 -5.86   3.66  5857  1   -.44    2.40  -.322    2.436     -.057    -.118 0   0   0
 -6.30   3.67  5863  1   -.46    2.40  -.347    2.436     -.061    -.113 0   0   0
 -6.75   3.67  5875  1   -.49    2.40  -.372    2.440     -.068    -.118 0   0   0
 -7.19   3.67  5881  1   -.51    2.40  -.397    2.440     -.072    -.113 0   0   0
 -7.65   3.65  5890  1   -.54    2.40  -.423    2.442     -.078    -.117 0   0   0
 -8.11   3.63  5900  1   -.56    2.40  -.449    2.444     -.084    -.111 0   0   0
 -8.54   3.62  5908  1   -.59    2.40  -.473    2.444     -.090    -.117 0   0   0
 -9.00   3.60  5919  1   -.61    2.40  -.499    2.447     -.097    -.111 0   0   0
 -9.44   3.60  5931  1   -.64    2.40  -.524    2.449     -.104    -.116 0   0   0
 -9.89   3.58  5946  1   -.66    2.50  -.550    2.453     -.014    -.110 0   0   0
-10.31   3.56  5960  1   -.69    2.50  -.575    2.456     -.023    -.115 0   0   0
-10.77   3.55  5976  1   -.71    2.50  -.602    2.460     -.033    -.108 0   0   0
```

Figure 8. Illustration of a Flight Made Perpendicular to Centerline, Made to Verify Lateral Coverage of the Loran-C Signal.

V. OTHER OPERATIONAL TOPICS

An instrument approach, no matter which guidance signal is used, requires access to ancillary support systems to insure reliability and safety. It is appropriate to predict that Loran-C will permit non-precision approaches to rural airports at low cost, but to be realistic, the costs must include provision or upgrade of support systems where required. In most cases, lack of support does not prohibit establishment of an approach, it just causes increased minima. In the limit, of course, the IFR approach makes no sense if its minima require VFR conditions.

An altimeter setting is required before commencing an instrument approach. If the altimeter used is more than five miles from threshold, TERPS criteria require a five-foot MDA increase for each additional mile. Providing altimeter setting on approach may involve either the cost of personnel or automated equipment, at the airport site.

Runway lighting is necessary, to avoid restriction of the approach to daytime only. Approved runway markings are required, to permit straight-in minimum MDA rather than a circling-only approach with higher MDA.

ATC communications are required at the initial approach fix altitude. If VHF communications are not available throughout the approach, then telephone communications are required at the airport for filing and closing flight plans.

Use of Loran-C does not preclude the use of step-down fixes at NDBs or marker beacons; these can often permit lower minima, but at some capital and recurring cost. Provision of approach lighting systems does increase visibility credit and may lower minima.

VI. CONCLUSIONS

Loran-C ground monitors must be provided for local-area assurance of signal integrity on approach. Specific tolerances on Loran-C signal variations permissible during approach operations will be set; local signal characteristics may require different tolerances at different locations. Range of monitor validity has yet to be determined, in the general case.

Loran-C receiver integrity checks will be required, and must be made rather near the associated primary navaid. It is not yet certain how much time may elapse between the integrity check and the initiation of the approach. More study is needed.

Waypoint resolution, currently set at 0.1 minute of latitude and longitude, should be sufficient for Loran-C NPAs; use of receiver data bases can permit added resolution, however, and reduce workload.

Flight data can be obtained without a ground-truth tracker system which is accurate enough for precommissioning approach-design studies.

The process of establishing Loran-C non-precision approaches must not be permitted to choke off future technical and procedural evolution. Initial operations will, of necessity, be conservative, even limited. The experience gained in the next few years will certainly point to refinements and improvements in both ground and airborne regimes. Active pseudo-differential use of monitor data, multiple-triad approaches, reduction in required SNR and inclusion of VNAV as an element of approach guidance are a few areas where Loran-C approach improvements can be made without changes in the basic design philosophy.

VII. REFERENCES

[1] M. B. El-Arini, "Airport Screening Model for Nonprecision Approaches using Loran-C Navigation, Document MTR-83W180, MITRE Corporation, McLean, VA, May, 1984.

[2] "United States Standard for Terminal Instrument Procedures," Department of Transportation, July, 1976.

[3] "Approval of Area Navigation Systems for Use in the U. S. National Airspace System," AC 90-45A, Department of Transportation, 1976.

Biographies

Robert W. Lilley, Ph. D., is Deputy Director of the Avionics Engineering Center, Ohio University, Athens, Ohio. His research and engineering activities have ranged from the early ECHO satellites to Omega, VOR, MLS and Loran-C systems. An active commercial, instrument-rated pilot, he has conducted flight measurements in support of Loran-C non-precision approaches in Ohio, directed sensor and navigation processor design and implementation for Loran-C receivers and is currently involved in the performance-assurance aspects of Loran-C for approach use.

Daryl L. McCall, MSEE, is a Project Engineer for the Avionics Engineering Center, specializing in point-positioning navigation systems. Current activities center on Loran-C non-precision approach operations, GPS and differential GPS ground and airborne evaluation systems. Mr. McCall is a student pilot.

Title: Results of Loran C Flight Tests at Bedford, Massachusetts

Author: Robert H. Erikson
FAA Technical Center
Atlantic City Airport, NJ 08405

ABSTRACT

The National Association of State Aviation Officials (NASAO) has requested the Federal Aviation Administration (FAA) approve Loran C for nonprecision approaches. To this end a joint effort is being conducted to collect the necessary data to obtain approval. The first phase of the effort is known as the pilot or implementation phase one and is intended to gain operational experience from a limited number of aircraft and airports. At present, the tests will be limited to eight airports. The program involves the installation of local area Loran C monitors, establishment of approach procedures, and the training through experience of various FAA personnel, manufacturers, and pilots. The FAA Technical Center has been asked to fly at each of the selected airports to verify: the data being collected by the monitor agrees with actual airborne data, the signals in space are sufficient for navigation and the designed approach procedure is flyable. Results of flight data collected at Bedford, Massachusetts are presented in this paper.

OBJECTIVE

Collaborate with the Aviation Standards National Field Office (AVN) to establish flight inspection criteria for Loran C nonprecision approaches in an evaluation program limited to eight airports and selected users. Issues to be addressed are approach plate/procedure validation, accuracy/area calibration validation and signal quality validation.

BACKGROUND

The National Association of State Aviation Officals (NASAO) has requested the Federal Aviation Administration (FAA) approve Loran C for nonprecision approaches. To this end a joint effort is being conducted to collect the necessary data to obtain approval. The first phase of the effort is known as the pilot or implementation phase one and is intended to gain operational experience from a limited number of aircraft and airports. The program involves the installation of local area Loran C monitors, establishment of approach procedures, and the training through experience of various FAA personnel, manufacturers, and pilots. The FAA Technical Center has been asked to fly each of the selected airports to verify: the data being collected by the monitor agrees with actual airborne data, the signals in space are sufficient for navigation and the designed approach procedure is flyable.

TEST CONDITIONS

APPROACH PLATES. No approach plate had been designed for Bedford, Massachusetts by Aviation Standards National Field Office (AVN) prior to the need to fly the airport. The FAA Technical Center used the existing localizer approach as a guide to generate a Loran C approach. The waypoints were chosen to overlay the existing localizer approach so that testing could begin. Figure 1 shows the approach plate used. Point IAF was defined as on the runway centerline extention, 14.0 nmi from the runway threshold. Point FAF was the outer marker and point MAP was the runway threshold. The outer marker was 3.9 nmi from the runway threshold. The waypoint values may be found at the bottom of figure 1. Waypoint resolution for these tests were 0.01 minutes or 61 feet. At present the Random Navigation (RNAV) standards call for a resolution of only 0.1 minutes or 607 feet. The FAA uses the North American Datum of 1927 (NAD-27) to define it's waypoints. The Loran C community uses the World Geodetic System of 1972 (WGS-72) to define it's coordinates. The difference between the two systems at Bedford is approximtely 16 feet in latitude and 131 feet in longitude. In Florida the difference in latitude increased to about 120 feet and in Oregon the difference in longitude increased to about 300 feet.

MONITOR DATA. The Loran C monitor installed at Bedford by Transportation Systems Center (TSC) recorded the following average time difference (TD) values measured in microseconds. The data presented here were collected by the monitor during the actual flights. The monitor position was converted to WGS-72 coordinates. Defense Mapping Agency (DMA) values for position were calculated using the DMA model of Loran C propagation over seawater and the WGS-72 coordinate system. TD bias for the day of flight was the difference between the measured TD values at the monitor and the DMA values. TD bias was the area calibration value. Flights were conducted on June 18, 1985 between 20:17 and 21:06 Eastern Daylight Time (EDT).

Average Value of Monitor TD's (microseconds): TDW = 14117.44 TDX = 26025.98
Actual Position of Monitor: N 42°27'54.7" W 71°17'20.5" (WGS-72)
DMA Values for Position (microseconds): TDW = 14117.673 TDX = 26028.114
TD Bias Day of Flight (microseconds): TDW = -0.23 TDX = -2.13

AREA CALIBRATION VALUES. The Loran C monitor installed at Bedford was used to obtain the area calibration values for the June 18 flight tests. The time differences used were the average of one days data occurring the previous week. The Advanced Navigation INC. ANI-7000 Loran C receiver used for this test had not been updated to enter area calibration values as a TD bias. Area calibration, therefore, required entering the complete TD's and position of the monitor. The monitor position values listed below and furnished by TSC were inserted in the ANI-7000 receiver. The coordinates were reformatted to degrees, minutes and fractional minutes as required by the ANI-7000 receiver.

Monitor Position used: N 42°27.92' W 71°17.37'
Chain and Triad used: 9960 MWX
Calibration TD's used (microseconds): TDW = 14117.40 TDX = 26025.59
TD Bias (microseconds): MW = -0.27 MX = -1.52

LORAN C ENVIRONMENT. The following Loran C parameters pertain to Bedford using the 9960 chain.

Transmitter	Distance from Airport to Transmitter (nmi)	Bearing from Airport to Transmitter (degrees)
M	247	275
W	298	28
X	94	141

Line of Position	Gradient (ft./microsecond)	Direction of LOP (degrees)
MW	592	152
MX	533	208

DATA COLLECTION. Data was collected using an ANI-7000 Loran C receiver for the Loran C parameters and a Magnavox Z-set Global Positioning System (GPS) receiver for aircraft position. Six approaches were made to the runway, however, the first run was deleted because no GPS data was available. The ANI-7000 receiver output data approximately every 2 seconds and the GPS receiver every 1.2 seconds. All data was recorded on 9 track magnetic tape every second. Each record was time tagged with local time code generator time to account for data latency during collection of flight data. Post flight data processing involved stripping the GPS data off the magnetic tape and creating a position file which included a new position every 0.1 seconds. The position file was then time merged to within 0.1 seconds of the time when the Loran C receiver position and time differences were valid. Data from five Loran C receivers were recorded on tape but only the ANI-7000 receiver data was processed for this project. The GPS receiver computes its geodetic coordinates in WGS-72. The ANI-7000 receiver (SN 1285) used for data collection had the following versions of software:

Receiver: 4.14
Navigation: 5.08
Output: 1.07

TERMINOLOGY. Refer to figure 2.

Along Track Error (ATE): The difference between the actual position of the aircraft and the Loran C indicated position in the direction of desired track.

Crosstrack Error (CTE): The difference between the actual position of the aircraft and the Loran C indicated position perpendicular to the desired track.

Flight Technical Error (FTE): FTE is a measure of how well the pilot can follow the guidance proved by the system under test. The parameter is measured by recording the needle deflections displayed on the course deviation indicator (CDI) used by the pilot.

Total System Cross Track Error (TSCT): TSCT is defined as the distance between the actual position of the aircraft and the desired track. The distance is measured perpendicular to the desired track. The parameter is a measure of how good the pilot and navigation system function together.

Time Difference (TD) Bias: TD bias is the difference formed by subtracting a computed TD value based on the actual aircraft position and the Loran C receiver measured TD value. The calculated value uses a DMA seawater propagation model. The value is equivalent to the area calibration values that would be printed on the approach plates as defined in the latest Loran C Minimum Operational Performance Standard (MOPS).

ATMOS: ATMOS is defined as the atmospheric noise as measured by the ANI-7000 Loran C receiver. Typically this is the root mean square (RMS) level of the atmospheric noise measured through a 30 kilohertz (kHZ) bandpass filter.

SNR (FS): SNR (FS) is the signal-to-noise-ratio (SNR) as measured by the ANI-7000 receiver and is computed by subtracting the atmospheric noise from the field strength of the station. Due to implementation of the atmospheric noise measurement, SNR (FS) may be contaminated when in close proximity to a Loran C transmitter. Resolution of SNR (FS) is in 1 dB steps.

SNR (PHASE): SNR (PHASE) is the SNR computed from the phase jitter of the standard sampling point of the Loran C pulse. SNR calculated from the phase jitter will see the Loran C transmitter signal as a cross rate signal and should be more representative of the actual SNR as perceived by Loran C processors. Resolution of SNR (PHASE) is in 3 dB steps and is limited to +9 dB.

Envelope to Cycle Difference (ECD): ECD is measured by the ANI-7000 Loran C receiver in microseconds. It is an indication of pulse shape.

95%: This parameter is an estimate of the maximum value for which 95 percent of the data is included. It is formed by adding twice the standard deviation of the data to the mean.

RESULTS

Figure 3 shows the position of the aircraft as determined by the position reference system. The vertical axis of the plot is minutes of latitude with north being up. The horizontal axis of the plot is minutes of longitude with east being to the right. Tic spacing on each axis is 1 minute. The scale has been adjusted to compensate for the difference in conversion of minutes to nautical miles. In the lower left corner of the plot is a scale equivalent to 1 nautical mile. The dashed lines show the AC 90-45A limit for total system crosstrack of 0.6 nmi. The IAF, FAF and MAP waypoints are labeled on the plot as I, F, and M, respectively.

Summary of Navigation Equipment Errors: Review of the data showed all runs and segments except for run 6 (IAF-FAF) met the 1823 feet limit as specified in the Advisory Circular (AC) 90-45A. However, when all runs were combined the results were inside the AC 90-45A limit.

Summary of Pilotage Parameters: Review of the 95% FTE data showed no run or segment exceeded the FTE limit of 0.5 nmi (3038 feet) found in AC 90-45A. Review of the 95% TSCT data also showed it did not exceed the limit of 0.6 nmi (3645 feet). The pilot was not flying under the hood, therefore, results were an indication of expected values but may not represent that of a large sampling using various pilots.

Summary of Time Difference Bais: The mean and standard deviations of the TD bias for TDW (Seneca-Caribou) and TDX (Seneca-Nantucket) were calculated for each run and segment. The data showed that the values were similiar from run to run when the same flight segments were compared. A slight difference existed between the initial segment (IAF-FAF) and the final segment (FAF-MAP). When comparing the mean TD bias obtained on all runs to the monitor data for the same time, a discrepancy was found. The difference was 0.53 microseconds for TDW and 0.73 microseconds for TDX. If the difference is converted to feet, a position difference of 61 feet north and 390 feet west was obtained. When rotated into errors with respect to the direction of flight the difference showed a 394 foot lag in the direction of flight with very little error perpendicular to the flight path. This can be attributed to a lag between the receiver TD valid time and when the TD was measured. Ground speed during the initial segment was faster than for the final segment.

Summary of Mean SNR: Review of SNR (FS) showed Caribou at -5.5 dB, below the criteria established for allowing a nonprecision approach (0 dB). Bedford is located only 94 nmi from the Loran C transmitter at Nantucket. As described above the atmospheric noise measured in this area would be expected to be contaminated by this transmitter. If SNR (PHASE) was used all transmitters in the triad were close to +9 dB, the upper limit of the measurement and well within the established criteria for nonprecision approaches. When the flight results were compared to the monitor data a difference existed. In general, the monitor value was between the two ANI-7000 methods to obtain SNR values. At present this does not present a problem but the calibration and measurement of SNR must be addressed.

Summary of MEAN ECD: Review of the ECD mean data showed some run segments exceeding the criteria for nonprecision approaches (less than or equal to plus or minus 2.4 microseconds) but when all runs and segments were combined the results were inside the limit.

Flight Observations: Guidance from the ANI-7000 Loran C receiver was easy to fly and provided the necessary guidance to line up with the runway. As the flights progressed it was perceived that the approaches seemed to come in at an angle to the runway. Rechecking the waypoints used, showed the values to be correct. Figure 4 shows the position of the aircraft as determined by the localizer. A localizer is a standard FAA approved approach aid which provided runway centerline guidance. The normal microamp deflection has been converted to a displacement in feet by using the distance from the localizer and localizer course width. It should be noted that the localizer data did not verify the flight observations but showed straight in approaches.

CONCLUSIONS

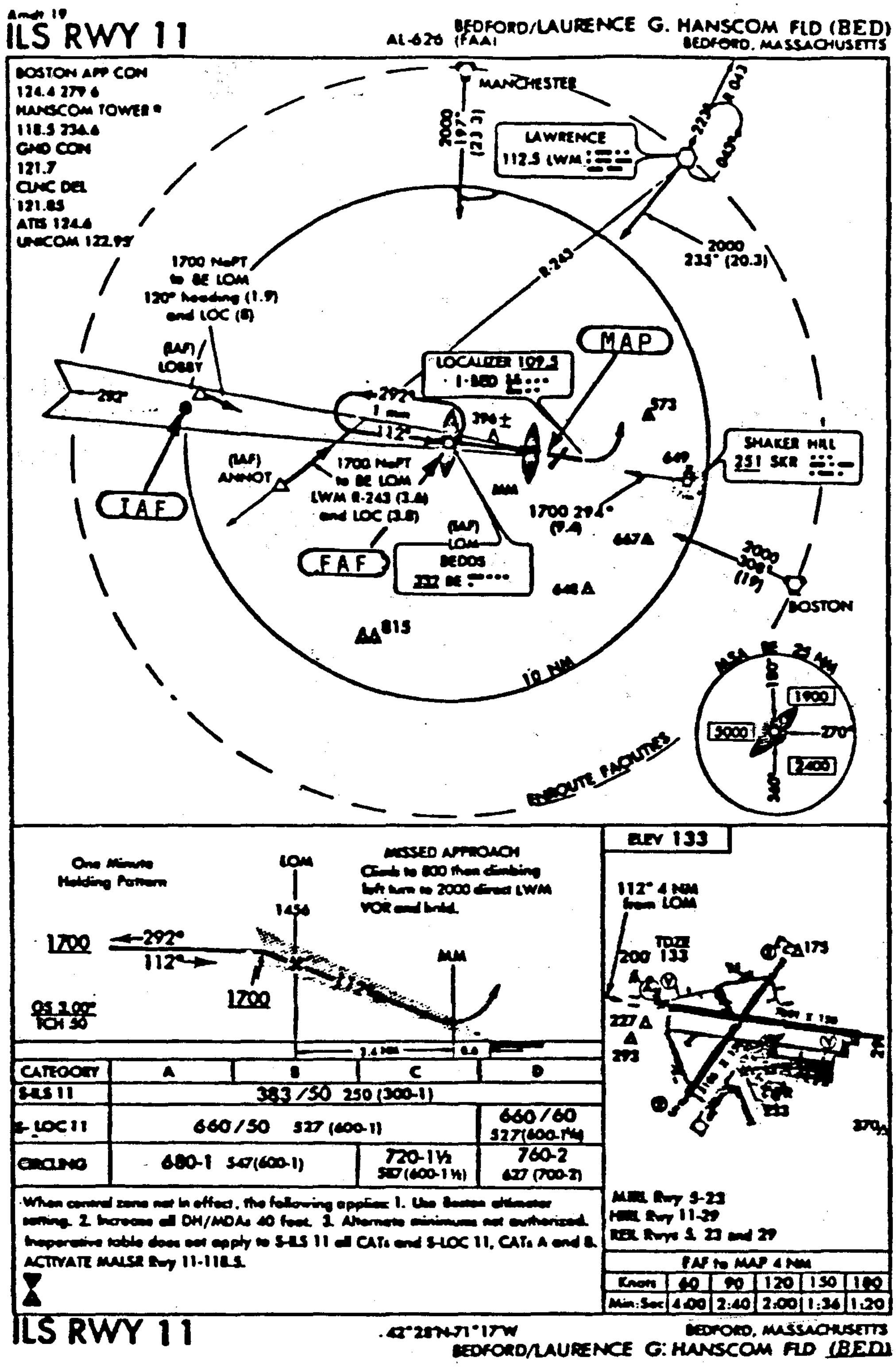
Presented on the next page is a summary of data for Bedford, Massachusettes. It shows a summary of the parameters measured and how they compared with the established criteria for nonprecision approaches.

Spec.	Parameter	Limit	Type	Units	Measured Value	Meets
SNR	M (PHASE)	>0	Mean	dB	9.0	Y
	M (FS)	"	"	"	3.0	Y
	W (PHASE)	"	"	"	8.7	Y
	W (FS)	"	"	"	- 5.5	N
	X (PHASE)	"	"	"	9.0	Y
	X (FS)	"	"	"	15.2	Y
ECD	M	<2.4	Mean	Microsec.	1.87	Y
	W	"	"	"	0.88	Y
	X	"	"	"	2.25	Y
Along Track Error		<1823	95%	Feet	1207	Y
Cross Track Error		"	"	"	726	Y
Total System Cross Track		<3647	"	"	952	Y

In conclusion, it was shown that the area calibration was valid and that the signal quality parameters met the established criteria using an ANI-7000 Loran C receiver at Bedford, Massachusetts.

BIOGRAPHY

Mr. Erikson graduated from Drexel University in 1973 with a BS in electrical engineering. He starting working for the Federal Aviation Administration at the Technical Center in 1971 as a co-op and has been working there since graduation. Work assignments have included the evaluation of various navigation and communication systems related to aviation. For the past 5 years he has been project manager of several projects which were designed to evaluate and provide data for the approval of Loran C as a nonprecision approach aid. He is a member of the WGA and has authored several papers.



CATEGORY	A	B	C	D
S-ILS 11	383/50 250 (300-1)			
S-LOC 11	660/50 527 (600-1)			660/60 527(600-1¼)
CIRCLING	680-1 547(600-1)		720-1½ 587(600-1½)	760-2 627 (700-2)

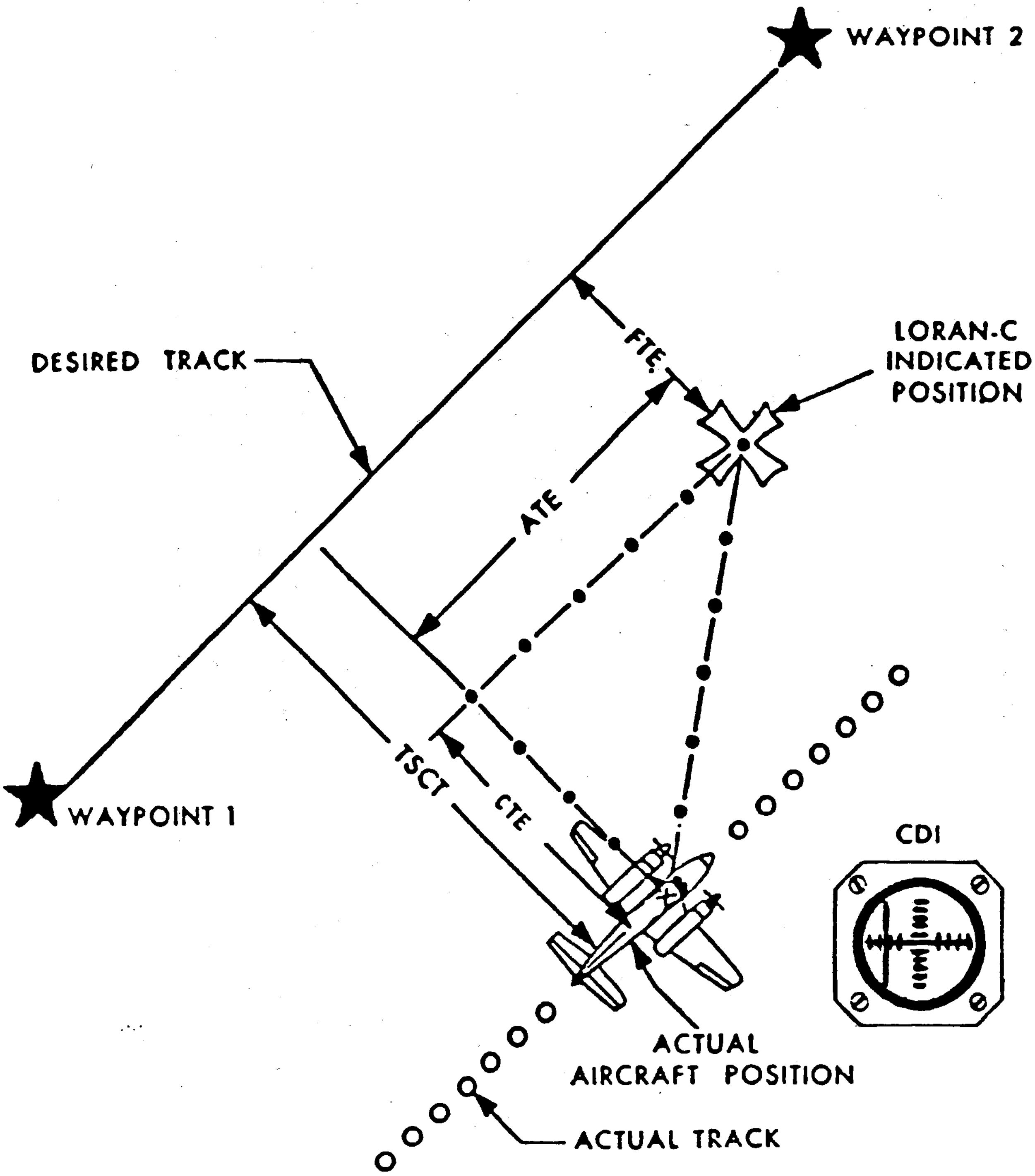
When control zone not in effect, the following applies: 1. Use Boston altimeter setting. 2. Increase all DH/MDAs 40 feet. 3. Alternate minimums not authorized. Inoperative table does not apply to S-ILS 11 all CATs and S-LOC 11, CATs A and B. ACTIVATE MALSR Rwy 11-118.5.

FAF to MAP 4 NM

Knots	60	90	120	150	180
Min:Sec	4:00	2:40	2:00	1:36	1:20

WPT.		
IAF	42° 30.00′	71° 36.82′
FAF	42° 28.78′	71° 23.37′
MAP	42° 28.37′	71° 18.78′

FIGURE 1. APPROACH PLATE FOR BEDFORD



TSCT = TOTAL SYSTEM CROSS TRACK ERROR
ATE = AIRBORNE EQUIPMENT ALONG TRACK ERROR
CTE = AIRBORNE EQUIPMENT CROSS TRACK ERROR
FTE = FLIGHT TECHNICAL ERROR

FIGURE 2. NAVIGATION SYSTEM ERROR TERMS

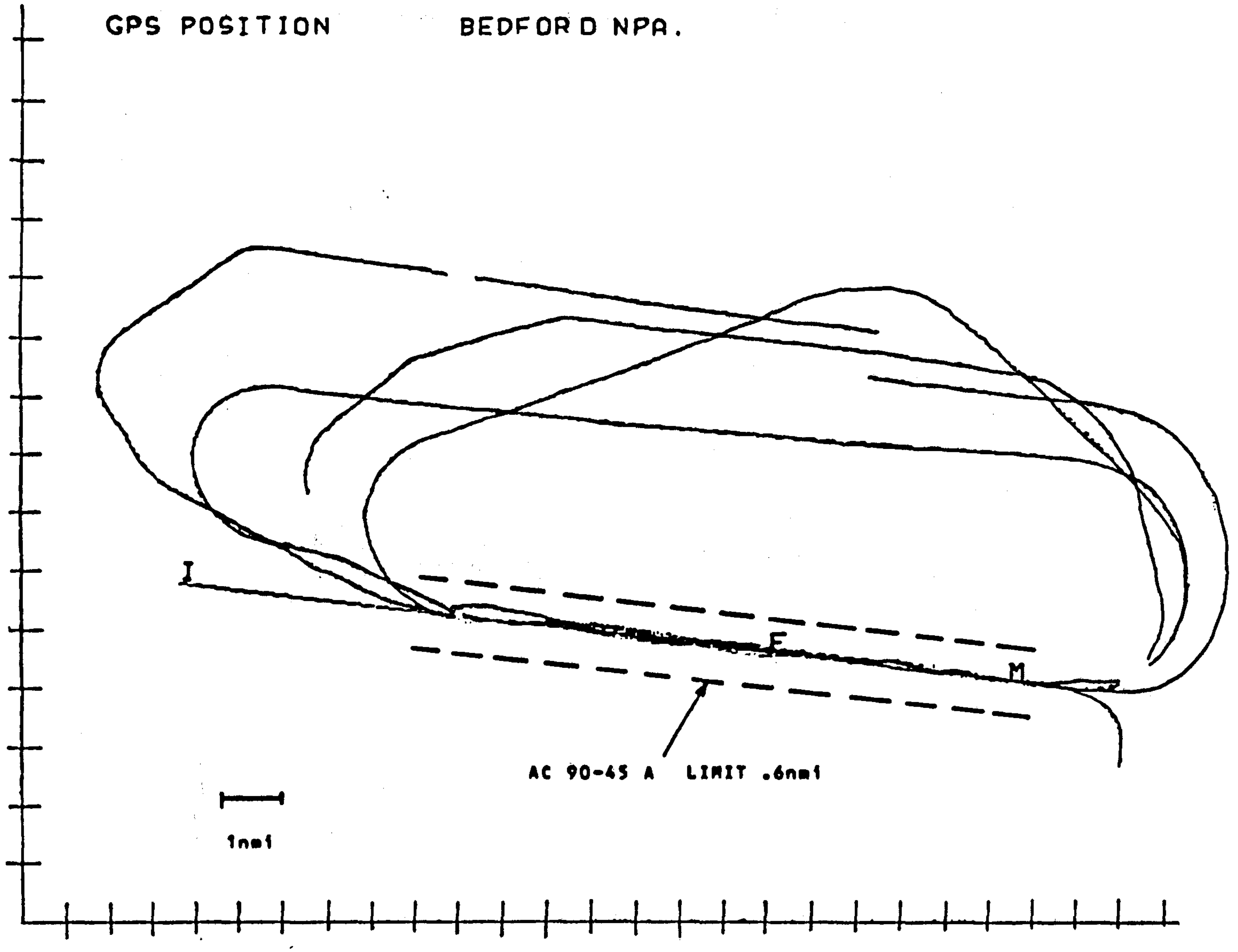
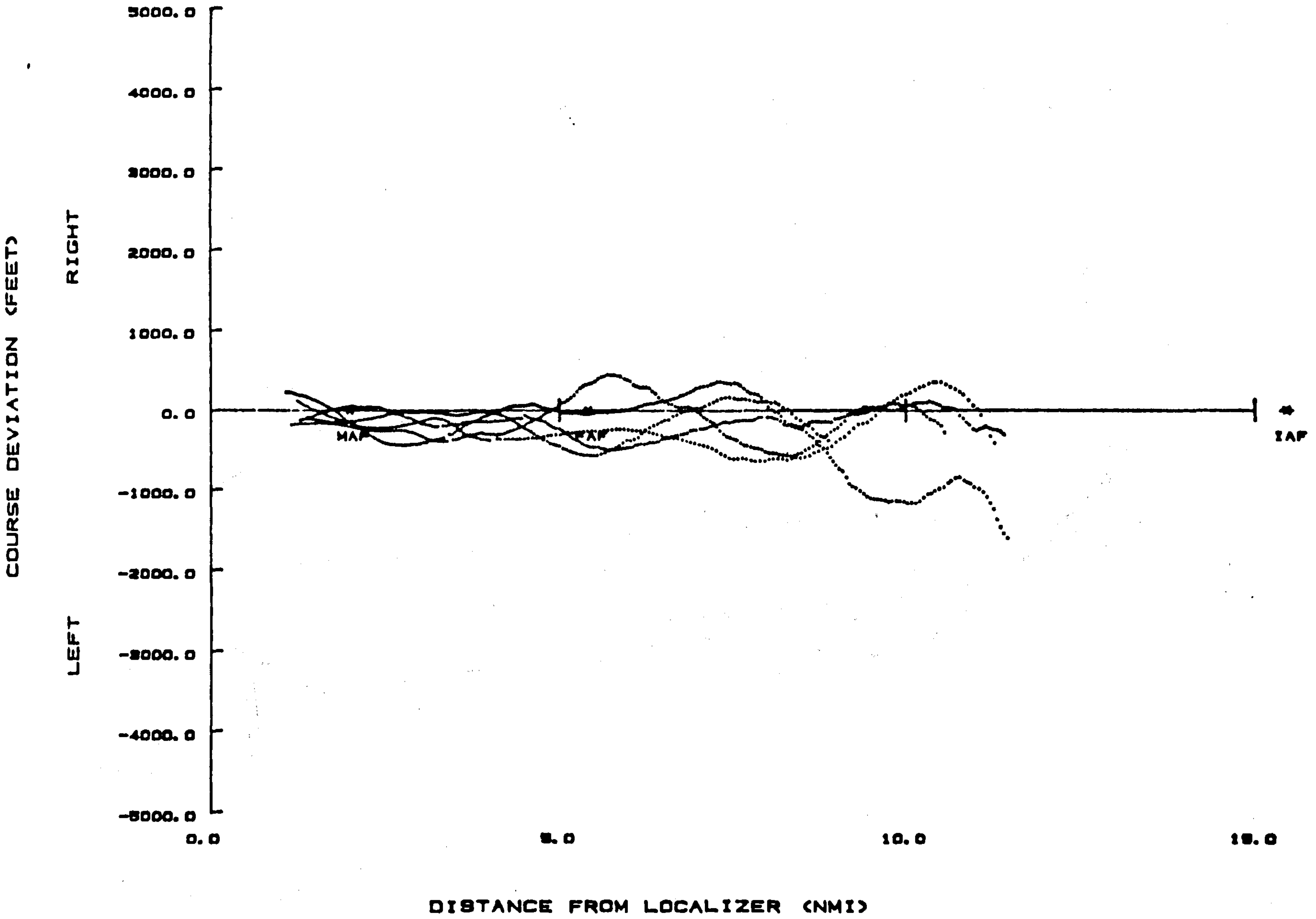


FIGURE 3. AIRCRAFT POSITION USING GPS



PILOT'S LOCALIZER DEFLECTION IN FEET VS. DISTANCE FROM LOCALIZER
FOR BEDFORD. MASS RUNWAY 11

FIGURE 4.

UPDATE OF FAA PILOT MONITOR PROJECT

W. A. WEEKS, APM-420
FEDERAL AVIATION ADMINISTRATION
WASHINGTON, DC

M. J. MORONEY, DTS-52
TRANSPORTATION SYSTEMS CENTER
CAMBRIDGE, MA

F. D. MACKENZIE, DTS-52
TRANSPORTATION SYSTEMS CENTER
CAMBRIDGE, MA

Presented at

The Wild Goose Association Meeting
23rd-25th October 1985
Santa Barbara, CA

ABSTRACT

The FAA is conducting a nationwide effort to investigate and eventually to approve the use of LORAN-C for IFR nonprecision approach operations in the National Airspace System.

In response to a growing number of user requests and the concerted efforts of the National Association of State Aviation Officials, the FAA implemented a Pilot Monitor Project to provide a grid stability database and to develop standards, procedures and operations for LORAN-C as a landing aid. This paper describes the operation of six LORAN-C pilot monitors deployed in Oregon (2), Texas, Ohio, Massachusetts, and Vermont, in support of this effort. Subjects such as determining air traffic control alarm limits, forecasting LORAN-C time difference corrections, and conditions for automatic insertion of control parameters are addressed.

INTRODUCTION

An event of significant import to the Wild Goose Association will take place in 1985 when the first FAA approved IFR, nonprecision approach will be flown using LORAN-C signals. It has taken some time for this outstanding aviation achievement to occur. In 1974 the U.S. Coast Guard equipped an aircraft with LORAN-C to demonstrate the potential of the LORAN-C system to provide navigation and guidance information with an accuracy suitable for approaches to small, isolated airports in Vermont. A major advance toward the goal of nonprecision approaches was made in 1981 when the FAA awarded the first en route Supplemental Type Certificate to the State of Vermont to use LORAN-C for navigation and guidance. Test data gathered in the Vermont program indicated that LORAN-C was suitable for all phases of flight. (1) Finally, this year, LORAN-C will be officially recognized for the major navigation contribution it can make to the general aviation aircraft community, as well as small commuter and cargo airlines (Table 1).

In preparation for the advent of LORAN-C nonprecision approaches, the FAA initiated a Pilot Monitor Project as part of the Supplemental Navigation Aids Program.

PROJECT OBJECTIVES

A primary objective of the Pilot Monitor Project is to enable the FAA to gain operational experience with a navigation system which is not owned, operated, or controlled by the FAA. Other objectives include development of an approval methodology for LORAN-C receiver installations in aircraft, development of approach procedures, and the formulation of standards and operations applicable to all supplemental navigation aids.

TABLE 1. CHRONOLOGY OF LORAN-C MILESTONES IN AVIATION

YEAR	EVENT
1972	WILD GOOSE ASSOCIATION ORGANIZED
1974	USCG AIRCRAFT TEST APPROACHES IN VERMONT
1977	VERMONT REQUEST FOR ASSISTANCE FROM DOT
1979	DOT/NASA/VERMONT JOINT LORAN-C TEST PROGRAM
1981	EN ROUTE STC AWARD TO VERMONT
1985	STC AWARD FOR FIRST IFR NONPRECISION APPROACH

PILOT MONITOR CONFIGURATION

The main components of a pilot monitor system, as shown in Figure 1, are a LORAN-C survey quality receiver, a small personal computer with 10.6 Mb memory, a visual/audio annunciator to relay LORAN-C triad status to air traffic control, either a dedicated phone line or hardline from the monitor to the annunciator, and a modem to permit frequent telephone interrogation of the monitor system to determine status and to gather data for statistical analysis. The purpose of the annunciator is to constantly give air traffic control a positive indication that the LORAN-C signals are acceptable for nonprecision approaches. This is accomplished by keeping a green lamp on the monitor set lit. If anything exceeds preset limits and conditions, the green light will be extinguished, and simultaneously a red light will be turned on and an audio alert actuated.

IMPLEMENTATION PLAN

The FAA cooperated with the National Association of State Aviation Officials to assure that authorized nonprecision approaches would take place in 1985. The first approach will be made at L.G. Hanscom Field in Bedford, MA. Shortly thereafter, seven additional airports, which also are participating in the Pilot Monitor Project, will be regularly issuing clearances for LORAN-C approaches. The FAA has visited regional offices responsible for these eight airports to bring their staffs up to date on the LORAN-C program. State officials have identified users at each airport who would be willing to install, or already have, an approved LORAN-C receiver in their aircraft and who will apply for a Supplemental Type Certificate. (2) The FAA is installing monitors at each of these airports and developing approach procedures (Figure 2). The airports and their characteristics are listed in Table 2. Each runway, user, and type of avionics equipment is listed in Table 3. For a year, starting in December 1985, the Pilot Monitor Project will operate this subset of a nationwide monitor network. At the end of this period the FAA will have an experienced cadre capable of operating a nationwide system of operational monitors.

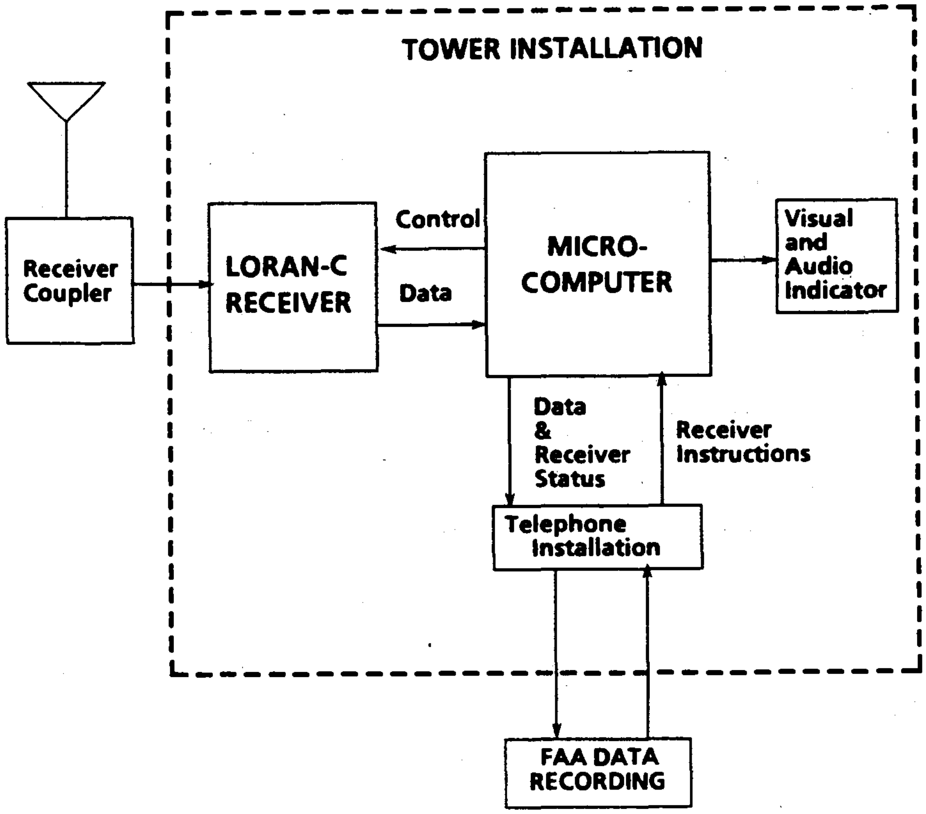
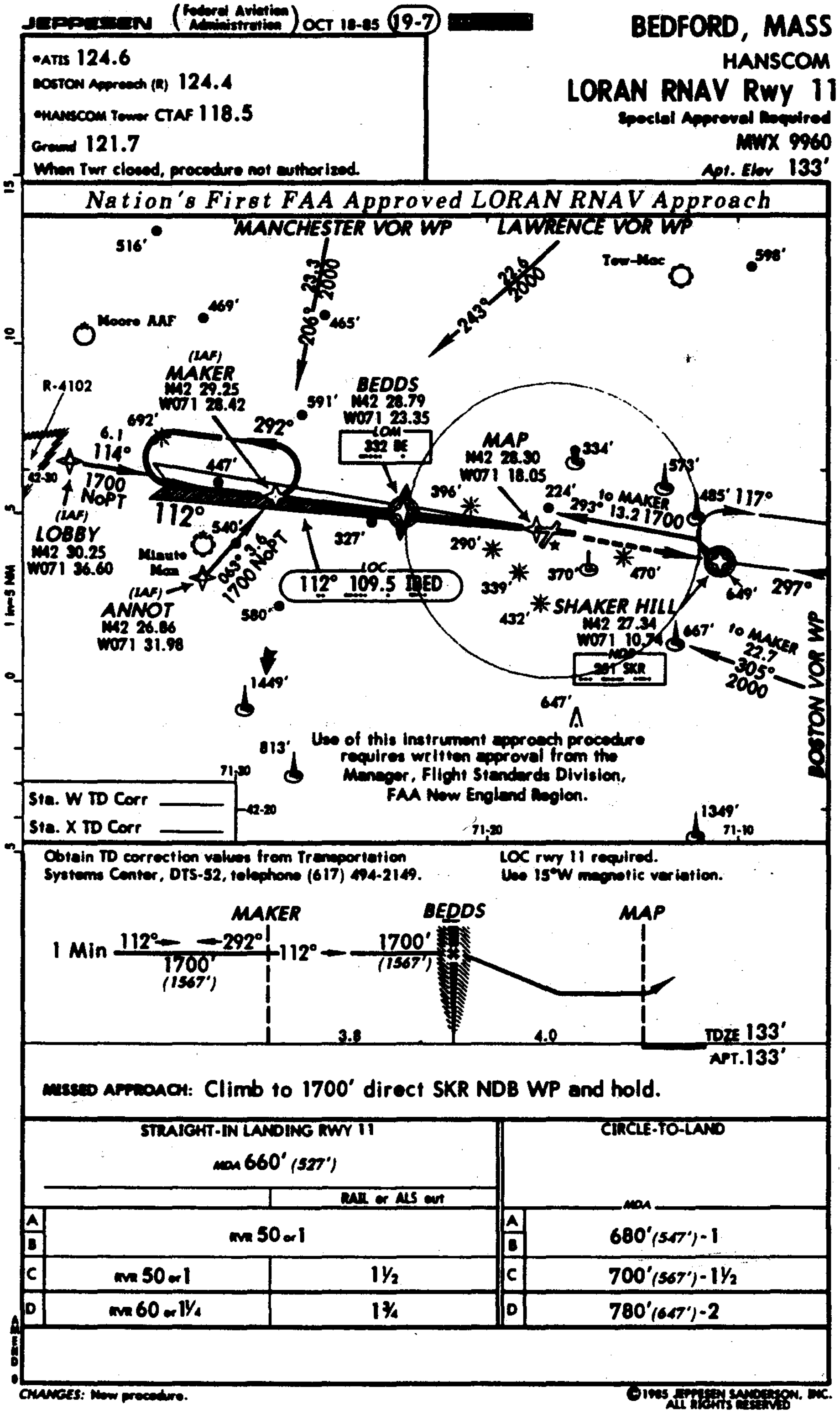


FIGURE 1. LORAN-C MONITOR CONFIGURATION

TABLE 2. AIRPORTS SELECTED FOR IMPLEMENTATION

NAME	CITY, STATE	AIRPORT LAT, LONG 1	CHAIN TRIAD	AIRPORT TD'S 2	CROSSING ANGLE
L.G. HANSCOM FIELD	BEDFORD, MA	42° 27′ 54″ 71° 17′ 22″	9960 MWX	14117.790 26028.270	56.40
PORTLAND INTL	PORTLAND OREGON	45° 35′ 20″ 122° 35′ 47″	9940 MWX	12247.190 28154.070	116.50
BURLINGTON INTL	BURLINGTON VERMONT	44° 28′ 17″ 73° 09′ 12″	9960 MWX	14224.570 27259.290	41.40
OHIO STATE UNIVERSITY	COLUMBUS OHIO	40° 04′ 48″ 83° 04′ 24″	9960 MYZ	42927.290 56425.390	61.80
JEFFERSON COUNTY	PORT ARTHUR BEAUMONT, TX	29° 57′ 02″ 94° 01′ 14″	7980 MWX	11010.360 26357.660	104.00
ORLANDO EXECUTIVE	ORLANDO FLORIDA	28° 32′ 43″ 81° 19′ 59″	7980 MYZ	44355.690 62321.000	121.51
MCNARY FIELD	SALEM OREGON	44° 54′ 36″ 123° 00′ 05″	9940 MWX	12663.310 28076.280	114.60
MANSFIELD LAHM MUNI	MANSFIELD OHIO	40° 49′ 17″ 82° 31′ 00″	9960 MYZ	43342.230 56888.780	53.63

NOTE 1. NAD 27 AIRPORT LOCATION
NOTE 2. AIRPORT SCREENING MODEL



JEPPESEN (Federal Aviation Administration) OCT 18-85 (19-7) [redacted]

BEDFORD, MASS

HANSCOM

LORAN RNAV Rwy 11

Special Approval Required

MWX 9960

Apt. Elev **133'**

*ATIS 124.6
BOSTON Approach (R) 124.4
*HANSCOM Tower CTAF 118.5
Ground 121.7
When Twr closed, procedure not authorized.

Nation's First FAA Approved LORAN RNAV Approach

Use of this instrument approach procedure requires written approval from the Manager, Flight Standards Division, FAA New England Region.

Sta. W TD Corr ______
Sta. X TD Corr ______

Obtain TD correction values from Transportation Systems Center, DTS-52, telephone (617) 494-2149.

LOC rwy 11 required.
Use 15°W magnetic variation.

MISSED APPROACH: Climb to 1700' direct SKR NDB WP and hold.

	STRAIGHT-IN LANDING RWY 11 MDA 660' (527')			CIRCLE-TO-LAND MDA
		RAIL or ALS out		
A	RVR 50 or 1		A	680'(547')-1
B			B	
C	RVR 50 or 1	1½	C	700'(567')-1½
D	RVR 60 or 1¼	1¾	D	780'(647')-2

CHANGES: New procedure.

FIGURE 2. APPROACH PROCEDURE - RWY 11, HANSCOM

TABLE 3. USER AVIONICS AND RUNWAY REFERENCE

NAME	NAV REFERENCE	RUNWAY	USER	EQUIPMENT
L.G. HANSCOM FIELD	ILS	11	SPRAGUE ELECTRIC	ONI 7000
PORTLAND INTL	ILS	10R	LAMB - WESTON	ONI 7000
BURLINGTON INTL	ILS	15	NORTHERN AIRWAYS	ONI 7000
OHIO STATE UNIVERSITY	ILS	09R	STATE	MULT.
JEFFERSON COUNTY	ILS	12	VOIGHT	TI 9100
ORLANDO EXECUTIVE	ILS	07	STATE	
MCNARY FIELD	ILS	31	STATE	ARNAV - R60 APOLLO 612
MANSFIELD LAHM MUNI	ILS	32	FISHER BROS.	LNS - 616

CURRENT STATUS

The project to complete an approved nonprecision approach in 1985 is ahead of schedule. Six airports already have monitor systems and approach procedures, and seven have been flight inspected (Table 4). In December 1985 all pilot monitors will be in place, seven procedures will be developed and all airports will be flight inspected. Users will receive weekly updates of time difference corrections for the following week (Table 5) and air traffic controllers will be issuing approvals for requests to make LORAN-C nonprecision approaches.

TABLE 4. LORAN-C PILOT MONITOR PROJECT SCHEDULE

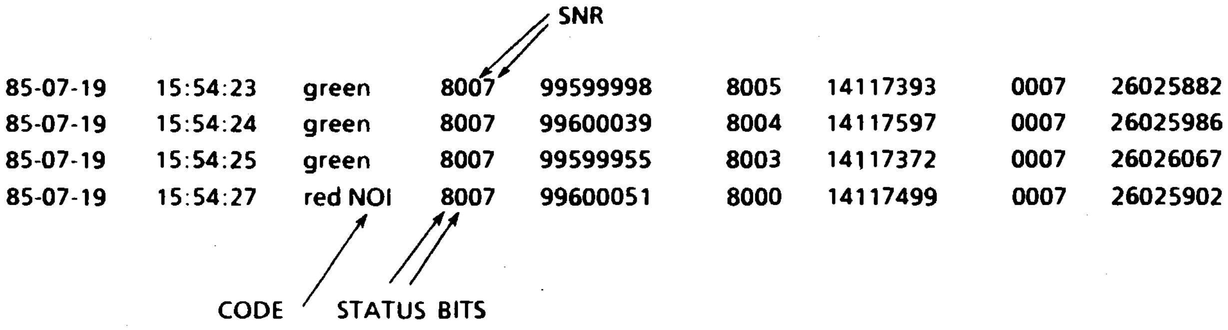
AIRPORT NAME	MONITOR INSTALLATION DATE	APPROACH PROCEDURES COMPLETED	FLIGHT INSPECTION COMPLETED
L.G. HANSCOM	APRIL 17, 1985	OCT. 27, 1985	SEPT. 25, 1985
PORTLAND INTL	JUNE 13, 1985	OCT. 27, 1985	SEPT. 15, 1985
JEFFERSON COUNTY	JULY 15, 1985	OCT. 27, 1985	OCT. 1, 1985
OHIO STATE UNIVERSITY	AUG. 12, 1985	OCT. 27, 1985	SEPT. 26, 1985
BURLINGTON INTL	SEPT. 11, 1985	OCT. 27, 1985	SEPT. 25, 1985
MCNARY FIELD	OCT. 7, 1985	OCT. 27, 1985	SEPT. 15, 1985
MANSFIELD LAHM MUNI	NOV. 15, 1985	NOV. 27, 1985	SEPT. 26, 1985
ORLANDO EXEC.	DEC. 15, 1985	JAN. 27, 1986	JAN. 6, 1986

TABLE 5. TIME DIFFERENCE CORRECTION VALUES

NAME	AIRPORT LAT, LONG	MONITOR LAT, LONG	MONITOR TD'S	AVERAGE TD'S	ΔTD'S
L.G. HANSCOM FIELD	42° 27' 54" 71° 17' 22"	42° 27' 55.7" 71° 17' 20.8"	14117.790 26028.270	14117.383 26025.966	−0.4 −2.3
PORTLAND INTL	45° 35' 20" 122° 35' 47"	45° 35' 30" 122° 36' 15"	12246.340 28153.310	12245.394 28155.116	−1.0 +1.8
MANSFIELD LAHM MUNI	40° 49' 17" 82° 31" 00"				
JEFFERSON COUNTY	29° 57' 02" 94° 01' 14"	29° 59' 19.56" 94° 02' 31.54"	11008.700 26358.250	11007.853 26355.648	−0.8 −2.6
OHIO STATE UNIVERSITY	40° 04' 48" 83° 04' 24"	40° 04' 34.75" 83° 04' 08.22"	42926.200 56423.700	42926.140 56423.770	−0.1 +0.1
BURLINGTON INTL	44° 28' 17" 73° 09' 12"	44° 27' 55.2" 73° 08' 24.2"	14221.130 27253.570	14221.598 27253.381	+0.5 −0.2
ORLANDO EXECUTIVE	28° 32' 43" 81° 19' 59"				
MCNARY FIELD	44° 54' 36" 123° 00' 05"	44° 55' 00" 123° 00' 00"	12659.400 28076.800		

ALARM LIMITS

The monitor computer determines whether LORAN-C system parameters are suitable for a nonprecision approach within the limits of AC 90-45A. (3) The real-time measurements available on which to base this determination are time difference values, signal-to-noise ratios,[1] and status bits, STS, (Figure 3, Table 6). If the STS are satisfactory the computer accepts signal-to-noise data from the monitor receiver. The signal-to-noise ratio limits are set 3 decibels below the lowest value seen during normal operation. Conditions such as loss of signal, unusual atmospheric conditions, or rain static can cause a red light, NOI. The SNR limit can be set as low as -10 decibels because all receivers examined to date can acquire and track signals in this type of environment.



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85-07-19   15:54:23   green     8007   99599998   8005   14117393   0007   26025882
85-07-19   15:54:24   green     8007   99600039   8004   14117597   0007   26025986
85-07-19   15:54:25   green     8007   99599955   8003   14117372   0007   26026067
85-07-19   15:54:27   red NOI   8007   99600051   8000   14117499   0007   26025902
```

FIGURE 3. STATUS MESSAGE

The limits on the receiver oscillator offset are set in the processor at ± 700 nanoseconds, i.e., if the measured value of the 9960 GRI is greater than 99600.7 microseconds or less than 99599.3 microseconds, the red light is turned on, OSC. This value is a measure of receiver performance. If the offset stays within ± 700 nanoseconds, accuracy requirements will be met. The measured oscillator offsets are used to adjust the measured values of time differences.

Events that could cause the red light to be turned on, and their priority (given that multiple events occur), are listed in Table 7. Hardware failures, HRD, cause the red light to blink. Other unacceptable conditions cause a steady illumination of the red light. For the Pilot Monitor Project, a red light will be reported by air traffic control to airway facilities, who in turn

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[1] Signal-to-noise ratio is defined as 20 LOG (A/sigma), where LOG is base 10, A is the amplitude of the LORAN-C signal envelope at the tracking point, and an instantaneous reading of noise is detected after passing through the receiver front end and is assumed to have a Gaussian distribution with zero mean and standard deviation sigma. There are a few instances where a higher minimum signal-to-noise ratio is desirable such as when an instantaneous detection of time difference drift is needed, or if it is desired to reduce the allowable error used for airborne receiver jitter.

TABLE 6. DECODING STATUS (STS) BIT MESSAGES

VALUE OF FIRST DIGIT	MEANING
8	WARNING SIGNAL WAS LOST AT SOME TIME (NO RED LIGHT)
4	RECEIVER IN SEARCH (RED)
2	TRACKING TOO HIGH, CYCLE STATUS ENABLED (RED)
1	TRACKING TOO LOW, CYCLE STATUS ENABLED (RED)
VALUE OF SECOND DIGIT	
8	CYCLE STATUS ENABLED (NO RED LIGHT)
4	NOT SETTLED (RED)
2	SIGNAL HAS BLINK STATUS (RED)
1	SIGNAL LOST, FRONT EDGE SEACH ON (RED)

TABLE 7. DECODING CAUSES OF RED ALARMS

CODE	MEANING
HRD	HARDWARE FAILURE
PAR	FILE NOT READABLE, POWER UP
CHG	NEW PARAMETERS BEING INSTALLED
TIM	NO REPORT FOR OVER 10 SECONDS
STS	STATUS BYTES UNACCEPTABLE
NOI	SIGNAL-TO-NOISE RATIO TOO SMALL
OSC	OSCILLATOR IN RECEIVER DEFECTIVE
DIS	DISTANCE BOUNDARY EXCEEDED
POW	PARAMETER VERIFICATION REQUIRED

will call the Transportation Systems Center (TSC). Engineers at TSC will access the monitor to determine the cause of the red light alert and, after the condition has been corrected, the red light will be turned off and the green light reactivated. The notification process is reversed once the system is put into a green status. The third event, CHG, is a red light that comes on five minutes before seasonal adjustments are entered into the processor. The green light comes on five minutes following the data insertion. The STS, NOI, and OSC codes have already been explained. See Figure 4 for a diagram of the red and green light process.

The distance error, DIS, attributed to time difference value drifts, is calculated using the expression in Table 8 and compared to a preset value. If the distance error is less than this value the light remains green, otherwise, the red light will be lit. In AC 90-45A the allowable airborne equipment along track error is 0.3 nautical mile and the allowable equipment crosstrack error is 0.33 nautical mile. A boundary circle with a radius of 0.3 nautical mile was chosen to simplify calculations within acceptable safety limits. A boundary buffer of 0.1 nautical mile inside this circle represents the value chosen by the Radio Technical Commission for Aeronautics (RTCA) Special Committee 137 in the Minimum Operational Performance Standards (MOPS) (4) as the location computation error, i.e., the error associated with the receiver's ability to compute latitude and longitude from a known set of time differences. To assure operation within the MOPS, the radius currently being used is 0.2 nautical mile (1216 feet).

The value of the maximum and minimum probable time difference offsets in aircraft receivers is the measured time difference, minus the expected time difference ± the value of the receiver error budget (Table 9). The distance offset in feet in the direction of the gradient vector is the time difference offset multiplied by the gradient. The square of the distance error, if less than 1216 feet, results in a green light condition. The expected time difference values are the saltwater model value plus the time difference corrections. The measured value is the value read each second from the monitor receiver. Added to the measured value are the errors allocated to the airbrone and the monitor receivers. These errors are combined in a root-sum-squared relationship. The assumption is made that the values of the variables from the two receivers are normally distributed and independent. The receiver error budget includes receiver bias, a propagation model error, tracking loop jitter, grid bias and seasonal error (Table 10).

Receiver bias is defined as follows: if 100 receivers are placed at the same location, receiver bias is defined as the radius of the circle which would include 95 percent of the time difference values. The monitor receiver has a bias of 20 nanoseconds. In the SC-137 MOPS, a value of 200 nanoseconds is designated as the maximum time difference measurement error for the airborne receiver.

Propagation model error is the error allowance for the various implementations of the saltwater propagation model. The monitor receiver has a zero error value because of its function as the generator of time difference corrections. The MOPS document recommends a value of 100 nanoseconds for the airborne receiver.

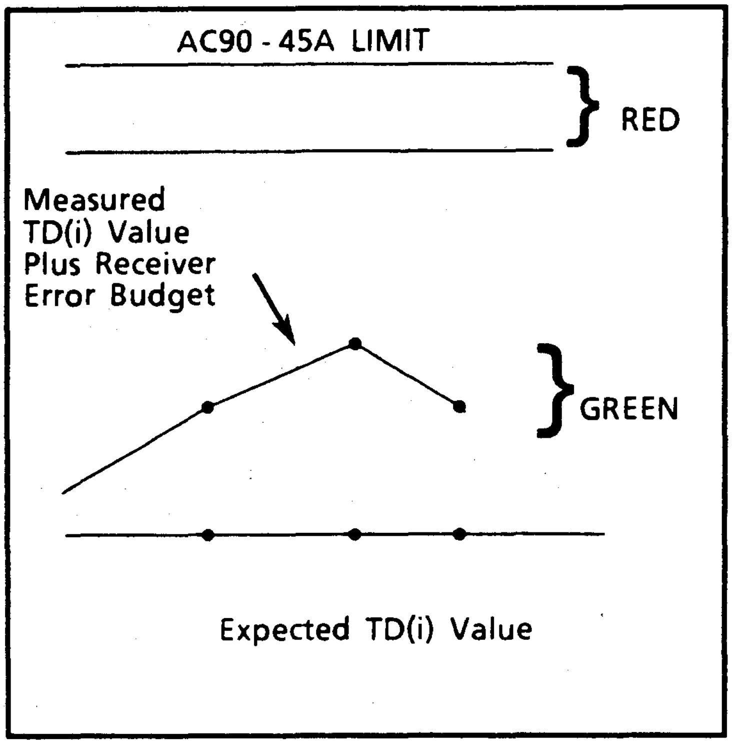

FIGURE 4. RED AND GREEN LIGHT PROCESS

TABLE 8. DISTANCE ERROR CALCULATION

$$D^2{}_E = \frac{D(1)^2 - 2D(1)D(2)\text{Cos}\phi + D(2)^2}{(1 - \text{Cos}^2\phi)}$$

D_E = Distance Error
$D(i) = E(i) \cdot \text{Gradient} \quad i = 1, 2$
$E(i)$ = TD offsets in the airborne receiver
$D(i)$ = Distance offsets in the direction of the gradient vector
ϕ = Angle between the two vectors normal to the TD grids in the direction of maximum increase in TD value

TABLE 9. TIME DIFFERENCE CALCULATION

E(i) = Measured TD(i) – ExpectedTD(i)
+/– Receiver Error Budget (i)

Measured TD(i) = Monitor TD Value
Measured Each Second

Expected TD(i) = Airport Screening Model
Value Plus the TD Corrections

(i) = 1, 2

TABLE 10. LORAN-C ERROR BUDGET

CARIBOU / NANTUCKET		AIRBORNE VALUE USED (NANOSEC.)	MONITOR VALUE USED (NANOSEC.)
SOURCE	RANGE (NANOSEC.)		
Receiver Bias	20 to 200	200	20
Propagation Model	0 to 100	100	0
Receiver Scatter	0 to 600	0	0
Grid Bias	0 to 50	0	0
Seasonal Error	0 to 500	0	0
RSS	20 to 814	224	20

Tracking loop jitter is a function of the signal-to-noise ratio value and the time constant of the receiver. The lower the ratio (higher the noise), the larger the tracking loop jitter is. The longer the time constant, the smoother the output is, i.e., smaller value of jitter. The monitor tracking loop jitter always is measured during installation. If the loop jitter is included in the error budget, a predictor of a red light situation can be developed. If the loop jitter is not included, a more workable approach is possible in poor geometric situations, e.g., Jefferson County, TX. Without the predictor function, there will be a few seconds of delay before detection of the red light condition. In all cases, the monitor will detect a red light situation within the time period (≤ 10 sec.) allocated for blink detection, so it is not necessary to include an allowance for receiver jitter in the red light algorithm.

Grid bias is the difference in measured time difference values when the airborne receiver and the monitor receiver are not receiving signals along the same path. The MOPS document uses a grid bias value of 200 nanoseconds for airborne receivers. The propagation corrections are measured at the airport to which the airborne receiver is flying and are distributed to users weekly. When the corrections are added to the saltwater model values, the resulting TD's will very closely represent actual propagation values at the airport at the time of the approach. In these cases, the error attributed to grid bias will be negligible.

Seasonal error is related to the frequency of the propagation corrections. In the Vermont seasonal data, the peak to peak variation over a period of a year was 500 nanoseconds. In this case, using an average value for an entire year would require a seasonal error value of ± 250 nanoseconds in the error budget. Updating seasonal corrections on an eight week schedule would greatly reduce this value. Updating corrections weekly, as in the monitor project, makes this error negligible.

In summary, the major contribution to the error budget for the Pilot Monitor Project is receiver bias and propagation model error (Table 10).

TIME DIFFERENCE CORRECTIONS

All LORAN-C navigators contain a mechanism which converts the received time difference values into latitude and longitude coordinates. These coordinates do not necessarily correspond exactly with map coordinates because of differences in electromagnetic propagation characteristics from one area to the next. In order to deal with propagation anomalies, receiver designers store information in the navigator that is used to correct the values so that system-displayed coordinates more closely coincide with surveyed coordinates. In addition, designers provide a method to calibrate a receiver by entering the surveyed latitude and longitude of a point along with the measured time difference values of that point. The system computer then calculates a correction factor which is applied to other points. In order to accommodate "low cost" receivers, the FAA has adopted a policy of providing time difference corrections for each airport. The form of the corrections are ± X.X microseconds. These corrections may be necessary to achieve nonprecision approach accuracies. To determine the time difference correction values, the FAA uses the time differences predicted by a saltwater model and measured time differences data at the monitor site. The model's characteristics are listed in Table 11 and 12. The model, which is the airport screening model originally developed by MITRE Corporation, is located on the Data General MV8000 computer at FAA Headquarters in Washington, D.C. The time differences are measured at the monitor site. The difference between values predicted by the saltwater propagation model and the measured time difference values are the propagation correction values. If the corrections are from measurements in the vicinity of the airport to which they apply and are distributed to the users frequently (once a week), they will very closely represent the actual time difference values. In this case, the error attributed to them will be very small, i.e., 0 to 100 nanoseconds.

In the LORAN-C Pilot Monitor Project, each user will be called weekly and given the time difference correction values for the next week. In addition, a hard copy of the corrections for all eight airports will be sent to each user. In the operational system, the corrections will appear on approach plates and can be updated on the usual eight week cycle.

AUTOMATIC CONTROL

Every second at L.G. Hanscom Field and at seven other airports in CONUS, LORAN-C monitor receivers are interrogated by their processors. If preset conditions are exceeded, red lights go on and nonprecision approaches to the airports will not be allowed. Green lights are relit when the processor has verified that conditions are acceptable for safe operation. Events which could cause the red light to be lit because established limits were exceeded include: electromagnetic disturbances, seasonal drifts, transmission interruptions, cycle jumps, signal blink, local power failures and the switching of transmitters or generators. Electromagnetic disturbances, thunder storms, solar activity, etc., cause the signal-to-noise ratio values to decrease. If the values are less than -10 decibels (all pilot monitor airports have higher thresholds), the red light will come on. When the disturbances diminish and the values return to acceptable levels, the processor verifies that parameters are within safe limits for at least sixty seconds, and then the green light is relit. The same type of automatic control of red and green signals occurs when time difference values drift beyond set limits. If the time differences return within the limits for sixty seconds, the green light is turned on. During transmitter outages and blink periods the processor follows the same procedures. Table 13 describes the frequency and causes of momentaries in one month in the 9960 chain. .On occasions after a transmitter has not been operating, the monitor receiver can experience difficulty acquiring the third cycle track. When the signal returns, the receiver usually, but not in every instance, will reacquire and track the correct cycle (twice in a seven-day period the incorrect cycle was selected at L.G. Hanscom Field), however, if the receiver locks on the wrong cycle, the light turns red and stays red until the receiver is reset by a remote operator. NOTE: Operationally, this could be a processor initiated action.

One additional automatic control action takes place if a receiver cannot acquire a station following an outage. If this red situation exists for 15 minutes, the processor puts the receiver in the acquisition mode, and sixty seconds after all parameters are within tolerance, a green status is initiated.

TABLE 11. AIRPORT SCREENING MODEL INPUT

CATEGORY	INPUT
AIRPORT NAME	L.G. HANSCOM FIELD
CITY, STATE	BEDFORD, MA
LATITUDE LONGITUDE	42° 27′ 54″ 71° 17′ 22″
MAXIMUM GDOP	3000 Ft / Micro sec
MINIMUM SNR VALUE	0 dB
SEASON	SUMMER

TABLE 12. AIRPORT SCREENING MODEL OUTPUT

CATEGORY	OUTPUT
BEST CHAIN	9960
BEST TRIAD	MWX
EXPECTED SNR_M	21 dB
EXPECTED GDOP	956 Ft / Micro sec
EXPECTED $GRAD_1$	592.4 Ft / Micro sec
EXPECTED SNR_1	14 dB
EXPECTED TD_1	14117.79
EXPECTED $GRAD_2$	532.3 Ft / Micro sec
EXPECTED SNR_2	29 dB
EXPECTED TD_2	26028.27
CROSSING ANGLE	56.4

TABLE 13. FREQUENCY AND CAUSE OF MOMENTARIES, JULY 1985

CAUSE	SENECA	CARIBOU	NANTUCKET
TRANS. SW	6	14	12
OVERLOAD	0	20	10
POWER	0	19	4
OTHER	2	0	0
TOTAL	8	53	26

When local power is interrupted, the system stays in the red status until a remote operator verifies that all the parameters are correct and then the processor turns the green light on.

Corrections for seasonal drifts are inserted into the controller menu by the remote operator to take effect at a preselected date and time. Five minutes before and after the preselected time, the red light comes on. This is followed by a green light if all parameters are normal.

Additional automatic control features will be added to decrease the dependence on an off-site operator and increase the green on-air status. The first feature will be the initiation of cycle select following transmitter outages if, after the station resumes transmitting, a distance error is detected for 15 minutes. The second may be automatic verification of parameters after local power loss.

SUMMARY

The Pilot Monitor Project is proceeding well ahead of schedule. Even as the remaining monitors are being installed, a great deal is being learned about the characteristics and peculiarities of monitors and their operations. We know, for example, that in locations with very large gradients, it will be necessary to require that airborne receivers have low bias values and accurate conversion algorithms. If a receiver operates in a time difference way-point mode, however, then the need for an accurate conversion algorithm is reduced. The seasonal error contribution to the total time difference error budget will diminish in size as seasonal data are collected at the installation site. Automatic reacquisition of the LORAN signal, after blink or station outage have caused loss of the tracking point, will improve signal availability. Automatic verification of the correct control parameters following local power interruptions will improve signal availability.

The most important part of the Pilot Monitor Project has yet to occur, i.e., the operational use of the monitors in the air traffic control system. The real worth of the project will be judged by the degree to which it facilitates the introduction of operational LORAN-C monitors into the National Airspace System.

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2. MacKenzie, F.D., "Certification of an Airborne LORAN-C System." Navigation, Journal of the Institute of Navigation, Vol, 29, No. 2, Spring 1981.

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A DRAMATIC DEMONSTRATION OF LORAN-C CAPABILITIES

Laurence J. Cortland
II Morrow, Inc.
Salem, Oregon

ABSTRACT

In the recent past, finding a method to demonstrate dynamic Loran-C navigation system scenarios to anyone but the most sophisticated user was a difficult task at best. Recently a most effective method of demonstrating the dynamic navigation situation was developed which gives a complete picture in a manner that is simple to understand yet complete in detail. The system was assembled by II Morrow, Inc. initially to demonstrate nonprecision approaches for the National Association of State Aviation Officials (NASAO) sponsored Washington, DC DC-3 flight demonstrations. The results were so impressive it has subsequently been installed in the II Morrow corporate aircraft and demonstrated at the Ontario, Canada, Air Space Review and soon will support Loran-C capabilities demonstrations to the federal government of Canada. This paper describes the details of this display system and its uses.

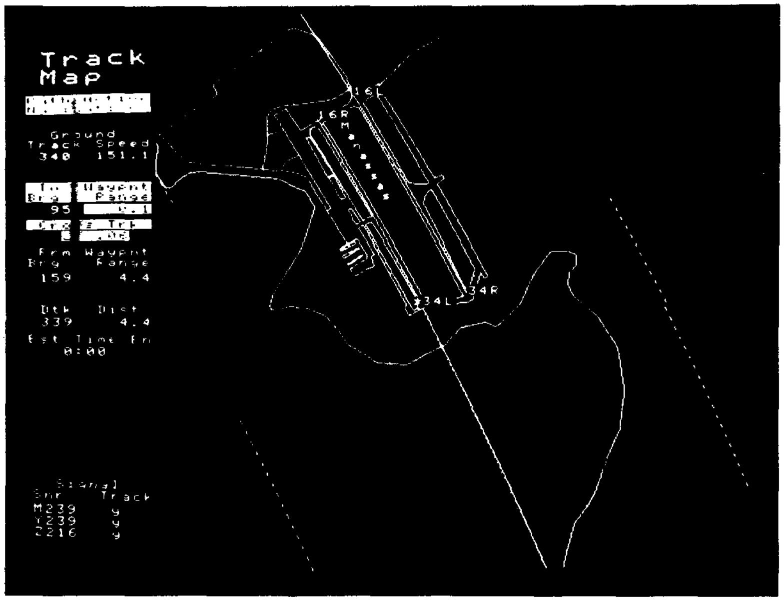
INTRODUCTION

A four-day educational display of Loran-c capabilities was demonstrated in Washington, DC to interested government officials and staff members in late July. The purpose of this display was to demonstrate the capability of Loran-C equipment in displaying an accurate position and to show the flexibility current Loran-C equipment offers.

It became apparent that many people were not aware of the capability of Loran-C and others thought of Loran-C as "old World War II technology" that was difficult to use and would not work in today's environment. The obvious solution was to offer the decision makers a first hand look at Loran-C in action.

A variety of equipment was used to make the demonstration practical and understandable to everyone, even if the participants knew nothing about aviation or Loran-C. The primary display involved a II Morrow, Inc. Vehicle Tracking System (VTS) modified for airborne use to show a visual picture of the aircraft's position on a video map displayed by a 19-inch color monitor. Advanced Navigation, Inc. provided a working model 7000 receiver control unit for the participants to see and operate if they desired. It was pointed out to the passengers that the aircraft was using the model 7000 to navigate with and the video display was being driven by a II Morrow, Inc. Apollo II Loran-C unit with no connection between the two systems.

The audience was expected to contain a mix of people whose knowledge of aircraft navigation procedures ranged from rated pilots to those who had never flown. Therefore, the display must be understandable to the uninitiated. The intent of the flight display equipment was to convey to the passengers in the DC-3 a plan view of the area to be flown with the position of the aircraft leaving a trail on the map containing the highlights of the terrain below. More details in the map were to be shown as sections of the map were expanded. This included lines depicting the accuracy requirements for nonprecision approach around the subject airport, as shown in Figure 1.



Track
Map

Ground
Track Speed
340 151.1

To Waypnt
Brg Range
95 [illegible]

Frm Waypnt
Brg Range
159 4.4

Dtk Dist
339 4.4

Est Time En
0:00

Signal
Snr Track
M239 y
Y239 y
Z216 y

Figure 1. Nonprecision approach accuracy lines on Manassas Airport detail map.

II Morrow was uniquely qualified to assemble the required display-tracking system since both disciplines are contained within products presently being produced by the company. The display technology is fully developed in the VTS being used by police agencies and transit companies and the Loran technology is from the Apollo II line of very successful low cost airborne Loran navigators.

As described later in this paper, the VTS system usually tracks a large number of remote vehicles by polling and displaying their ID's on a detailed street map. In addition all vehicles being polled and their status are shown next to the map. The VTS control console software program was modified to track a single aircraft, with the option of leaving a trail. Instead of status, the navigation data, supplied via the Apollo II RS232 bus, was displayed. This allowed the passengers to evaluate the along track and cross track data in addition to the dynamic map display and the real world as seen out the aircraft windows.

WASHINGTON, DC DEMONSTRATION

The National Association of Aviation Officials sponsored the four-day demonstration of Loran-C RNAV capabilities in the Washington area 23 to 26 July 1985. This demonstration was held in conjunction with the third in a series of

FAA/NASAO working group meetings coordinating the nonprecision approach implementation program. Invitations to participate in the flight demonstrations were made to members of Congress, their staffs, DOT/FAA and state aviation officials, other government agencies, aviation organizations, and the press. The event was supported by Racal-Megapulse, Inc., II Morrow, Inc., Advanced Navigation, Inc./ONI, Northern Airways, Inc., and Polhemus Associates, Inc.

Installation. The flight hardware was installed, under the direction of Mr. W. Polhemus, in a DC-3 aircraft at the Northern Airways Facility in Burlington, Vermont, prior to being flown to Washington National Airport. The display system hardware consisted of a VTS control console modified with the special airborne software, a 19-inch high resolution color monitor, an Apollo II Loran Navigator, a 28-VDC to 115-VAC converter, and interconnecting cables. The complete system was mounted in a rack that was installed forward in the passenger cabin on the starboard side, as shown in Figure 2. The 19-inch color monitor was situated high in the rack so visibility was good throughout the cabin. In addition equipment was developed to record the navigation data received from the Apollo II for reconstructing the entire flight through the VTS system. A block diagram of the system is shown in Figure 3.

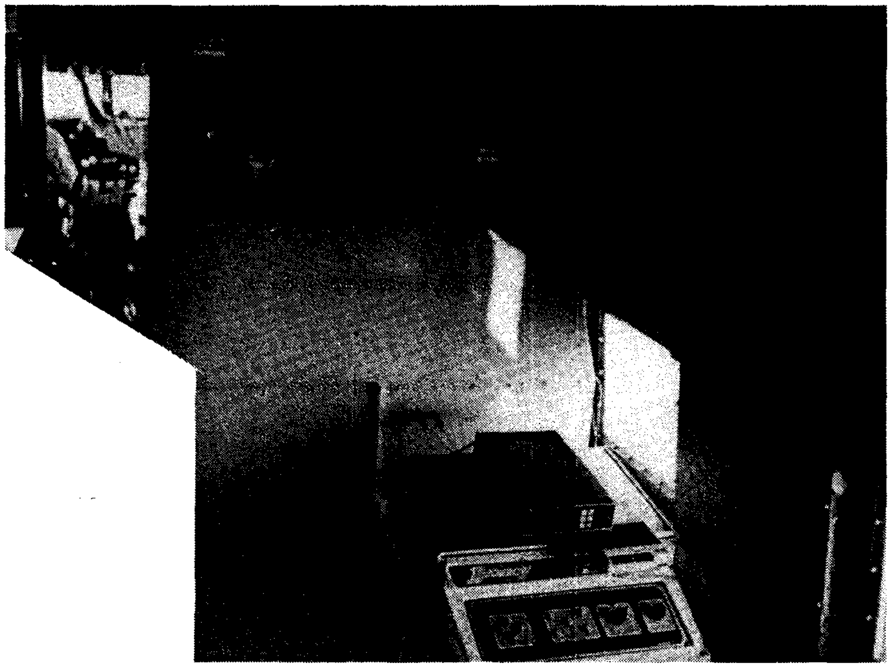


Figure 2. VTS tracking system installation in DC-3.

Map Details. The Washington area map presented on the color monitor was developed at the II Morrow factory from 1/24000 scale maps produced by the U.S. Geological Survey. The desired detail was first identified on the paper map and then digitized using a Hewlett Packard graphics terminal and a Houston Instruments digitizing pad. Three colors were used to develop the Washington demonstration map:

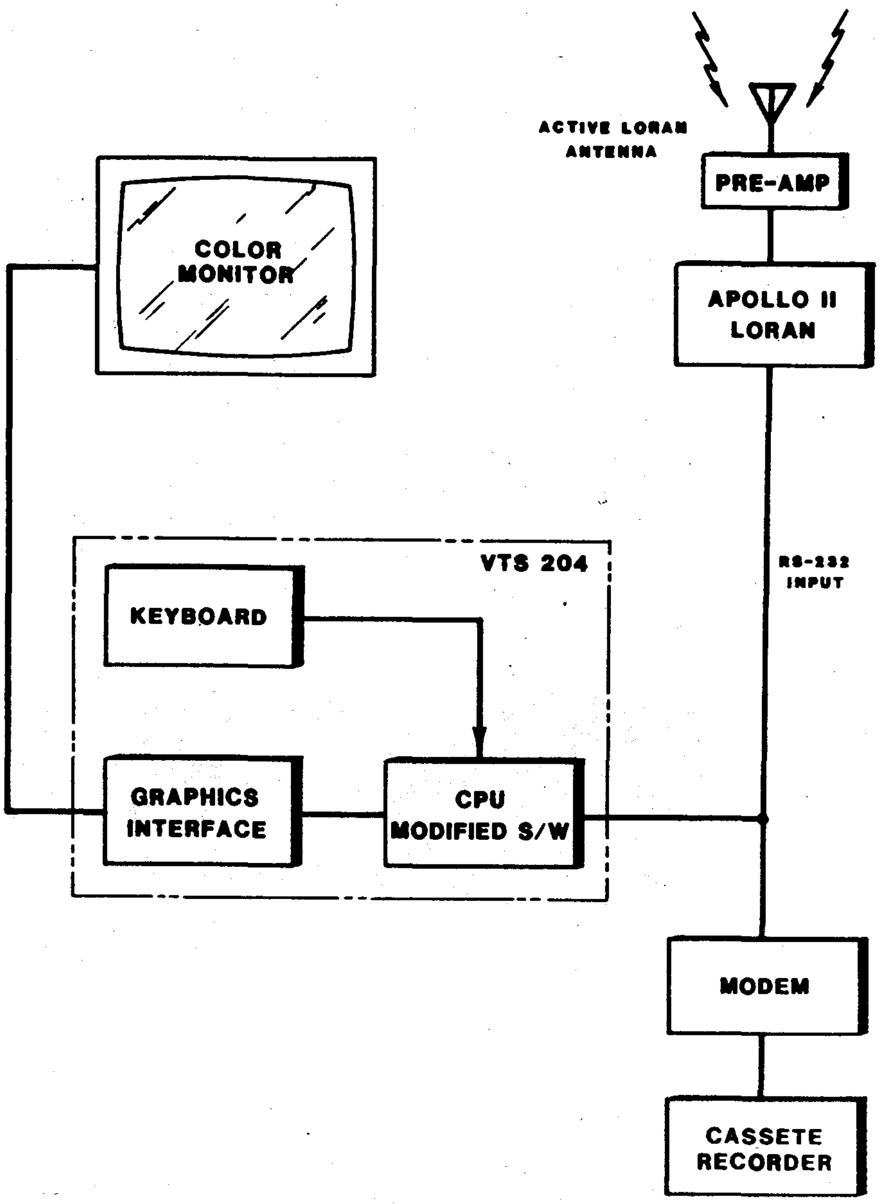


Figure 3. Aircraft approach monitor system.

- blue for rivers, streams, and lakes
- green for airport details, major highways, and streets
- magenta for navigation details

In addition, solid, dashed, and dotted lines were used for further definition. When displayed on the monitor this kind of detail allowed great flexibility and ease of quickly identifying multiple details that might otherwise be missed.

The three airports of interest, National, Manassas, and Dulles, were digitized in great detail. Precision runway threshold coordinates obtained from FAA flight services were used to construct exact runway center lines which extended 5 miles from the airport. These magenta lines provided instant identification of airport locations on the full map. On the expanded map of each airport, these lines provided the means to monitor progress during the nonprecision approaches. Nonprecision approach crosstrack requirements of AC90-45A were shown as parallel dashed magenta lines drawn 0.6 nm to either side of center line on the Manassas map. To emphasize realistic Loran accuracy requirements, dotted magenta lines were placed 900 feet on either side of centerline. National and Dulles airports were also digitized in detail but only the centerline extensions were added to all the runways. When the desired details had been digitized, the data was transformed and formatted to reside in EPROM. 128 Kbytes of map EPROM capacity was available in this console. Airport and pattern details are depicted in Figures 4 and 5.

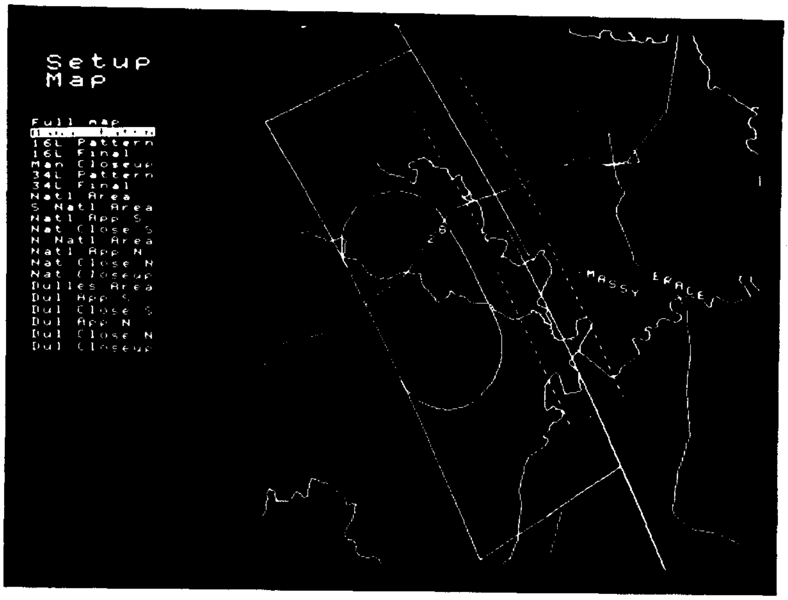


Figure 4. Manassas Airport pattern details.

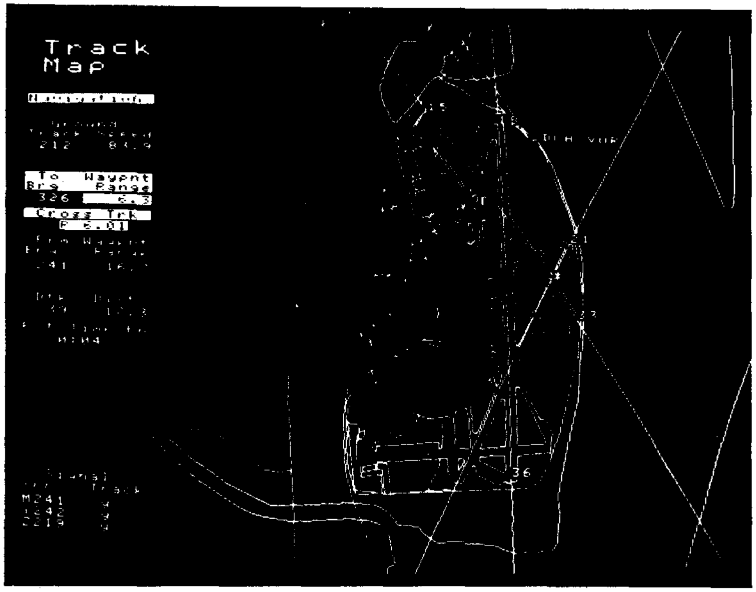


Figure 5. National Airport details.

The full map, shown in Figure 6, covered an area of approximately 30 nm by 30 nm and pictured upper level terrain detail, nav-aid locations, major highways, major rivers, and airport runway extensions. This level was very useful for enroute navigation and displaying a complete picture of the entire flight. Seven levels of ever-increasing detail were available for display. These expanded levels could be reached by either a zoom function or menu selection. The zoom operated by positioning a revical on the desired area on the map and then reducing the revical size. The area within the revical could then be expanded to the full screen size bringing out all the detail stored at that level. The fully expanded map detailed an area of about 2 nm by 2 nm. At this level, for example, all of the taxiways at a selected airport would be displayed.

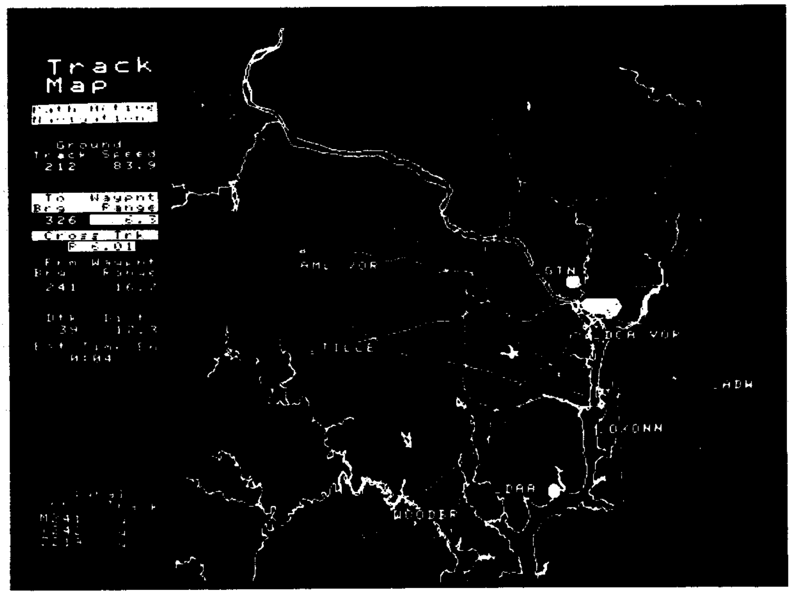


Figure 6. Full map of Washington, DC area with path of DC-3 flight.

Calibration and Ground Truth System. The DC-3 arrived from Vermont at Washington National Airport on Monday, 22 July. Static demonstration equipment and aircraft support equipment were unloaded and set up at the FAA's Flight Operations Section in Hanger 6. All briefings, debriefings, and flight operations were conducted with the very able help from the FAA staff at this facility. A short check flight was scheduled in the afternoon for calibration and final detail resolution.

The Apollo II receiver was set to operate on the Northeast U.S. Chain (GRI 9960) with Seneca as the master and Carolina Beach (Y) and Dana (Z) chosen for the secondaries. This configuration was used throughout the demonstration. With the receiver in track the aircraft was taxied to each of the runway ends and the Loran-C derived position were recorded and compared to the known runway end positions. From this data initial correction factors for Δ latitude and Δ longitude were calculated and inserted into the Apollo II Loran-C navigator.

The aircraft was then flown on the intended demonstration flight route to Manassas County Airport where the aircraft landed and runway-end data was again recorded. This data was compared to the actual positions and together with the data from National Airport a final pair of calibration numbers were calculated and inserted. These values were also used throughout the flight demonstrations.

Dynamic taxi runs were then made on both Manassas runways checking the aircraft symbol position and the map runways to actual positions visually. Next, the aircraft was taken airborne and approaches were made to RW16L using the Instrument Landing System (ILS) to verify position of the map pattern data and aircraft cross track position on final approach. Along track was verified visually by comparing aircraft reported position when crossing the runway thresholds.

The calibration/test flight was completed by flying from Manassas back to the Woodbridge waypoint then up to the Georgetown NDB for an approach and landing at National Airport RW15. Manassas Airport had been chosen to keep our demonstration flight out of the heavy Washington, DC, air traffic and because RW34L had no approach landing aids which is similar to thousands of runways across the U.S

Flight Operations and Results. Demonstration flights commenced on Tuesday, 23 July 1985 flying similar routes to the check flight with the exception that a low pass was made over Manassas Airport rather than touching down. Each flight took about 45 minutes to complete. Nine flights in total were made, one was cancelled due to a heavy rain storm. In all, 105 invitees participated in the flight demonstrations; the most notable of whom were Admiral Donald Engen, Administrator of the FAA, and Admiral Theodore Wojnar, Chief of Navigation Branch, USCG.

As can be expected air traffic in the Washington, DC area was heavy and direct routes to the waypoints were not always possible but air traffic control worked with the program as much as possible. Approaches were flown to both Manassas and National Airports and every approach was on or very near the runway center line. The largest deviation from centerline on final approach was judged to be less than 200 feet. The tracking display system worked flawlessly, continuously displaying the aircraft position and leaving a trail behind of the path made good on the selected map display. Aircraft navigation data of the three flights on 26 July were recorded on cassette tapes. This data can be played back through the VTS system and recreate the flight display for analysis and demonstrations. In this mode the map display is controlled independent of the navigation data so that particular details of the flight can be highlighted and analyzed.

Comments from the participants at the debriefing emphasized that they had gained a real appreciation for the inherent accuracy and utility of Loran-C and had a better understanding from the manner in which the details were displayed.

VEHICLE TRACKING SYSTEM (VTS)

General System Description

The approach monitor system used in the Washington, DC demonstration is a modification of the II Morrow vehicle tracking system. VTS is a production tracking system being used by police and sheriff's departments, security agencies, and transit companies across the United States and in a few foreign countries.

The system is capable of tracking airborne, marine, and terrestrial vehicles. The following is a brief description of how the VTS operates.

Technical Description. The II Morrow, Inc. Vehicle Tracking System (VTS) operates through the interaction of three major functions:

- Mobile unit position location;
- Formatting and transmission of data;
- Central control and display.

A block diagram is shown in Figure 7. The mobile Loran units operate continuously tracking latitude and longitude of their vehicle's position. Every unit has an identification number equivalent to the vehicle identifier. Each unit is also connected to the vehicle radio's receive and transmit circuits.

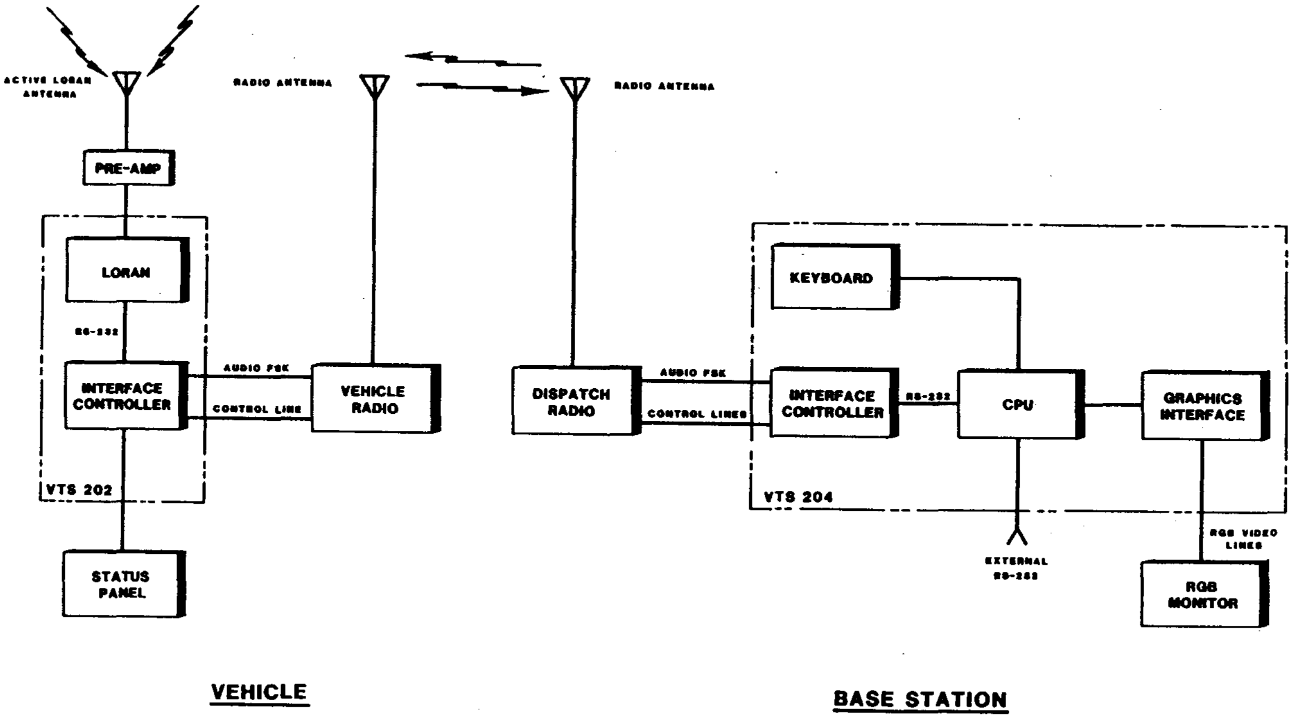


Figure 7. VTS system block diagram.

The control console located at the center of operations is set up by the operator to automatically poll selected vehicles by their identification number. The control console is connected to the base radio and handles transmission and reception of data.

The transmitted vehicle identification request message (poll) is received by all vehicles on the same frequency and is recognized by the identified vehicle's mobile unit. The mobile unit retrieves the latest latitude and longitude position. This position data, status panel message, and Loran receiver status are all formatted with the vehicle identifier and this data message is transmitted.

The base control console receives the data response to the polled request, analyzes the message, and processes and displays the received information on a high-resolution color monitor. The monitor shows a map with the streets of the area of interest displayed in green. The vehicles are shown as yellow rectangles inside of which is the alphanumeric designation of each vehicle. As vehicles are updated, vehicle rectangle will move to the new location as of the moment they were polled and updated. Approximately 40 vehicles are updated every minute. A map area 360 miles by 360 miles on a side can be displayed on the monitor. The map can be manipulated from the console by use of a menu or a revicle to zoom down to an area as small as four square miles, bringing out the details of the area. In addition to tracking data displayed on the map, communications and Loran status are also shown on a matrix next to the map.

While map tracking is the principal monitoring device used with the II Morrow VTS, a backup mode called the "track table" is an integral part of the system. In "track table," all vehicles being polled are listed. The offset north or south, east or west, from a commonly known landmark is printed to a resolution of a hundredth of a mile; the vehicle's signal status and operational status are shown, as is the time of last poll and the time of last status change. This data stream can also be transmitted via the RS-232 data port to a computer or a printer for record keeping and analytical purposes.

At the preselected interval, the next vehicle identifier request is transmitted by the control console in a poll message and the process is repeated. In addition to this standard polling method, a non-polled data transmission will be made from the mobile unit whenever a status panel button is depressed.

An eight or sixteen button status panel is also available. Mounted in the vehicle, it allows the operator to transmit status information to the control console. This status information is displayed on the status matrix as a letter or number.

A silent alarm or officer-in-distress transmitter is also available, either as a button on the eight or sixteen button array or as a separate floor-mounted button to be activated by foot. Upon activation of the silent alarm, the display of that vehicle on the TV monitor turns red, as does its status block, and an audible alarm is sounded. If the vehicle is not on the map segment being displayed, the map is automatically redrawn to place the vehicle in distress in the center of the map.

CONCLUSIONS

Much is being said about the rapidly growing support that Loran is now seeing.

- Advocacy position by the FAA
- DOD dual system philosophy
- Nonprecision approach program
- Support from aviation organizations
- Expanding world use
- Articles monthly in aviation magazines.

These things are all true and it makes those of us in the Loran community feel as if there is general understanding about the benefits that Loran has to offer here and now. I think the fact remains that the number of people who know ad understand are a very small minority. Loran is perceived by many to be an old system with old technology, that it is inaccurate and unreliable. That the chains will soon be shut down. What does exist is a lot of confusion about what the truth really is. What needs to be done is for the Loran-C community to continue taking the message to the public and the elected and non-elected officials. Much confusion has been generated. What needs to be done is for the

Loran-C community to continue taking the message to the public and the elected and non-elected officials that Loran-C is an accurate reliable system that utilizes state-of-the-art technology in both transmitting and receiving equipment. It is an extremely valuable navigation aid for high- and low-altitude flight operations, terrestrial applications, and seaboard navigation. This demonstration showed one way this message can be presented very effectively. I hope the Loran-C community will build on these results and double our efforts to expand Loran-C coverage, utilization, and understanding for the vast economic and safety improvements it holds for the United States and other countries of the world.

ACKNOWLEDGEMENTS

Recognition is due for the significant contributions made in the development of the VTS hardware and software from conception to operational systems by Lyle Gibby and Mike Liechty of II Morrow, Inc.

BIOGRAPHICAL INFORMATION

Larry Cortland
II Morrow, Incorporated

Larry received his BS in Electronic Engineering from California State Polytechnic University in 1961. He has spent over twentyfour years with navigation systems. Six years were spent with Litton Guidance and Control in support and development of Inertial Guidance Systems. He was with Teledyne Systems Company for seventeen years working directly in the support and development of Loran receivers and other navigation systems. At II Morrow, Inc. Larry is a product development specialist responsible for the Terrestrial Vehicle Tracking System (VTS).

AUTOMATIC DEPENDENT SURVEILLANCE INFORMATION TRANSFER REQUIREMENTS

William L. Polhemus

Polhemus Associates, Inc.
Cambridge, Vermont

ABSTRACT

This paper summarizes the results of an evaluation of Blunder and Error History within North Atlantic Oceanic and Remote Airspace as reported by the International Civil Aviation Organizations' North Atlantic Systems Planning Group. The purpose of the evaluation was to assist the Federal Aviation Administration in its study of desired characteristics of a future Automatic Dependent Surveillance system for oceanic air travel.

A requirement of any ADS system is for a highly reliable and accurate navigation system. Loran-C RNAV systems are candidates for some oceanic operating areas. When the FAA implements ADS within domestic airspace the navigation information will be supplied by Loran-C and GRP equipment.

The project from which this paper was drawn was sponsored by the DOT/Federal Aviation Administration, Systems Studies Branch, AES. Program Management was provided by Dr. R. Kalafus, Transportation Systems Center.

Introduction

The FAA and some segments of the air transport industry have for some time been interested in the implementation of automatic dependent surveillance as a means to increase safety of operations in non-radar oceanic and remote-area airspace. Used in conjunction with improvements in communications and navigation system performance, and introduction of automated air traffic control data processing and display, it is anticipated that significant reductions can be effected in the separation between aircraft. Success with implementation of these capabilities and reduction in spacing would permit more aircraft to operate on the Minimum Time Track between departure/destination pairs and nearer to the Optimum Altitude Profile which in turn would reduce operating costs.

This paper presents a summary of the causes of blunders, errors, misunderstandings and equipment inadequacies, as determined by ATC resources, occurring in North Atlantic Airspace during the 32 month period 1 Mar 1982 - 31 Oct 1984. This information is to be used to assist in determining information needs, reporting rate, and system requirements of on-aircraft ADS systems.

The Operational Need

The allowable horizontal separation between aircraft depends in part upon capabilities of the aircraft navigation system and in (very large) part upon the availability to Air Traffic Control, of credible evidence of position, direction, speed and intentions. Within domestic airspace this evidence is provided by explicit measurement of position by ground based radar observation of aircraft. Aircraft conformance with ATC-clearance is established thru frequent ground-based radar measurement of aircraft position and direct, real-time communications between Controller and Aircrew, thus avoiding the consequences of errors, blunders and or misunderstandings.

Over ocean, when aircraft are beyond radar range, only procedural discipline is available. Safety is assured by increasing the interval between aircraft to relatively large values in recognition of the limitations in navigation equipment, the chance for blunders and or misunderstandings, and the limitations in communication.

In the absence of independent surveillance information, the Air Traffic system becomes entirely dependent upon the correctness of the information obtained from the on-board aircraft navigation system as interpreted by aircrew. The lack of LOS communication necessitiates use of HF communications, 3rd party relay and consequently unacceptably long intervals between communications.

Of particular concern is ATC's inability to detect the frequent occurrence of human error: either in the control and interpretation of navigation systems; in occasional Controller-to-Aircraft communication misunderstandings leading to operation outside of assigned airspace; in failure to report equipment malfunctions or failures so that adjacent aircraft flight paths may be adjusted; or as evidenced by a relatively high incidence of improperly or incompletely equipped aircraft unsuccessfully attempting to meet the navigation standard while operating within Oceanic Airspace.

Organization of the NAT Airspace

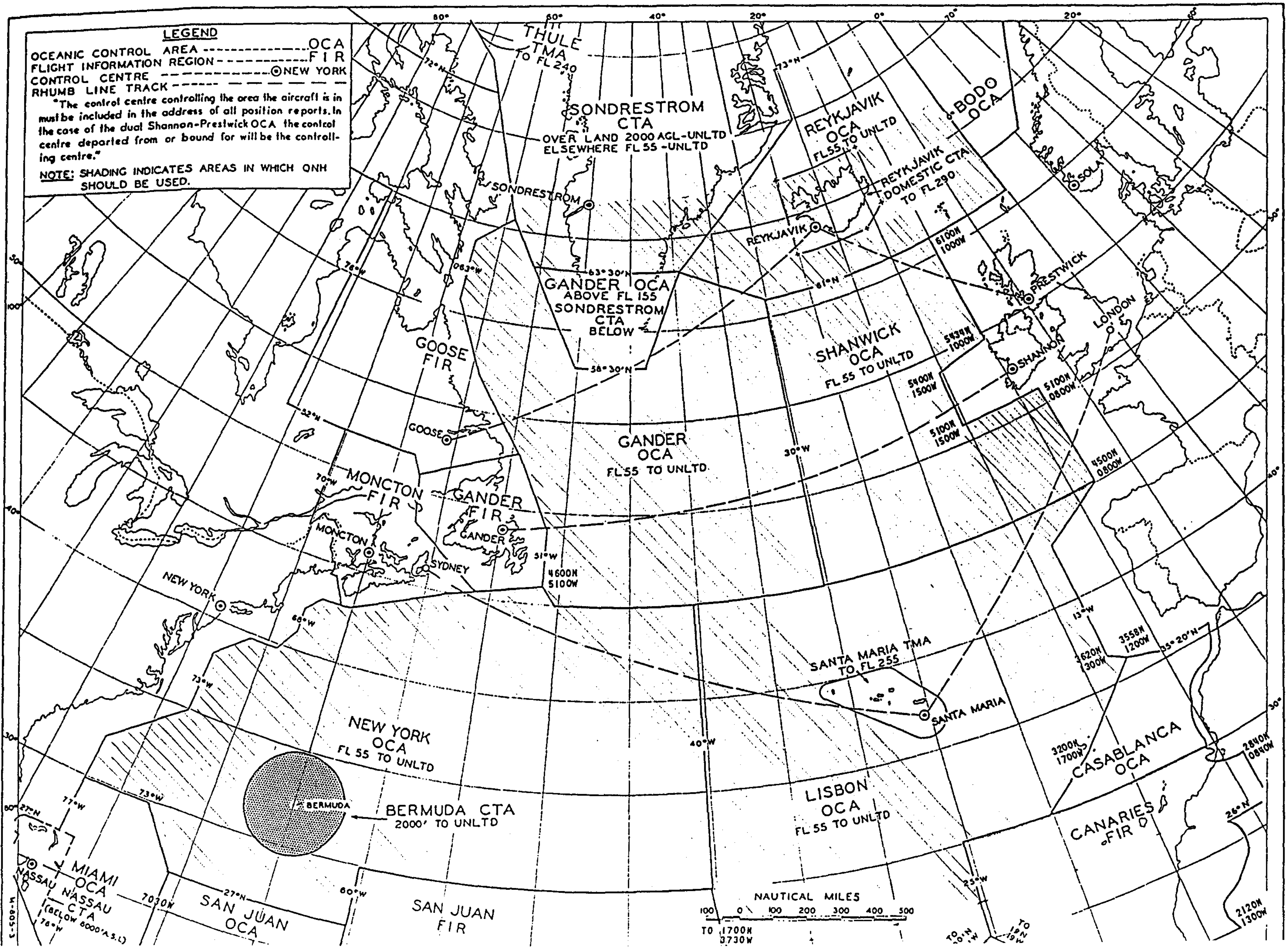
The investigation described in this paper is restricted to consideration of that portion of North Atlantic Oceanic Airspace which is situated between Latitudes 27°N and 67°N, bounded on East and West by the European and the North American continents, the shaded area of Figure 2-1.

Within this region the ICAO has designated four categories of airspace:

- A region called the NAT Minimum Navigation Performance Specifications (MNPS) Airspace.
- Within MNPS Airspace a sub-region called The Organized Track System (OTS) Airspace.
- The portion of MNPS Airspace identified as Not-OTS Airspace, and
- The remainder of the North Atlantic Region below and above the levels reserved for MNPS airspace operations, called Non-MNPS Airspace.

FIGURE 2-1

NORTH ATLANTIC CONTROL AREAS



The NAT Minimum Navigation Performance Specification Airspace

If the Oceanic airspace were thought of as a Club Sandwich, one would consider the bottom and top layers as low-density regions inhabited in the former case by reciprocating engined and turboprop equipped aircraft, and the latter by SST and a small number of very high altitude corporate jets. The lower layer extends from an altutude of 3000 feet to a height (Flight Level) of 27,500 feet; the upper layer begins at a height of 40,000 feet and extends upward therefrom to limits of aircraft operating altitude.

Between these two layers there exists a region which is relatively densely populated by turbojet aircraft. A small number of turboprop aircraft enter the lower portion of this special airspace but it is primarily the domain of the jet.

Because of the large numbers of aircraft seeking to use this particular altitude band special procedures and standards have been invoked by the member states to ICAO to assure minimum risk of collision or conflict. This airspace is called the Minimum Navigation Specifications Airspace.

This region between Flight Levels 275 and 400 has been reserved for MNPS Airspace operations. The regions of NAT Airspace which lie south of the 27th parallel, or north of the 67th parallel, or are above FL 400 or below FL 275 are considered non-MNPS airspace. These areas do not require the explicit certification of equipment, crew and/or procedures defined in the ICAO-MNPS Specifications; however aircraft operating within NAT Oceanic Airspace are required to be appropriately equipped for long range navigation.

The geographic boundaries are defined north/south as stated above; the Eastern Limits are set by the eastern boundaries of Santa Maria (Lisbon), Shanwick and Reykjavik Oceanic Control Areas (OCAs); and the Western Limits by the western boundaries of Reykjavik, Gander and New York OCAs (exclusive of the area of the New York OCA which is west of 60°W longitude and south of 38°30'N latitude. This latter area comprised the western Atlantic - Gulf of Mexico Minimum Navigation Equipment Required Required Region (MNER), Figure 2-2.

In addition to the problems which differences in aircraft cruise speed and cruise altitude pose for the Controller there is also the problem of handling crossing routes, joining and departing traffic and the occasional deviation in altitude, heading or track requested by aircraft encountering difficulties. The North Atlantic Route Chart illustrates the complexity of the traffic separation problem, Figure 2-3.

The MNP Specifications.

An operator desiring to use MNPS airspace is required to demonstrate to his respective licensing authority that the Aircrew, Aircraft and its associated navigation equipment and the standard operating procedures of the Operator are in conformance with the MNPS Separation Standard set forth below.

MINIMUM NAVIGATION EQUIPMENT REQUIRED
ATLANTIC/GULF OF MEXICO/CARIBBEAN

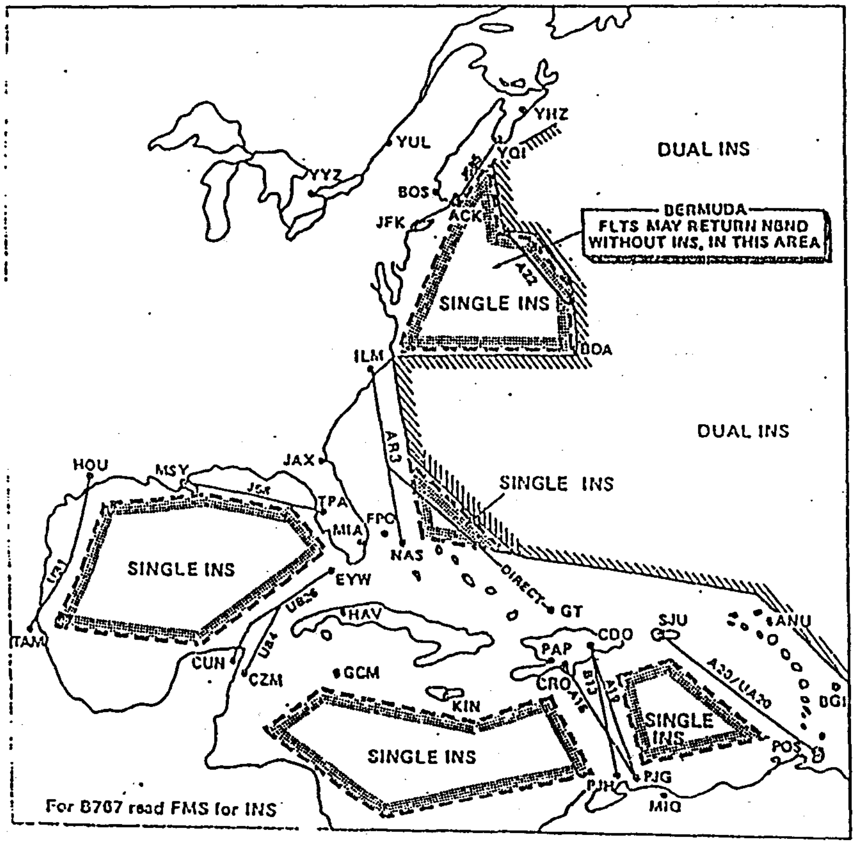
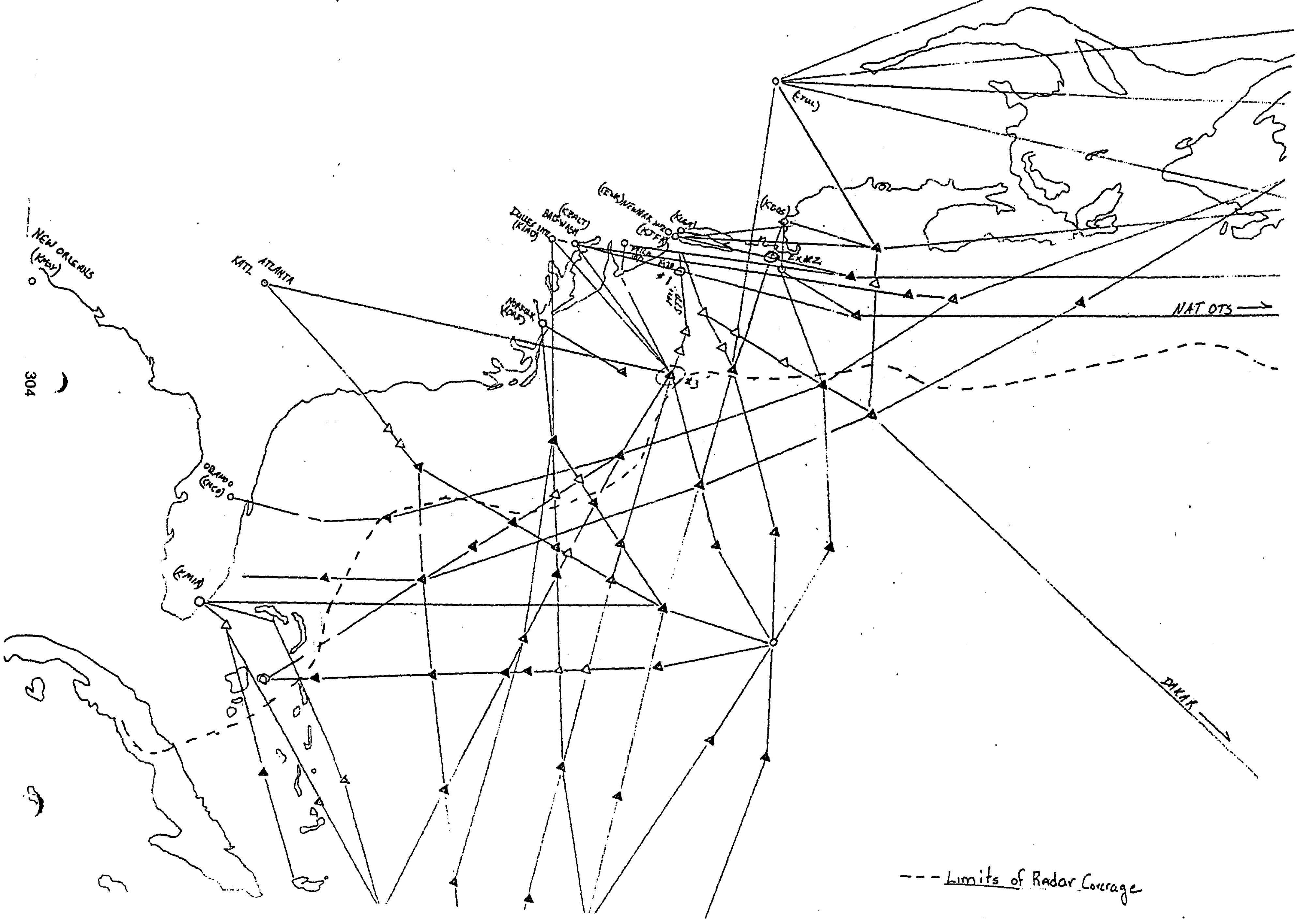


FIGURE 2-2

WESTERN ATLANTIC (NY OCA) CROSSING POINTS



(1) The following systems are judged to be capable of meeting NAT MNPS Performance Criteria:

- Inertial Navigation Systems (INS), Dual Installation
- Omega Systems, Dual Installation
- Single INS with Omega System for position update
- Single Doppler-Radar Navigator, plus Computer with Omega update, and
- where coverage is deemed adequate, Loran-C may be used to update INS or Doppler System in lieu of Omega.

(2) Navigation Performance. The minimum performance required of a navigation system intended for use in the NAT MNPS Airspace is a function of the lateral separation interval....... the 'One Standard Deviation' value is set at approximately 1/10th of the interval. For the present this quantity has been set at 1 s.d. = 6.3 nm.

A second consideration is system integrity or reliability which is specified as " the proportion of total flight time spent by an aircraft 30 nm or more off track shall be less than 1 hour in 1900 hours". The Specification further states that the proportion of total flight time spent by an aircraft between 50 and 70 nm off the cleared track should be less than 1 hour in 8,000 hours.

Separation Criteria

Separation intervals within the NAT Oceanic Airspace are set forth in Table 2-1. The criteria for the MNPS Airspace are presented for both 1985 and for 2 future-year target dates, suggested by ICAO. These are called MNPS-Improved and MNPS-Advanced standards. The target dates for implementation of the indicated reductions in separation are 1995 and 2005, respectively.

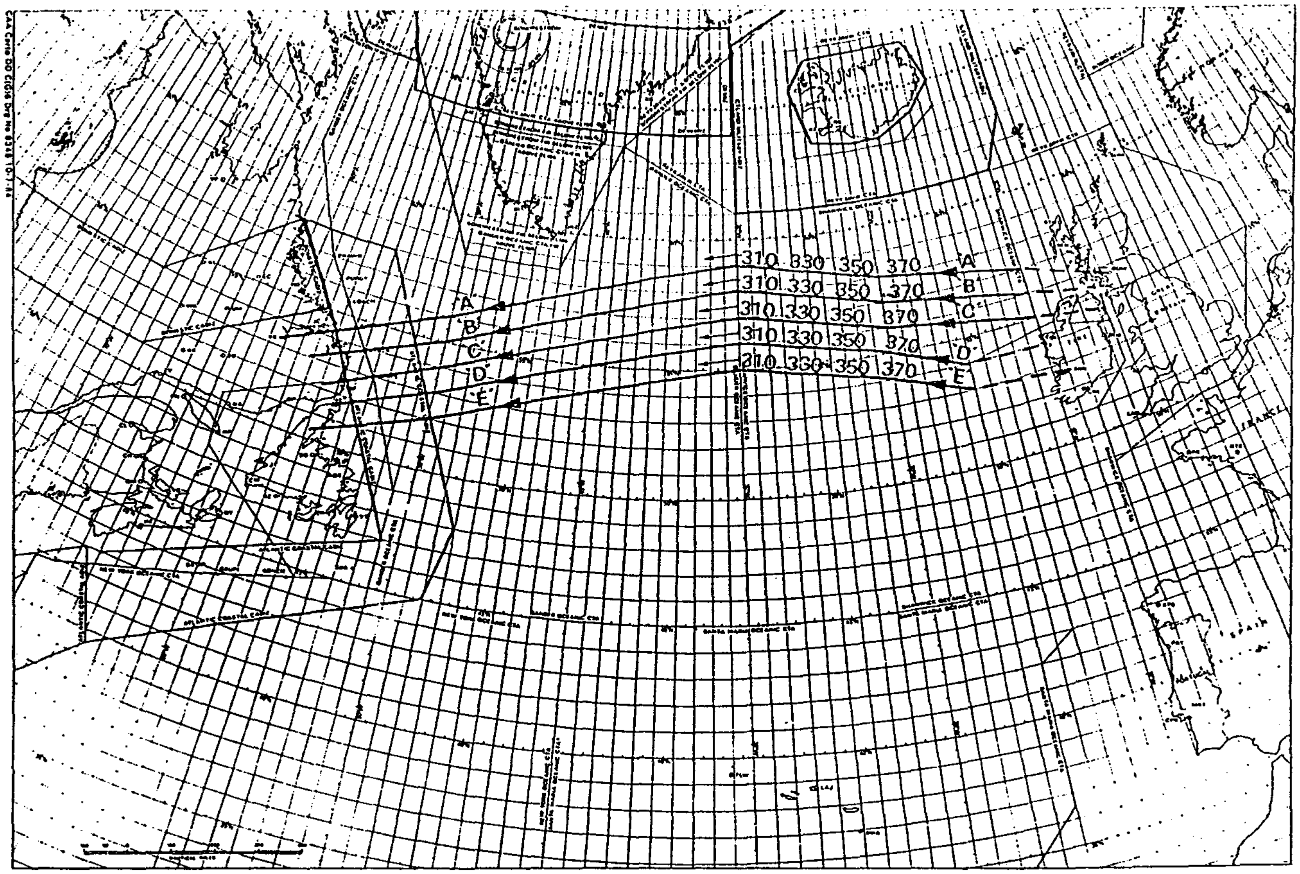
AIRSPACE/CAPABILITY	SEPARATION DISTANCES		
	Lateral (nm)	Longitudinal (minutes)	Vertical (Ft)
NAT-Uncontrolled	90	20	2000
Non-MNPS Airspace (NAT-Controlled)	60	15	2000
MNPS -1985	60	15	2000
		PROJECTED CRITERIA	
MNPS - Improved - 1995	30	5	2000
MNPS - Advanced - 2005	15	2	1000

SEPARATION INTERVALS
TABLE 2-1

The Organized Track System (OTS) Airspace

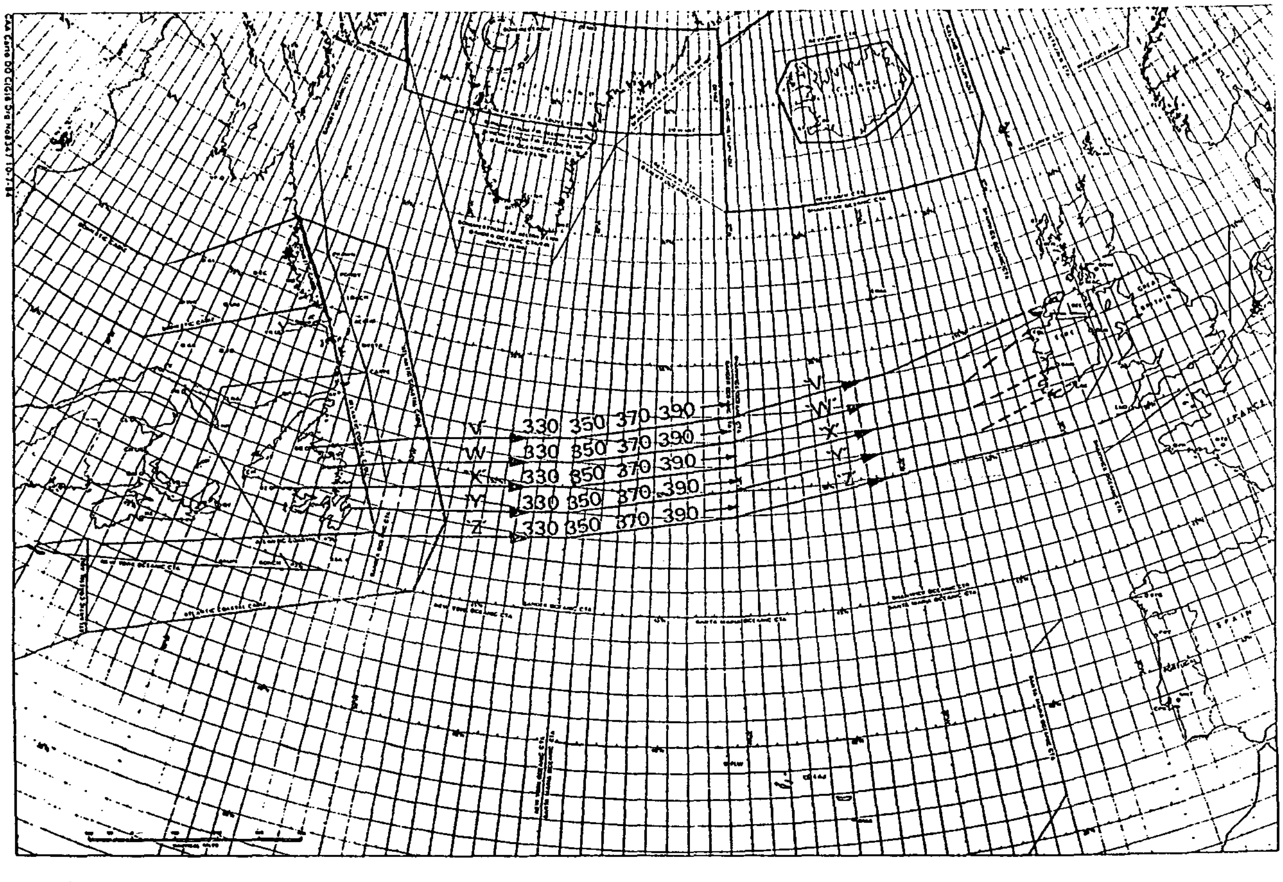
The NAT Organized Track System is a family of parallel flight paths located within a block or prism of airspace sandwiched within the MNPS Airspace. It is designed to facilitate movement of the principal turbojet traffic operating between Europe and the North American Continent, Figures 2-7 a,b,c. The OTS prism is limited to a maximum of six Flight Levels spaced 2000 feet apart beginning at FL 290 and topping out with FL 390. The flights paths are constructed so as to be separated by an interval of 60 nm, approximately parallel to the Minimum Time Track between North America and Northern Europe. This family of tracks is usually altered twice daily to accommodate the daily shift in traffic from daytime westward (minimum Headwind) to nighttime eastward movement (maximum Tailwind) as dictated by the high altitude wind patterns.

The limits of the OTS are defined by boundary lines located, respectively, 60 nm north and 60 nm south of the outer-most "tracks of the day". Figure 2-7c shows that the OTS prism resides within MNPS airspace. Outside OTS airspace, and between FL 275 - 400 the airspace is defined as "Not-OTS MNPS Airspace" but remains MNPS Airspace. Thus, for traffic not desiring to operate between OTS



Example of Day-time Westbound Organised Track System

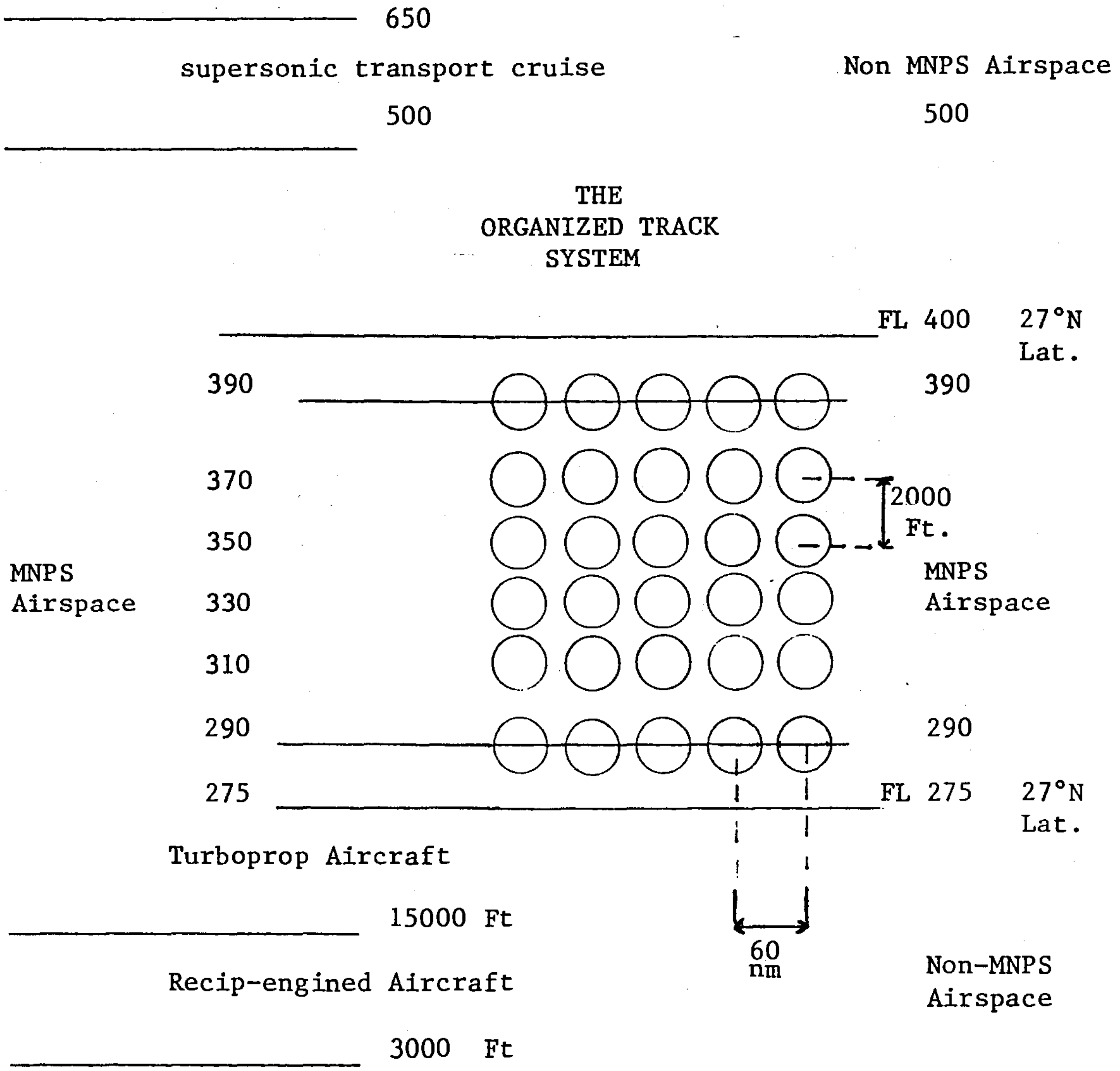
Figure 2-7a



Example of Night-time Eastbound Organised Track System

Figure 2-7b

THE ORGANIZED TRACK SYSTEM



Entry/Exit points, authorization can be obtained from ATC to operate on 'random' flight paths adjacent to the OTS at, or above, or below the Flight Levels reserved for the OTS.

Within the OTS provision is made, in the event of emergency, to isolate an aircraft requiring assistance from others on the same or adjacent tracks so that it may eventually be cleared from the OTS track and Flight Level to an alternate profile.

To gain approval to utilize the OTS an aircraft operator must first be granted Operational Approval for entry to the MNPS Airspace. The navigation performance required within the OTS is the same as for operation within the MNPS. Approximately sixty-five percent of operators utilizing the NAT MNPS also operate within the OTS. The remaining flights do not use the OTS for various reasons (i.e. because their destinations are in Iceland, or Scandanavia, or Southern Europe, etc.)

Causes of Error in Navigation

The descriptor 'Error' is used to include Errors of Information, Operator Errors or/and Blunders, Misunderstandings, Equipment Failures or Malfunctions, and Unsatisfactory Performance in Navigation resulting from entry to the airspace of unqualified aircrews or improperly equipped aircraft.

The existence of 'Errors in Navigation' were detected by the Air Traffic System radars located at facilities along the coasts of Newfoundland, Labrador, Iceland, Ireland and Scotland, at a time when the offending aircraft was 200 to 300 miles from 'coast-in'. Thus the data do not tell us anything of the incidence of errors beyond 300 nm which are ultimately detected and corrected by aircrew prior to coming within range of radar surveillance.

A special class of offenders is identified in the ICAO data called 'Not MNPS Certified'...it is noted that fully 26 percent of the offenders reported on appear not to have been qualified to operate within the MNPS. (Meaning not professionally qualified, equipment not adequate, or aircrew entered airspace with the correct but inoperative equipment. The following different configurations of equipment were reported by MNPS Airspace-Users despite the requirement that they use only those systems identified earlier.

	MNPS Qualified	Special Routes
Triple-redundant INS	Yes	Yes
Dual-INS	Yes	Yes
Single INS	No	Yes
Dual-Doppler	No	No
Dual Doppler plus Omega	Yes	Yes

	MNPS Qualified	Special Routes
Doppler-Omega	Yes	Yes
INS-DOP-Omega	Yes	Yes
Doppler-LORAN-C	Yes	Yes
Dual-Omega	Yes	Yes
AIRWAYS (VOR,DME,ADF)	No	Only G3,G11
AIRWAYS-Omega	No	Yes
AIRWAYS-INS	No	Yes
DOPPLER + Computer with Celestial	No	No

TABLE 3-1

Classification of Errors

The ICAO NAT SPG data classifies errors in navigation under the following headings:

- A - Aircraft not certified for MNPS Airspace operation
- B - ATC System loop error
- C - Equipment Control error including Waypoint insertion error
- D - Other navigation errors, including equipment failure notified to ATC in time for action to be taken
- E - Same as D, but notification occurred too late for ATC to take action
- F - Same as E, but notification not received by ATC (the middle man problem)

Classification A....Not MNPS Airspace Certified...also described as 'Not Qualified', 'Not Approved' and or 'Not Equipped' in accordance with the ICAO Standard.

Classification B....ATC-loop Errors...includes misunderstanding between aircrew and ATC, for example; Clearance misunderstood by Pilot, or Controller misunderstood Pilot's Request or his 'Read Back' of the ATC Clearance.

Other blunders listed under this classification included;

'Flew Wrong Route', manifested by a one degree error in Latitude attributed by SPG to misunderstanding of Clearance though one might have described the blunder as a Waypoint Insertion Error.

A third source of ATC-Loop error, called Communications Problem, might have been due to propagation anomaly or other environmental factor.

Classification C.....termed Equipment Control Error includes Waypoint Insertion Error. This class of errors accounts for the majority of violations among the 'old-pros' and will be of greatest interest to RNAV-system designers.

- Waypoint Insertion Errors....used to describe incorrect input of coordinates, or input of incorrect coordinates, or wrong sequencing of waypoints, etc.

- Failure to Cross-check between or among systems, say triply-redundant INSs, and thereby, failure to isolate a faulty system.

- Auto-pilot Steering Mode Selector left in HDG Mode.

- INS not properly aligned before take off.

- Improper Use of Equipment...due to lack of proficiency, lack of experience, or to use of equipment inappropriate to MNPS airspace.

Classification D (&E,F)....Equipment Failures and Malfunctions. Usually related to catastrophic failure or malfunction of such a nature as to make the navigation aid unusable so that aircrew was left with only a basic Dead Reckoning capability, the short range radionavigation aids and an uncertain knowledge of winds aloft.

- Omega System Lane Slip

- Inability to reconcile differences in readouts of position, direction and speed between Systems, i.e., between an INS and Omega System readout or between the two readouts of a Dual-Omega or Dual-INS installation.

Overview of NAT MNPS Airspace Navigation Errors

The NAT SPG data reports the execution of 207 blunders and errors related to navigation within the North Atlantic Region during the period 1 April 1982, to (approximately) 31 October 1984. During this period 242,774 ocean-crossing flights were completed within the MNPS portion of the NAT Airspace. The total flights completed outside MNPS Airspace were not reported.

During the 31 months beginning 1 April, 1982, the Central Monitoring Agency acquired data on 207 instances of errors in navigation, in the range 30 to 500 + nm, distributed as shown below.

		Total NAT Region	Non MNPS Airspace of NAT	All MNPS Airspace	Not OTS Airspace	OTS Portion of MNPS
Errors	30 nm	207	92	115	74	41
	60 nm	102	49	53	34	19
	100 nm	27	19	8	7	1
	200 nm	5	3	2	2	0
	500 nm	2	1	1	1	0
Total Flights		---	N/A	242,774	78,601	164,173

TABLE 3-2

Rate of Encroachment - MNPS Airspace

1982 - 1984

	Total MNPS	OTS of MNPS	NOT OTS of MNPS
Flights	242,774	164,173	78,601
Errors ≥ 30 nm	115	41	74
RATE		1/4004 flts (20 ds)	1/1062 flts (10.6 ds)
Errors ≥ 60 nm	53	19	34
RATE		1/8641 flts (43 ds)	1/2312 flts (23 ds)
Errors ≥ 100 nm	8	1	7
RATE		1/164,173 flts (820 ds)	1/11229 flts (112 ds)
Errors ≥ 200 nm	2	0	2
RATE			1/39,300 flts (393 ds)
		200 flts/day	100 flts/day

---

*assume 300 flts/day in Total MNPS distributed 200 to OTS and 100 to Not OTS.

TABLE 3-4

Distribution of Errors by Classification or Cause.

One hundred twenty-nine errors in navigation were detected within the MNPS Airspace during the 31 months of operations...in which 242,774 flights were completed. Table 3-5 shows the distribution of these errors:

"They did not belong in MNPS Airspace:, People Errors (ATC-Loop and Equipment Control Errors), and Equipment Difficulties (Failures/Malfunctions).

DISTRIBUTION OF ERRORS BY CAUSE

	Total Flights MNPS	TREND		
		'82	'83	'84
	242,774			
They did not belong in MNPS	32 (25%)	17 (30%)	10 (20%)	5 (21%)
People Errors	80 (62%)	32 (57%)	33 (67%)	15 (62%)
Equipment Difficulties	17 (13%)	6 (12%)	4 (17%)	17 (13%)
Total Errors	129	55	47	37

TABLE 3-5

Characterization of Errors.

Tables 3-8 (a), (b), and (c), summarize typical sources of errors and some of the individual actions which produce these errors.

Detection of Blunders

ATC-Loop and Equipment Control Errors including Waypoint Insertion Errors are classed as Blunders and attributable either to the Air Traffic Controller or to the Aircrew.

It is postulated that an automated electronic capability will become available by which the Air Traffic Service will be able to interrogate the on-board navigation and G&C systems, and thereby learn of the introduction of a blunder or the onset of unsatisfactory behavior of the navigation system.

The assumed capability would make possible the automatic verification

CAUSES OF ERRORS

MNPS AIRSPACE

ICAO NAT-SPG CLASSIFICATION	CATEGORIES OF ERRORS	CAUSES OF ERRORS	CONTRIBUTING FACTORS
- AIRCRAFT UNAUTHORIZED, IMPROPERLY EQUIPPED, AIRCREW UNQUALIFIED -			
A	Aircraft not MNPS Equipped and INFREQUENT Flyers	1. Military Operators	1. Ignorance of Required Procedures; aircraft not properly equipped; Aircrew not COMPETENT.
		2. Ferry Flights and Repositioning of Aircraft.	2. Aircraft Equipped Airways Only, Aircrew not qualified for Overwater Navigation; Unfamiliar with MNPS Procedures and Standard.
		3. GA Aircraft - Onetime Flights	3. Same
		4. ATC Inadvertantly Fails to Enforce Entry Requirements.	4. Aircrew inproperly indicates Certified for MNPS.
		5. Military Operators	5. Utilize Flight For Training Purposes; e.g., Doppler + Computer + Celestial.
- ATC/AIRCREW MISUNDERSTANDINGS -			
B - 1	ATC Loop Error	1. Pilot/Crew misunderstands Clearance	1. Language Difficulty, radio interference, Faulty COM Equipment, Cockpit workload, Experience/Training.
		2. Controller misunderstands read-back of Clearance	2. Language difficulty, Radio Interference, Faulty COM Equipment
		3. ARINC Personnel misunderstand and/or Relay incorrectly	3. Miscopying/relaying messages or clearances.
B - 2	Pilot FLYS Wrong Route	1. Can be ATC Loop Error	1. Pilot hears what he expects to hear said, rather than what is actually said; example, he had requested LIMA to 60°N10°W but is cleared LIMA to 61°N10°W...he flies the former and ATC separates aircraft on the basis of the latter.
B - 3	Communications Problems	1. Not Properly Equipped	1. No HF equipment on board, VHF range 200 nm - will provide adequate COM only on G3,G11 Special Routes
		2. Effective COM Blackout, Fading.	2. Propagation Anomalies

Table 3-8 a

CAUSES OF ERRORS

MNPS AIRSPACE

ICAO NAT-SPG CLASSIFICATION	CATEGORIES OF ERRORS	CAUSES OF ERRORS	CONTRIBUTING FACTORS
	- AIRCREW ERRORS -		
C - 1	Waypoint Insertion Error	1. Insert coordinates incorrectly or insert Incorrect coordinates	1. Transposional digits, selecting Adjacent Numbers, Improper Lat/Long. characteristic (N/S,E/W).
		2. Insert Coordinates in Incorrect Waypoint.	2. For example Coordinates for WP m inserted for WP n.
		3. Selects Improper Waypoint to Steer to (i.e., #2 to #4)	3. Skipping or selecting a forward Waypoint.
		4. Given incorrect coordinates in Flight Plan.	4. Received incorrect Data from Airline Flight Planning.
C - 2	Switch Operation	1. Autopilot Mode Select	1. Autopilot HDG/NAV Mode Select SW left in HDG Hold (Constant Hdg) rather than following NAV Mode Steering Error Signals.
		2. Waypoint Leg Change SW	2. Waypoint LEG CHANGE AUTO/MANUAL Selector SW unknwingly/inadvertantly left in MANUAL.
C - 3	Failure to Cross-check Navigation Systems	1. NAV System Error tied to Autopilot drift.	1. With respect ot Triply-Rudundant INS, failed to Select Best System; or DUAL-Systems, validate each , select Best; or Compare with DR.
C - 4	Initialization Procedures	1. Insufficient time to Align, Preflight Preparations	1. Initialization never completed Cycle, cold weather procedures not observed.
		2. Improper Alignment Procedures	2. Improper Ramp Co-ordinates used on ground to align system.
		3. Correct ramp coordinates not available.	3. Unplanned stop at unsurveyed Airport or parked on unsrveyed location on ramp.
C - 5	Improper Use of Equipment	1. Lack of Training/Experience (disregard Omega for DR/ Celestial or DOP-CELESTIAL.	1. In daylight, Single Line of Position/MPP (Unfamiliar with NAT-MANPS Operating Requirements.)
		2. Set-up Nav System incorrectly (new FMS)	2. Programming procedures not followed.
		3. Improper Use of Gyro/Compass System in Dual Omega or Omega-Doppler System.	3. Heading Reference Left in free gyro when should be in Magnetic or vice-versa, Magnetic Variation in Error, Gyro setting Error uncorrected, Gyro Procession correction not correct.

Table 3-8b

CAUSES OF ERRORS

MNPS AIRSPACE

ICAO NAT-SPG CLASSIFICATION	CATEGORIES OF ERRORS	CAUSES OF ERRORS	CONTRIBUTING FACTORS
	- EQUIPMENT PROBLEMS -		
D (& E,F)	Equipment Failure/Malfunction Anomalous Behavior		
		1. Single Isolated Failure	1. Unit failure, neglect of maintenance.
		2. Multiple Failures	2. Loss of signal, loss of Tracking abilities
		3. Propagation Anomalies	3. SID's, PCA's, Modal Interference, MET effects (thunder storms)
		4. Degraded Behavior	4. Aging, Excessive Gyro Drift, Accelerometer Err
		5. Software Problems	5. Programmed Improperly, defective.

Table 3-8c

of stored information, the position of relevant switches (i.e., Auto-Pilot steering mode), progress with respect to approved flight plan and significant deviations in speed, track, position, etc., in excess of specified threshold quantities. Some of the parameters one might monitor include Mach No., Altitude, Cross Track Distance, variation from last announced ETA, the differences in Lat/Long between on-board systems, etc.

Assessment of Navigation Errors, Mar. 1983 - Feb 1984.

The pressure to reduce separation between aircraft primarily affects the MNPS Airspace, thus emphasis has been placed on the OTS and the Not - OTS portions of the MNPS Airspace. During the 12 months referred to, the overall statistics appear as follows:

	Non MNPS Airspace	Not OTS Part of MNPS	OTS Part of MNPS
Flights Completed	UNK	30,888 (36.2%)	54,445 (63.8%)
Errors Experienced (> 25 nm)	38	36	13
Rate of Encroachment	UNK	1:858 Flts	1:4,188 Flts

With respect to operations within OTS Airspace during 1983-84, approximately 99.95% of all flights met the MNPS Standards, (i.e., 54,432 flights remained within ± 30 nm of assigned track).

Distribution of errors for the period is shown below. Note that for a number of cases two 'causes' were assigned: for example, an aircraft designated by SPG as Class A, Not MNPS-Certified, because it was equipped with only a single INS, was determined to have made a Waypoint Insertion error, a Class C error. Both errors were considered in the statistics, thus the totals shown for each class will be greater than the Total Errors reported in the first row of this Table.

The ICAO team reported completion of 85,333 MNPS Airspace flights of which 54,445 utilized the Organized Track System. Forty-nine separate cases of encroachment or near-encroachment involving 63 errors were reported, 17 of the 63 "errors" were correlated with lack of MNPS capability, Classification A; the remaining 46 cases are of interest to the ADS assessment. At 46 events per 85,333 flights the rate of unsatisfactory performance is 1 per 1855 flights. The data indicate that at least 10 of the ATC-Loop errors should have been detectable, utilizing the FPR Mode of a hypothetical ADS; and that 25 of the 26 Equipment Control Errors might also have been detected, leaving a total of 11 undetected errors. In theory these actions would have improved the rate of encroachment to 1

	Non MNPS Airspace	Not OTS Part of MNPS	OTS Part of MNPS
Total Errors Experienced	38	36 (49)	13 (14)
Attributable to:			
A Not MNPS-Equipped	NA	3	1
Not Oceanic Airspace Qualified	16	NA	NA
B ATC-Loop Errors, Subtotal		13	-0-
Allocations:			
- Misunderstanding		4*	-
- Wrong Route		6	-
- ATC Fault		2	-
- Comm Prob. (No HF)		1	-
C Equipment Control Error, subtotal		14	12
Allocations:			
- Waypoint Insertion		10	8
- Auto Pilot NAV/HDG; Select in Hdg.		1	2
- Failed to Cross Chk		2	1
- Initialization not completed correctly		-	1
- Improper Use/Celestial		1	-
- Unable Select Btwn Systems		-	-
D Equipment Fail/Malf., Subtotal		6	1
Allocations:			
- INS-Single		1	-
- Omega-Dual		3	-
- Omega-Single		1	-
- Dual Dop-Omega		1	-
- INS-Dop-Omega		-	1

DISTRIBUTION OF ERRORS, 1982-83

event in 7758 flights.

Seven equipment failure/malfunction cases were reported for MNPS Airspace operations, one in the OTS and six in the NOt-OTS space. Five of the seven cases claim failure or unuseability of dual or multiple systems which leads to speculation about aircrew knowledge of equipment. Only one case claims degraded behavior. Four of these seven MNPS cases however, do not (or just barely) exceed the lateral separation criteria of ½ lane width equal to 30 nm while the remaining three resulted in errors large enough to place the aircraft approximately overflying the adjacent track.

Additional study might indicate the possibility of independent detection of faults by ATC(perhaps as early as the 1 or 2 sigma level, i.e., 6.3 - 12.6 nm) which would then have allowed for implementation of some kind of corrective action.

With respect to the OTS portion of the MNPS, 13 aircraft were involved in instances of unsatisfactory performance in navigation in completing 54,445 flights (plus 1 Class A incident), a rate of 1 incident per 4188 flights. These were distributed as follows:

o ATC-Loop Error	0
o Equipment Control Errors	12
o Equipment Failure/Malfunction	1

It will be observed that principal Cause of Error was Aircrew Blunder, Equipment Control Errors.

Eight of these Errors were identified with incorrect Waypoint Insertion, two with failure to select the NAV mode for Auto Pilot steering, one error was attributable to Failure to Cross Check differences between systems of a Dual Navigation system installation, and one error was credited to improper initial alignment of the three INSs in the aircraft. Ignoring the Class A offender it is seen that 92% of the errors observed in OTS Airspace were attributable to Human Error - - to Blunders - - all of which it is believed would have been detected by the ADS.

This assessment suggests that the OTS rate of encroachment might have been improved from 1 event in 4188 flights to 1 in 54,445 flights or, if detection of the IL-62 equipment failure had been accomplished, successful detection of all cases of error in navigation.

With respect to the Not-OTS Airspace Experience, there were 30,888 flights completed during this period. Thirty-six (36) aircraft were charged with unsatisfactory performance, a rate of 1 encroachment per 858 flights! Thirteen of the 36 aircraft were indicated as being both Not MNPS-Equipped and as involved in either a Class B, C or D problem.

o Not MNPS-Equipped	16
o ATC-Loop Errors	13
o Equipment Control Errors	14
o Equipment Failures/ Malfunctions	6

Administrative elimination of the 16 Class A offenders and ADS detection of 25 of the 27 ATC-Loop and Operator Errors would have improved the encroachment rate to 1 event in 6806 flights ....and with addition to ADS of a capability to detect the onset of equipment failures or major malfunctions a rate of 1 event in 27,222 flights.

Assessment of the NAT NON-MNPS reported errors in navigation suggest that 34 of the 38 cases may have involved Infrequent Oceanic Airspace Flyers; also that 25 (65%) of their operations utilized the Greenland-Iceland-Scotland route; that about half the aircraft were relatively short range vehicles (C-185,BE 20), approximately 30 percent were medium range aircraft (DC-9, BAC 1-11) and only 20% had the extended range expected of overwater operators (C-130, B-707) and thus might be considered Frequent Flyers and candidates for ADS.

Almost 60% of those who flew the Not-MNPS portion of the airspace did so with inadequate navigation aids (i.e., ADF, VOR, DME) and apparently relied heavily upon DR to get them to destination.

Detection of Errors

The preceding paragraphs established something of the kind, frequency of occurrence and causes of errors experienced within the NAT region. The next step is to identify acceptable ways in which one might automatically detect their presence.

The data show that there are at least five discrete areas to address in the process of eliminating or greatly reducing the incidence of errors:

- Eliminate (administratively) unauthorized entrants to MNPS Airspace (NAT SPG classification A) which account for 29% of 'violations', and undertake development of a special procedure to accommodate 'Infrequent Flyers' within the Goose Bay-Greenland-Iceland-Scotland route structure.

- Electronically detect ATC-Loop errors...15% of cases within full MNPS and 12% of cases within the OTS portion of the MNPS.

- Electronically detect Operator Blunders, the Classification B & C errors....which account for 53% of all blunders in MNPS Airspace and 71% of the blunders experienced within the OTS over the 31 months for which data was available.

- Electronically determine the presence of faults, malfunctions, degraded behavior and system failures which accounted for 10% of full-MNPS-Airspace errors and 14% of OTS unsatisfactory performance over the 31 months.

ATC-Loop and Operator Control Errors. These Errors and Blunders should be electronically detectable through hardcopy or computer/computer comparison of readouts from the onboard navigation equipment with the equivalent data in file on the ATC Computer.

Since the Flight Plan is generated by the ATC System, concurred with by the aircrew, and then 'stored' in the navigation system by virtue of inputing the succession of Waypoints . . . its correctness and sequencing can be confirmed at any time by requesting a readout.

Improper positioning of Leg Change or Auto Pilot Steering Mode Switches will result in the aircraft departing from Assigned Track as indicated by the accumulation of Cross-Track Error (which should remain at zero), difference between the quantities Present Track and Bearing to Waypoint, and or incorrect computation and readout of Distance to Go to Waypoint. Build up of difference values in any of these parameters would be cause for illumination of an Advisory or Warning Light both in cockpit and at ATC.

Equipment Failure or Malfunction (and Excessive Error Buildup). Where similar dual systems are carried, and it is determined that they disagree as to a major parameter, a means will be required to assess the worth of each and to select the appropriate result. Also, where a navigation system is navigating in error, its reported position may appear to be right on the Assigned or Desired Track. Since the stored WP information will be correct and switches correctly positioned, neither the FPR nor the LL modes of the ATC system will detect a discrepancy.

Thus the detection process must include a Validation Mode. Its function could be as simple as comparing the relative differences in position and advising ATC and Aircrew whenever the Delta-Positions reach some threshold, say 2/10 of the lateral separation distance between tracks.

It is anticipated, however, that the data validation process may require the ability to assess a broad range of inputs, in effect providing at ATC the equivalent of a second or third flight deck system.

Conclusion

The functions of an Automatic Dependent Surveillance System are, at a minimum, to provide automated reporting of present navigation position, Track, ETA, etc.; system intentions; and navigation system status. A crucial aspect of this reporting is that the data be credible, that ATC be given means to extract additional information from the navigation system when questions arise and that the Controller have near real-time radio access to the flight deck crew.

GLOSSARY

ADS	Automatic Dependent Surveillance
Aeradio Station	- HF message handling
AFTN	Aeronautical Fixed Telecommunications Network
AIP	Airman's Information Publication
ATC	Air Traffic Control
ATS	Air Traffic Service
CMA	Central Monitoring Agency (of the UK National Air Traffic Services)
ETA/ATA	Estimated Time of Arrival/Actual Time of Arrival
EUR	Europe
FANS	Future Air Navigation Systems (Committee of ICAO)
FIR	Flight Information Region
Mach Number Technique	...cruise speed (and climb speed when applicable) assigned and flown at a Constant True Mach Number.
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
LOS	Line of Sight (distance)
MNER	Minimum Navigation Equipment Required (Airspace)
MNPS	Minimum Navigation Performance Specification (Airspace)
MTP	Minimum Time Path
MTT	Minimum Time Track
NAM	North America
NAT	North Atlantic
OACC	Oceanic Area Control Center
OCAs	Oceanic Control Areas
OTS	Organized Track System
SPG	Systems Planning Group (ICAO), usually NAT SPG
UK	United Kingdom (Ireland, Scotland, England)

BIOGRAPHICAL INFORMATION

William L. Polhemus
Polhemus Associates

Professional Navigator and Senior Partner Polhemus Associates, Inc of Cambridge, Vermont. Experience includes twentytwo years in military service; nine years in the U.S. Navy as a radio/radar operator assigned to aircraft carriers; and thirteen years in the USAF as a navigator-bombardier. USAF assignments included MATS, TAC and SAC.

Since 1962, he has completed a 'tour' with a commercial airline and twentyone years of successful operation of a small research, test and evaluation company.

Since 1968, his company has been involved in study, evaluation and documentation of Loran-C position, location and navigation capabilities in a variety of maritime, terrestrial and airborne applications.

His present work involves demonstration of the feasibility and desirability of using Loran-C RNAV within the National Airspace System.

MORE LORAN COVERAGE FOR LITTLE MORE MONEY BY DUAL RATING

WALTER N. DEAN
ARNAV SYSTEMS, INC.
PORTLAND, OREGON

ABSTRACT

The Loran-C chains were initially established to provide marine navigation, with the result that overland navigation is not well served in all areas of the U.S. Two areas have been indentified in which overland coverage for use by aircraft or land vehicles can be greatly improved without construction of additional transmitting stations. One of these is the Anchorage-Fairbanks area in Alaska, which can be much better served by dual rating the Port Clarence station to the Gulf of Alaska chain. The second is Central Texas, where navigation can be improved by dual rating the Raymondville station to the Great Lakes chain. The paper analyzes the feasibility, costs and benefits.

PROPOSED IMPROVEMENT IN ALASKA LORAN COVERAGE

Aircraft use of loran in the State of Alaska suffers from a "mid-state gap" analgous to the "mid-continent gap" in the Lower 48. Even worse, this gap occurs in the most populous area of the state.

Loran coverage in Alaska is provided by two loran chains. In the west, the North Pacific chain (9990) consists of a master station at St. Paul Island, an X secondary at Attu, Y secondary at Port Clarence, and a Z secondary at Narrow Cape, Kodiak. Figure 1 shows most of that chain. The master station at St. Paul is a relatively low power (250 KW peak) transmitter. Since the master station is essential to loran receiver operation, the relatively weak signal from St. Paul, further attenuated over portions of the Alaska range, results in marginal operation in the area indicated in Figure 1, which includes the Anchorage-Fairbanks corridor.

In the east, the Gulf of Alaska chain (7960) provides accurate navigation to the edge of the Anchorage area. The master station at Tok is a high power station and covers the area well. The station at Narrow Cape, Kodiak, is dual rated, serving also as the X secondary for this chain. The Y secondary at Shoal Cove is nearly 700 miles away. North of Anchorage, the signal from Shoal Cove is severely attenuated and the geometric accuracy of the chain is poor, so this chain cannot be used in that area.

A simple change can be made which will expand the coverage of the 7960 chain and completely fill the "gap." This change is to dual-rate the station at Port Clarence to the 7960 chain, in the same manner as the Narrow Cape station. The resulting loran coverage will be as shown in Figure 2. Port Clarence, with its 1350 foot tall antenna, is rated at one Megawatt peak power, giving it considerably greater range than the other stations in the 9990 chain.

The additional equipment required at Port Clarence to provide the dual rate capability consists principally of an additional timer unit and a pulse generator module. It is understood that there are some of these units available at the Coast Guard Supply Center in Brooklyn or the Electronics Engineering Center in Wildwood. If these can be used, the need for additional capital expenditures should be minimal. Since this project was originally proposed, the Coast Guard has developed some rather conservative estimates of the cost to provide the dual rate capability at Port Clarence.

Control of the new station can be accomplished at the existing control monitor at Kodiak. This station already monitors the 7960 X secondary (Narrow Cape), and that receiver could be used to also monitor and control the new Z secondary at Port Clarence. The monitor already controls Port Clarence operation as 9990-Y, so the necessary control lines are already in place.

Data are available confirming the availability of signals from Port Clarence in the areas of concern. In 1983, signal strength and signal-to-noise data were collected in conjunction with STC testing of the ARNAV AVA-1000. Figure 3 shows points from which data are available. At each of these points, the signals from the three stations which would provide the new coverage, Port Clarence, Narrow Cape and Tok, showed signal-to-noise ratios of better than 1:1. This is more than adequate for good loran operation, and provides a high degree of confidence that the proposed dual-rating of Port Clarence will provide the expected performance.

Table 1 lists the signal-to-noise ratios measured on Port Clarence and Narrow Cape at a number of representative locations about the state. At each of these locations, the signal from Tok, the third critical station, is well above the zero DB level.

TABLE 1

			SNR (DB)	
Location	Latitude	Longitude	Port Clarence	Narrow Cape
Fairbanks	N 64 49	W 147 51	+6	+3
Tanacross	N 63 23	W 143 20	+1	+3
Harding Lake	N 64 24	W 146 55	+6	+3
Clear	N 64 18	W 149 07	+6	+5
Talketna	N 62 18	W 150 06	+3	+10
Big Lake	N 61 34	W 149 58	+5	+10
Merrill	N 61 13	W 149 50	+4	+10
Bethel	N 60 47	W 161 49	+10	+8
Nome	N 64 31	W 165 26	+10	+5
Bettles	N 66 54	W 155 32	+3	+5
Tanawa	N 65 11	W 152 11	+7	+2
Livingood	N 65 32	W 148 33	+6	+6
Beaver	N 66 22	W 147 24	+5	+5
FYU	N 66 35	W 145 16	+1	+6

IMPROVED LORAN COVERAGE IN TEXAS BY DOUBLE RATING RAYMONDVILLE

It is well known that the loran coverage in Central and Western Texas leaves much to be desired. Navigation is provided by the Southeast U.S. chain, 7980, by the MWX triad, with the master at Malone, FL., the W secondary at Grangeville, LA., and the X secondary at Raymondville, TX. Navigation accuracy is particularly poor close to the M-W baseline extension, which goes through Central Texas. Figure 4 illustrates the present situation.

It is proposed that the loran coverage be improved by operating the Raymondville, Texas loran station as the Z secondary to the Great Lakes chain, 8970, in addition to its present operation as the X secondary of the Southeast U.S. chain, 7980. Texas will then be served by the 7980 MWZ triad, illustrated in Figure 5. The resulting improvement in geometric accuracy can be seen in Table 2, which compares the geometric fix accuracy obtained from the Southeast U.S. chain with the corresponding accuracy using Raymondville dual rated to the Great Lakes chain. The ratio in the last column shows the amount of improvement expected.

TABLE 2

Location	Fix Error (ft per microsecond) 7980 MWX	 8970 MWZ	Improvement Ratio
Houston-Hobby	9965	1064	9.4:1
Beaumont-Jeff	2795	994	2.8:1
Austin	6524	1299	5.0:1
Mineral Wells	9144	1385	6.6:1
Waco	11080	1473	7.5:1
Abilene	14769	2132	6.9:1
San Antonio	39456	1856	21.3:1
Midland	16431	2382	6.9:1
Little Rock	2882	1004	2.9:1

The question immediately arises - How well can these three stations be received in Texas? The answer to that question can be derived from both theoretical and empirical data.

Figure 6 is a conductivity map of the U.S., prepared by the FCC. If one examines the paths from the three circled transmitters to typical points in Texas, it can be seen that the conductivity numbers encountered are mostly in the 8-15 range, indicating very good conductivity. Figure 7 shows what this means in signal strength. For conductivities greater than 5, propagation is nearly as good as over seawater, which means that ranges of in the order of 900 to 1000 miles should be obtained from these transmitters.

It can be seen from the maps that the distances to Dana and to Malone will be similar for most Texas locations. The Dana station is slightly lower power (-3DB), but this is somewhat compensated by the fact that Malone is located in an area of lower ground conductivity. This is confirmed by actual signal measurements made in a number of locations in Texas over the past years.

Table 3 gives some examples of measured atmospheric signal-to-noise ratios in the area of concern.

TABLE 3

Location	Malone SNR	Dana SNR
Houston, TX	+3 DB	-2 DB
Corsicana, TX	0 DB	-5 DB
Dallas, TX	0 DB	-4 DB
Mineral Wells, TX	-1 DB	-2 DB
Butts, CO	-5 DB	-2 DB
Chanute, KS	-1 DB	0 DB

These values of SNR are more than adequate for satisfactory loran performance in this area.

The area of expected improved loran performance is indicated by the cross-hatched area in Figure 8. The limits of any of the coverage areas are never precisely defined, since loran receiver performance depends not only on signal strengths, but also on atmospheric noise conditions, specific receiver characteristics, and local noise and interference.

There are no difficult technical problems. The Great Lakes GRI has space in its interval to fit a Z station easily. A coding delay of 63,000 microseconds would be satisfactory. The remaining questions relate to the feasibility of dual rating the station and controlling the new rate. The transmitter at Raymondville is a solid state AN/FPN-64 with 32 HCG capacity. Dual rating involves adding another dual timer for the second rate. The additional prime power required will be in the order of 25KW, a relatively trivial amount.

A monitor is required to control the new secondary. An obvious location is the existing monitor at New Orleans, which receives both Dana and Raymondville very well. It is also possible to locate the monitor inland, in Fort Worth or Austin, where it can be under the control of FAA or state aeronautics personnel. The Coast Guard conservatiely estimates the cost of a monitor at $200,000.

CONCLUSIONS

The dual rating of Port Clarence will fill a major void in the loran coverage of the State of Alaska, at a very reasonable cost. The dual rating of Raymondville will obviously not fill the "mid-continent gap," but it is an economical and cost-effective first step to improve loran coverage in an important area. Both of these could be done within the existing budget restraints, if the users of loran in these areas feel strongly enough to make their desires known to the proper authorities.

Walter N. Dean

Walt has been a Director of the WGA since its inception, and has served variously as Vice President, Chairman of the 1981 Convention, Nomination and Elections Chairman, and Membership Chairman.

Since August 1982 he has been Vice President for Engineering for ARNAV Systems, Inc., building airborne loran navigators. For three years before that he had been a consultant on navigation systems, following 11 years at Magnavox and 26 years at Sperry, spent mostly on Loran-C and its predecessors Cytac and Cyclan.

Walt has ten patents and over twenty published papers, mostly on various aspects of loran.

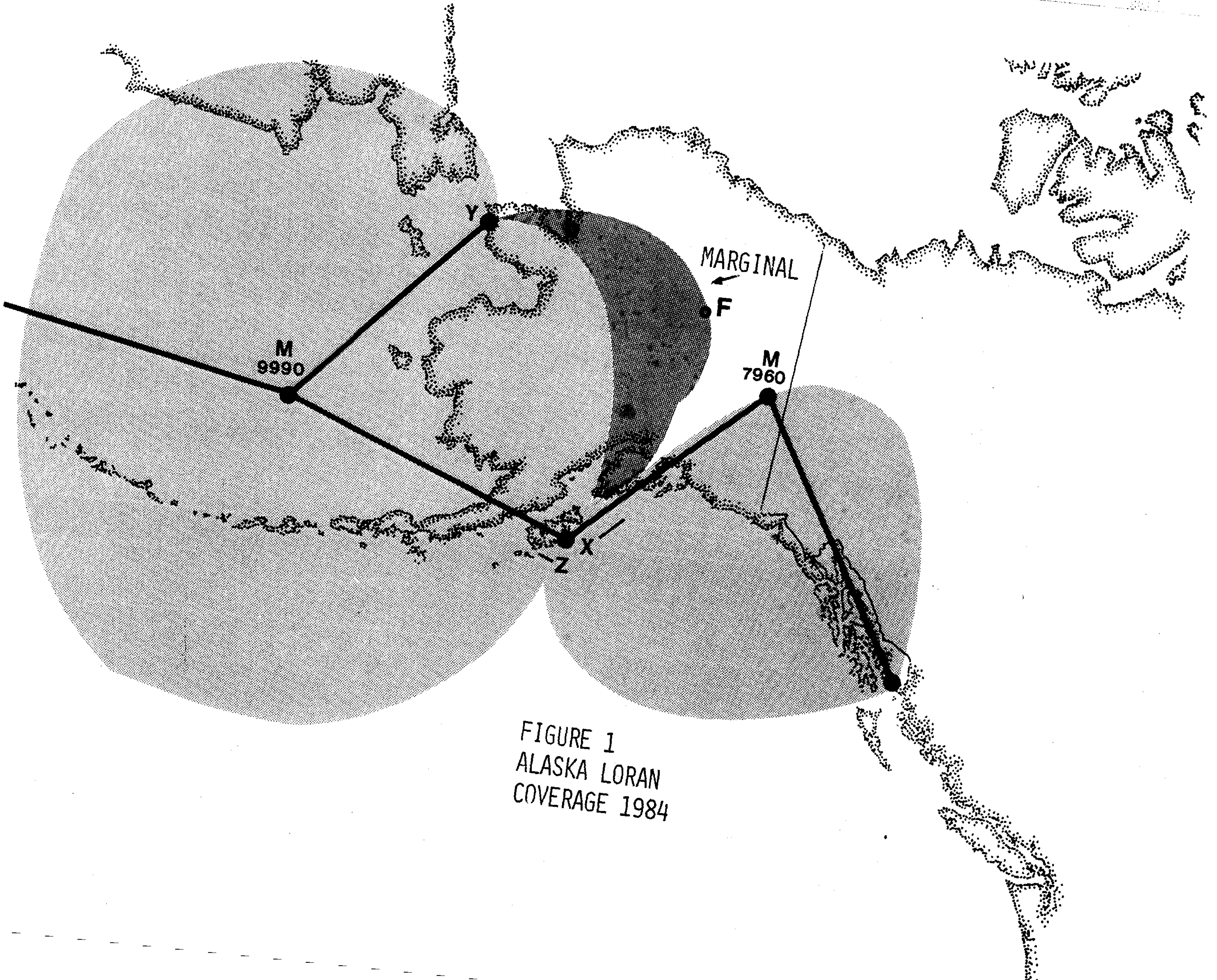


FIGURE 1
ALASKA LORAN
COVERAGE 1984

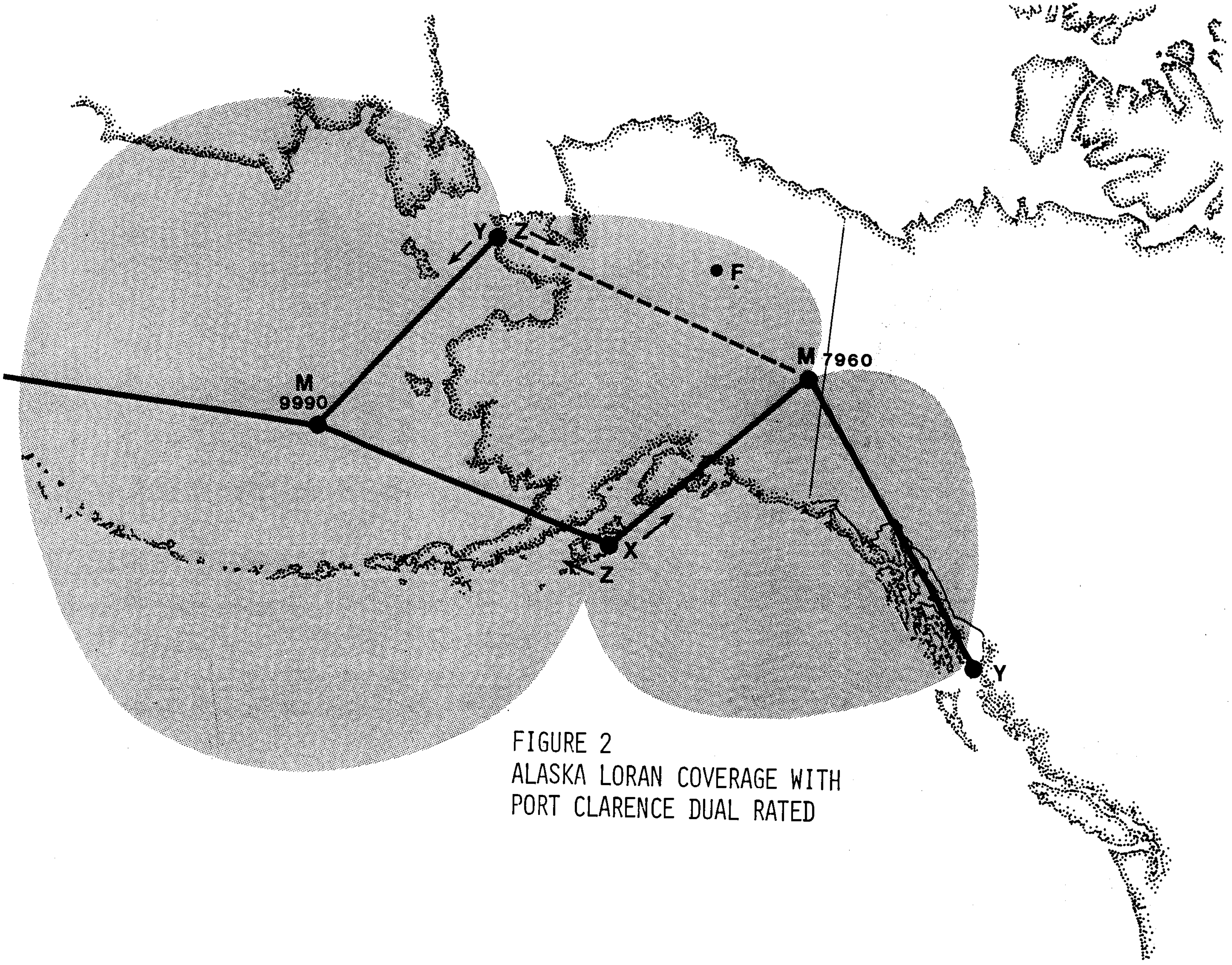


FIGURE 2
ALASKA LORAN COVERAGE WITH
PORT CLARENCE DUAL RATED

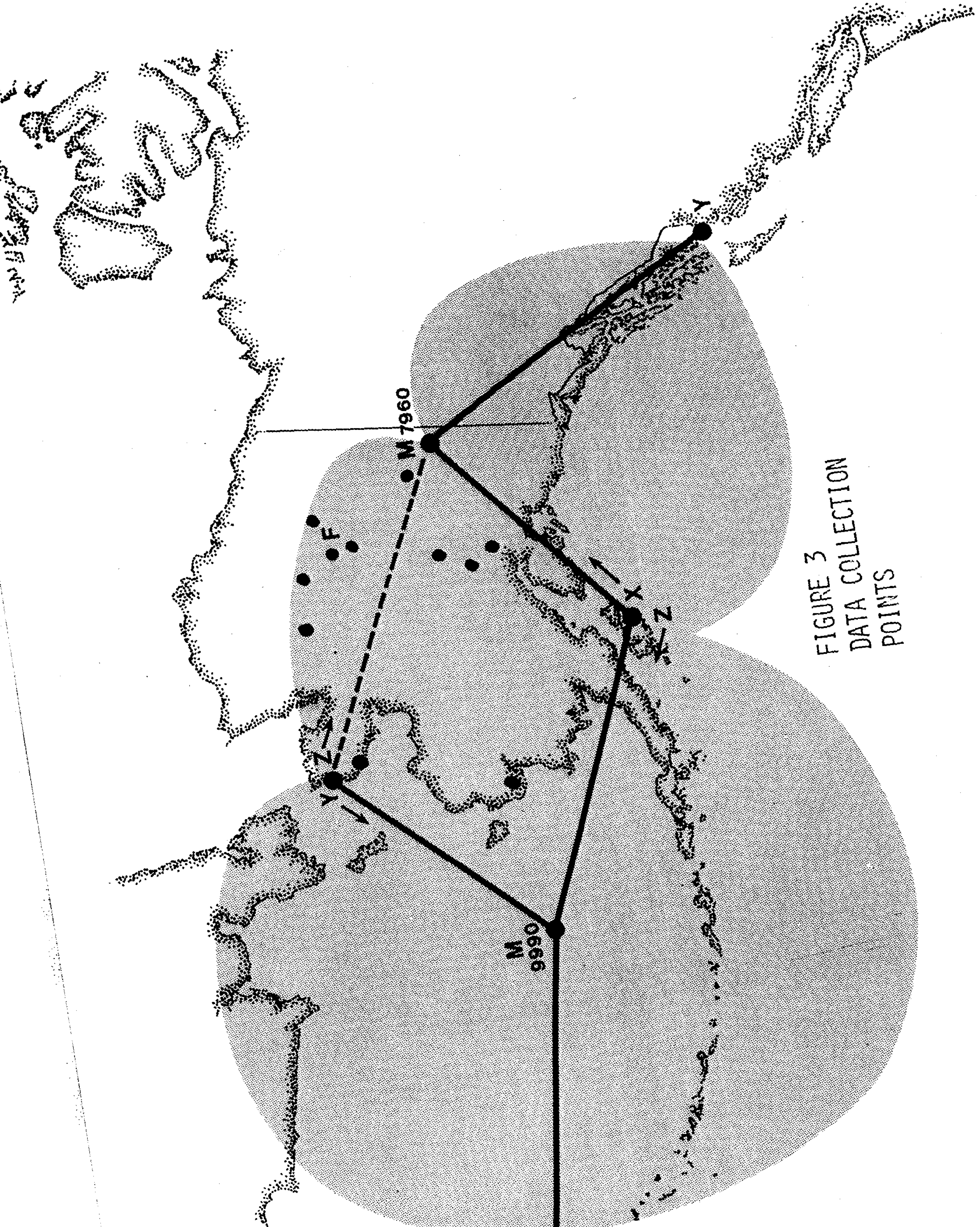


FIGURE 3
DATA COLLECTION
POINTS

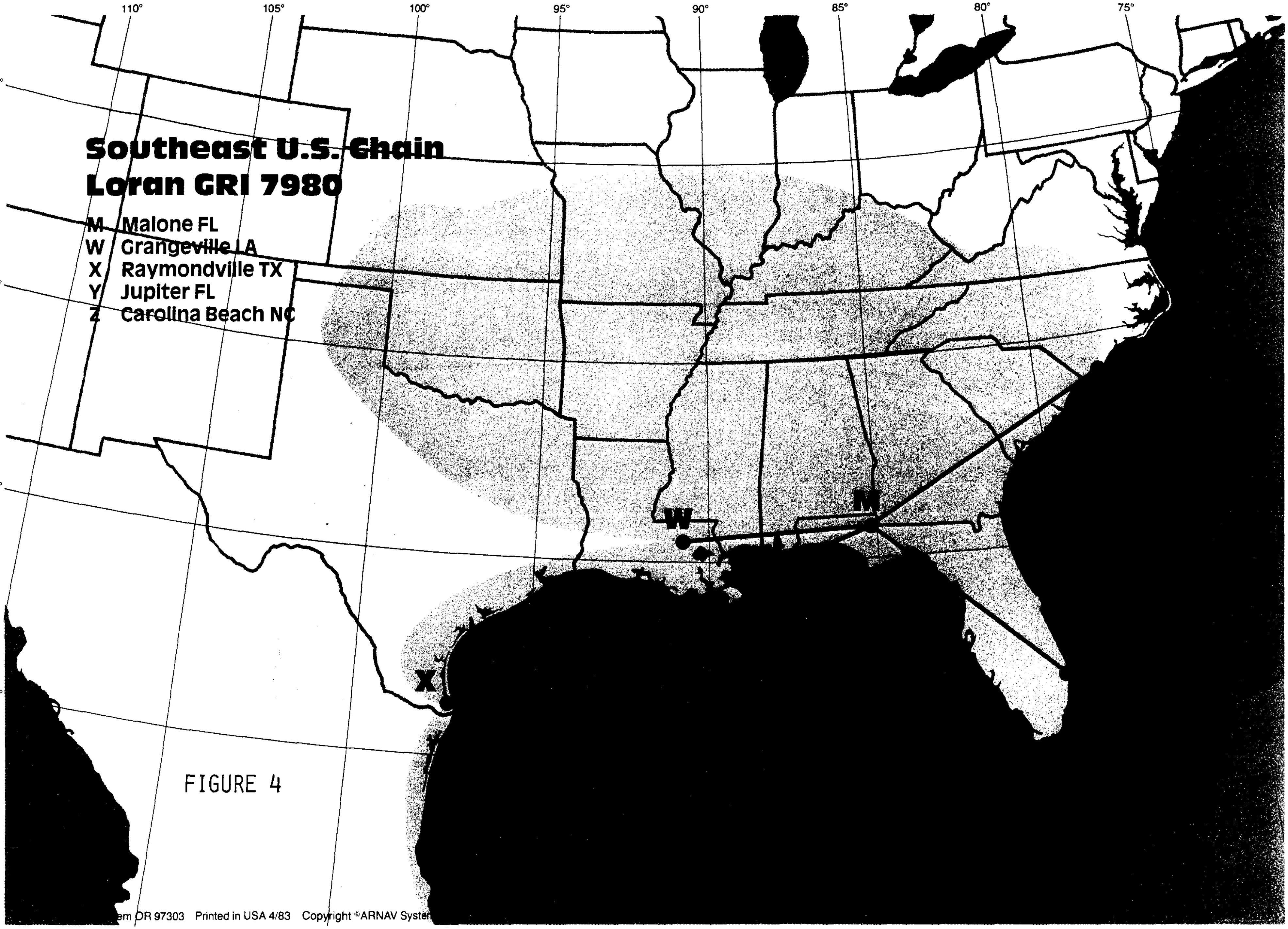

Southeast U.S. Chain
Loran GRI 7980
M Malone FL
W Grangeville LA
X Raymondville TX
Y Jupiter FL
Z Carolina Beach NC
110°
105°
100°
95°
90°
85°
80°
75°
40°
35°
30°
25°
W
M
X

FIGURE 4

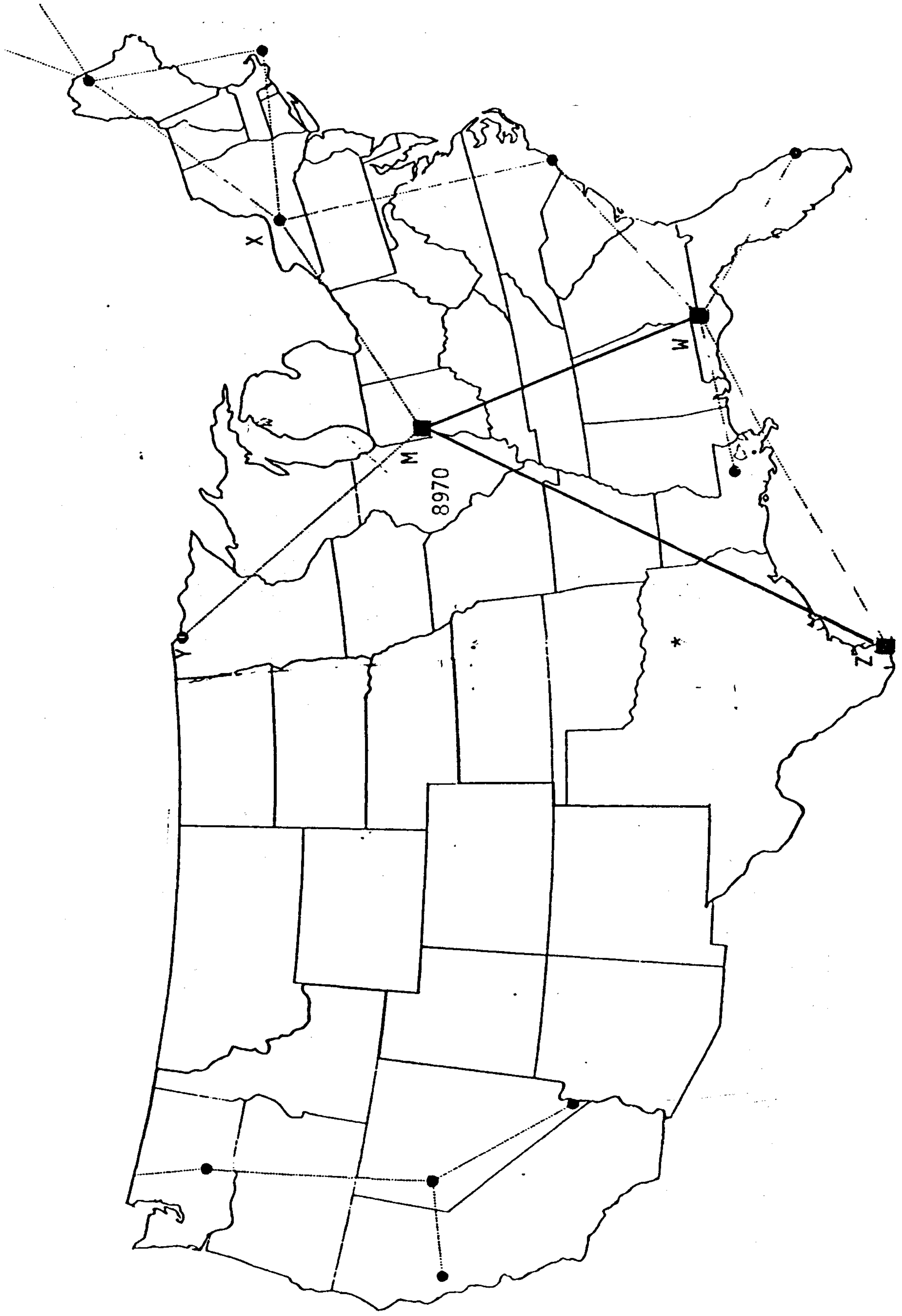
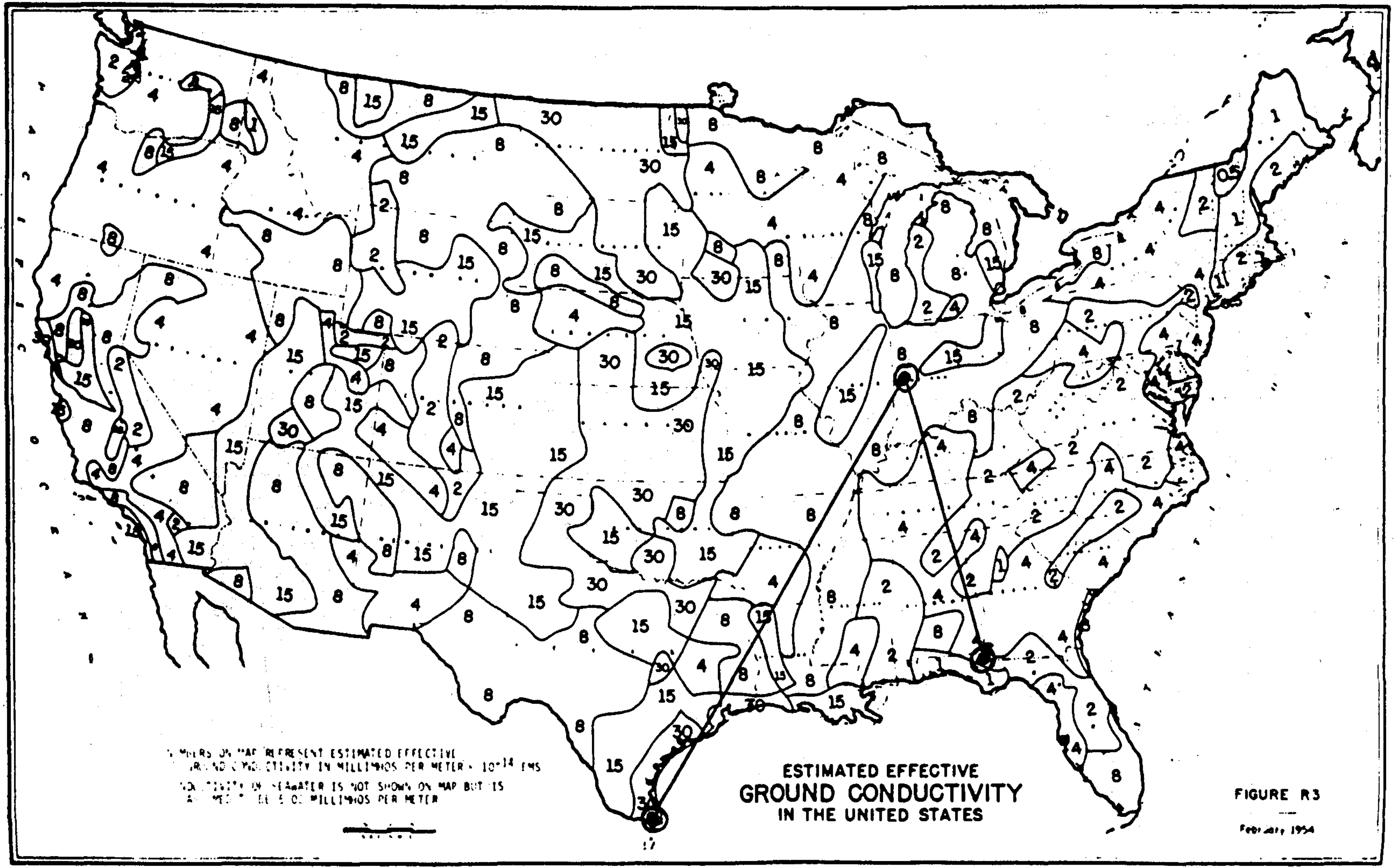


Figure 5. Proposed Addition to Great Lakes Chain

ESTIMATED EFFECTIVE GROUND CONDUCTIVITY IN THE UNITED STATES



TP2925-50

Figure 6

GROUNDWAVE FIELD STRENGTH

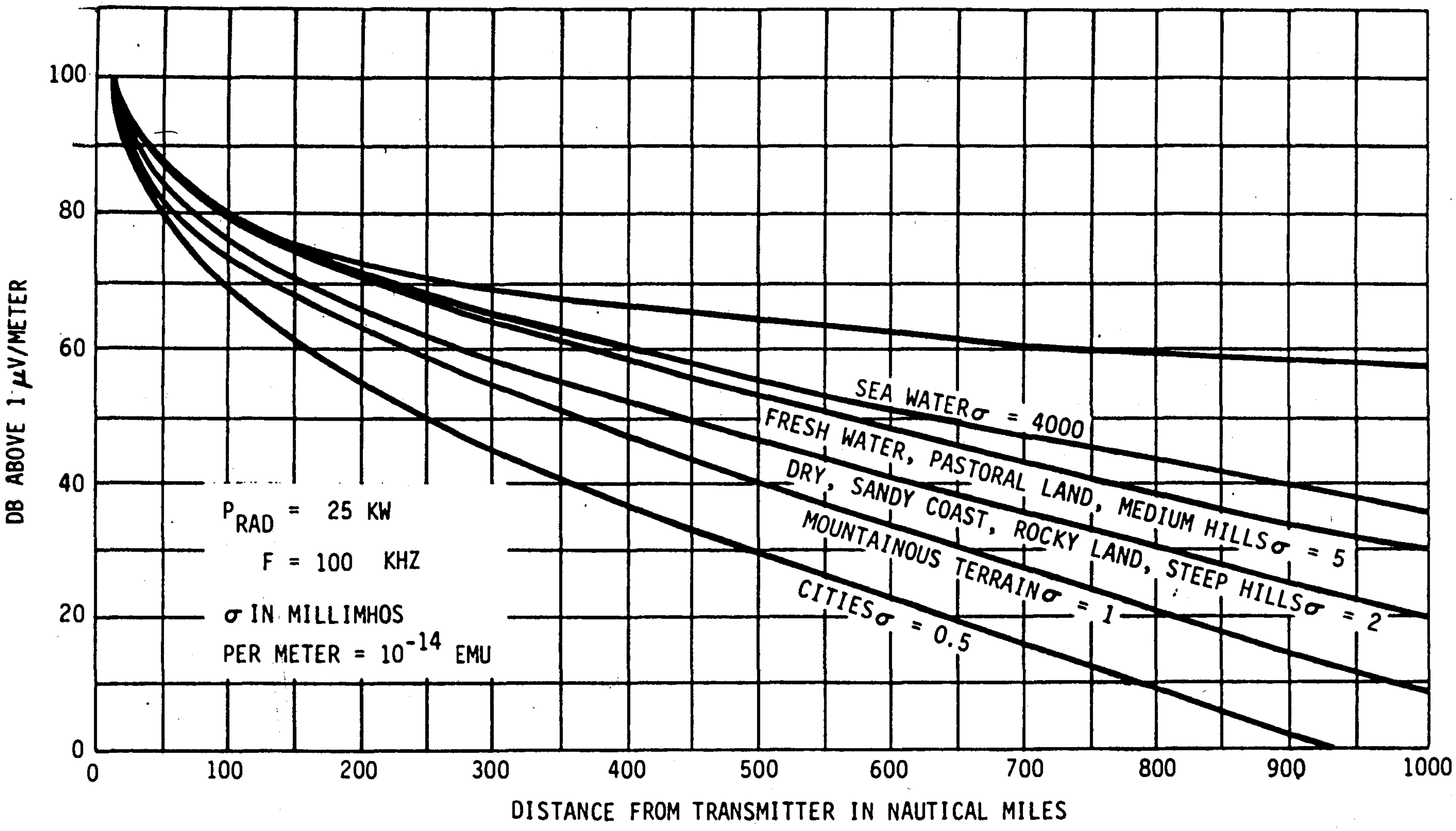


Figure 7

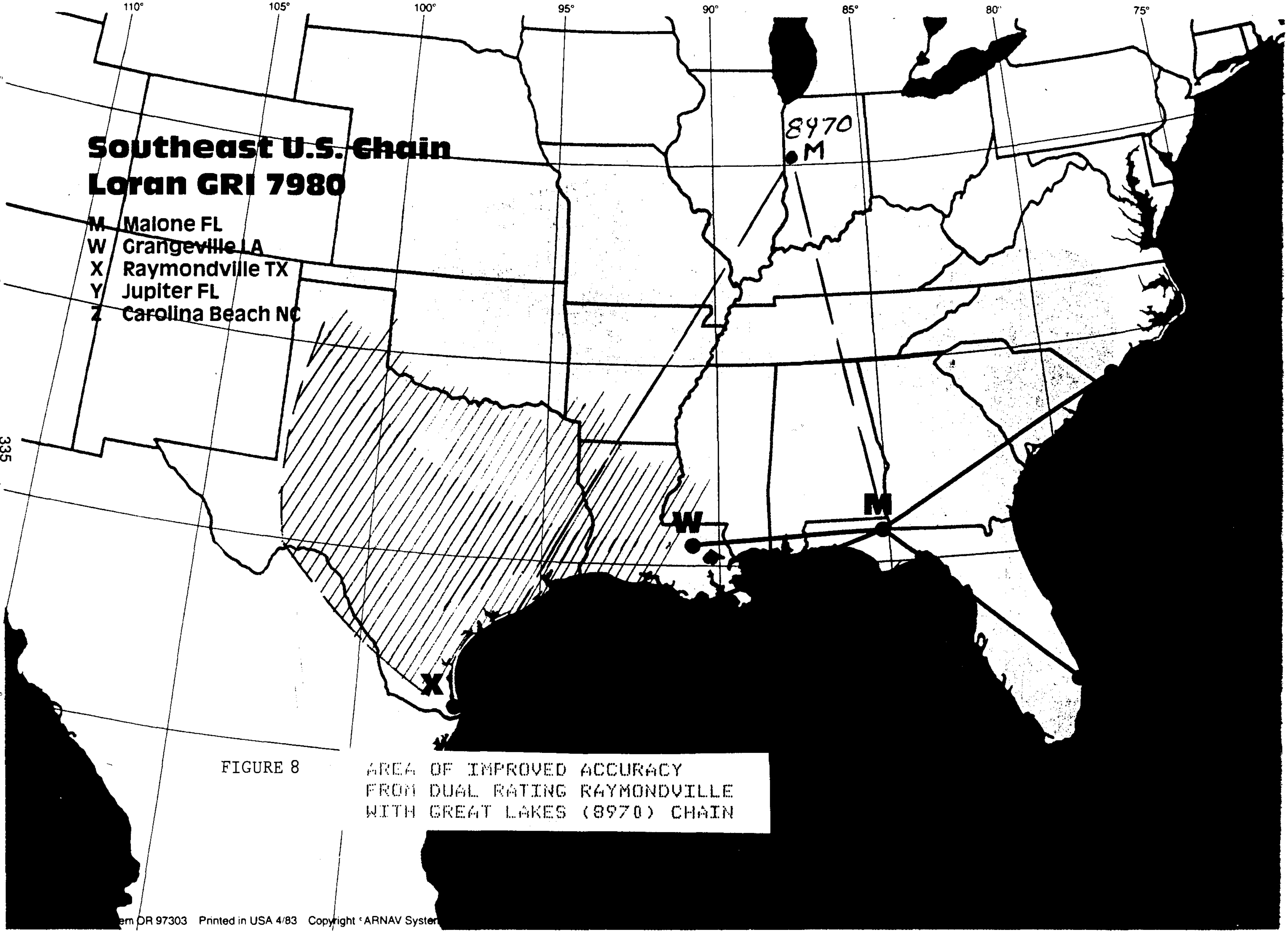


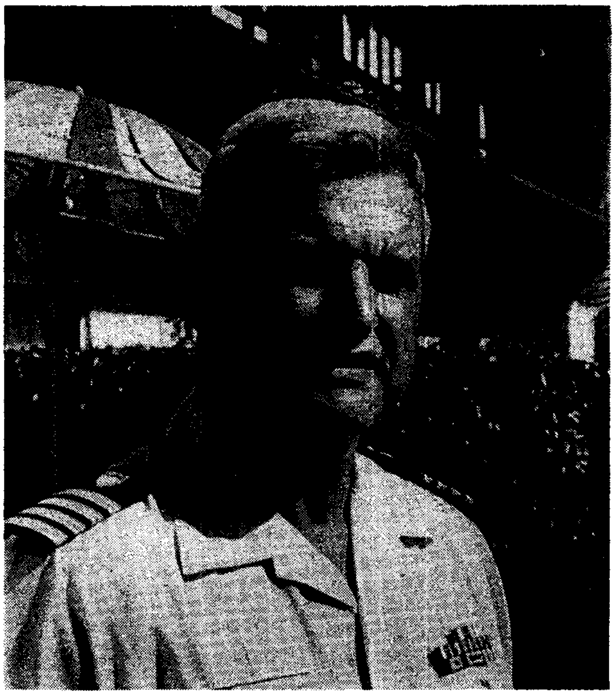
FIGURE 8

AREA OF IMPROVED ACCURACY
FROM DUAL RATING RAYMONDVILLE
WITH GREAT LAKES (8970) CHAIN

TECHNICAL SESSION No. 5 - PANEL

Session Chairman - CAPT. William F. Roland (USCG)
Chief of Staff
Fourteenth Coast Guard District
Honolulu, HI

PANEL MODERATOR



CAPT. Bill Roland

PANEL MEMBERS

(l to r) Bob Bronson, Chick Longman, Bill Polhemus (back) Dave Scull, CAPT Bob Cassis, Capt Gill Goodman, CAPT Bill Roland, Walt Dean

PANEL MEMBERS

CAPT William F. Roland, USCG - Moderator

Mr. Chick Longman - Federal Aviation Administration
CAPT Gill R. Goodman - USCG, Pacific Chain Commander
CAPT Robert H. Cassis - USCG
Mr. Robert D. Bronson - II Morrow, Inc.
Mr. David C. Scull - Department of Transportation
Mr. David A. Carter - JAYCOR
Mr. Walter N. Dean - ARNAV
Mr. William L. Polhemus - Polhemus Assoc., Inc.
Mr. Andres Stenseth - NODECA - Chairman, Loran
Working Group - Europe

PANEL ISSUES

I. Improving and expanding applications in aviation

1. How do pilots, instructors and schools handle training in Loran-C use?

2. Does the use of hyperbolic coordinates limit use?

3. Is the Federal leadership role in Loran-C changing?

4. How can we assist and assure the implementation of the mid-continent chain particularly if FAA initiatives are delayed?

5. How can we aid the approval and implementation of non-precision approach procedures? (RTCA SC 158 & 137).

6. Will there be control conflicts with multiple airport monitors and system area monitors?

7. Who pays for the development of approach plates and airport monitors to implement non-precision approaches?

8. What are the potential impacts on navigation service if Loran-C operation is turned over to the private sector?

II. The range and significance of "Coordinate Conversion Problems".

1. Is there a de facto standard algorithm for coordinate conversion?

2. Is there a maximum error standard for coordinate conversion? If not, is it worth trying to establish?

3. Are problems being reported in coordinate conversion that may be traceable to the routines rather than the receiver?

4. Is it important that routines read different Latitudes and Longitudes, if references are to time differences?

III. What improvements will open new markets for Loran-C receivers, or even for new chains?

1. Can we drop the minimum SNR for acquisition by another 6dB to open the commercial market in Hawaii?

2. How about an automatic skywave procedure that extends

range, especially with multiple chains. The idea isn't new, but is hardware available to do it?

IV. Other Issues.

1. Is a single radionavigation system (ie, GPS NAVSTAR) for all marine, aviation and terrestrial uses in the best interest of national security and the nation's economy?
2. Could international integretity and standardization for Loran-C be improved under an international directorate?
3. Is there really a future for Loran-C in harbors and and entrances and if so who should pursue this nationally and internationally?
4. Does anyone have a Loran-C bulletin board system on his personal computer? This would be useful for passing on system/technical information as well as for advertising.
5. How about coordinating the next WGA meeting with a general aviation convention? WGA has met with Fish Expo in the past.

REPORT OF PANEL DISCUSSION
14th ANNUAL WGA CONVENTION

Panel Members:
Mr. Bob Bronson, II Morrow, Inc.
Mr. Dave Carter, JAYCOR
Capt Bob Cassis, USCG
Mr. Walt Dean, ARNAV Systems Inc.
Capt Gill Goodman, USCG
Mr. Chick Longman, FAA
Mr. Bill Polhemus, Polhemus Associates Inc.
Mr. Dave Scull, DOT/RSPA
Mr. Andreas Stenseth, Norwegian Defense Communications Administration
Capt Bill Roland, USCG, Moderator

After introductions and administrative matters, the discussion was opened with a statement by Mr. Longman, that no consideration had yet been given to the impact of having many airports certified for Loran-C non-precision approaches (NPA's), would have on the number of aircraft likely to be airborne in poor weather, and therefore the effect on safety of flight. Further, he raised the issue of who will prepare the thousands of NPA documents needed to publish the procedures. He suggested that administrative procedures which permit certified organizations to gather data and present the observations and recommended NPA's to the FAA, are a possible alternative. The FAA would, in turn, review the submission, and if acceptable, would then publish the NPA.

Mr. Polhemus then brought up the difficulty we all face in reconciling the congressional and administration claims of navigation system proliferation (multiple systems to do the same job are inefficient) against the advantages of redundancy for safety. To assist in making a convincing argument for the mid-continent chain, and future developments, we must logically promote the idea that having both Loran-C and NAVSTAR is reasonable.

It is fair to summarize at this point that the attendees overwhelmingly support the implementation of the mid-continent Loran-C chain, for aviation uses.

Mr. Scull suggested that the land users have no advocates in Washington, as aviation has the FAA, and maritime users have the USCG. He suggested that perhaps the WGA could take on the role of advocate, and could work through RSPA. Further, he suggested all WGA members who could should attend the congressional hearings on the mid-continent chain.

Another major discussion erupted on the subject of Loran-C system availability, notification of users when there would be outages, and selection of the time of day for planned outages. All agreed that the Coast Guard's principle of ignoring "momentarys" (signal outages of less than 60 seconds) was unsatisfactory to aviation receiver performance. These outages regularly cause problems. No satisfactory minimum was proposed. System outages for maintenance was brought up as a problem. Many in the aviation community say they don't get notifications. Also the planned outages should be set for late night hours when few users will be affected.

P-static was brought up in this discussion, because it affects receivers in a similar manner and because some shipboard users have found it to be limiting for them and feel further work needs to be done.

Coordinate conversion issues included Lat/Long versus range/bearing coordinate systems and the need for consideration of the human interface, the application of additional secondary factor (ASF) to the TD's before coordinate conversion, and the algorithm to be used. There was no consensus on the use of earth referenced (L/L) versus facility referenced (R/B) coordinate systems; however, all agreed that computer could provide the desired coordinate system. There was agreement that coordinate conversion algorithms should use Sodono's method and should be based on a sea-water path. There was no consensus on the application of ASF and differential corrections. This needs to be carefully considered by RTCA and RTCM in future MOP's and MPS's. WGA members must volunteer to participate in the subcommittee activities of these organizations, to assure thorough consideration of these contentious matters.

At the end of the discussion period, Mr. Stenseth presented a short discussion on the establishment and works of the Loran Working Group in Europe. The membership of the group consists of Agency representatives from each country having an interest in the use of Loran-C in Europe. The Group was formed to coordinate the shift from USCG to host nation funding and operation of Loran-C, as well as to coordinate national expansion plans. Some specific issues raised by the Group are: the need for continued USCG participation in world wide Loran-C planning, especially in the responsibility for rate selection; the fact that the Loran-C signal environment in Europe is more challenging for receiver designers (receiver manufacturers take note); and the need for differential Loran-C standards.

Mr. John Illgen alerted the panel to a recent paper published by Mr. Don Latham, Assistant Secretary of Defense for C^3I in the August 1985 issue of the Armed Forces Communication Electronic Association monthly publication. In the paper Mr. Latham indicates his concern with the policy focused on "where we are going in space and in particular our dependency on space, not just for communications, but for navigation, reconnaissance, etc.

Illgen indicated his support of the NAVSTAR GPS program but emphasized the need to revisit the question of GPS accuracy for the civil users, coverage, financial issues (cost of user equipment), and space segment replenishment before phase-out schedules become concrete. Finally, Illgen indicated Mr. Latham's key messages, "We must be very careful not to put ourselves in a situation where our dependency on space is so overwhelming that we jeopardize national security" and "We must have the right balance of survivability, endurance, capability, and cost between space systems and terrestrial systems" must be taken seriously.

RADM Wojnar, Chief of the Office of Navigation, USCG, agreed to continue participation with the Working Group.

In summary, there are challenges for the WGA as an organization, for individual members and their companies, and for the US Government, in the matters discussed by the panel members and the workshop attendees. A transcript has been prepared, but is unedited (for lack of time). It has been forwarded to the Convention Technical Chairman for inclusion in his records.

Respectfully,

/s/ Capt Bill Roland
Moderator

APPENDIX

THE 1985 CONVENTION

1985 WGA CONVENTION
TECHNICAL EXHIBITORS

Advanced Navigation, Inc.
621 Lofstrand Lane
Rockville, MD 20850
301-424-8730

Applied Physics Laboratory (APL)
Johns Hopkins Road
Laurel, MD 20707
301-953-5000

ARVAN, Inc.
P.O. Box 23939
Portland, OR 97223
503-684-1000

DELCO Electronics
6767 Hollister Avenue
Goleta, CA 93117
805-961-5370

Hunter Systems Company
5775 East Los Angeles Avenue
Simi Valley, CA 93063
805-527-2100

ITT Avionics Division
100 Kingland Road
Clifton, NJ 07014
201-235-0700

Kaman Tempo
816 State Street
Santa Barbara, CA 93101
805-965-0551

Marine Technology, Inc.
2722 Temple Avenue
Long Beach, CA 90806
213-595-6521

Micrologic
20801 Dearborn
Chatsworth, CA 91311
213-998-1216

II Morrow, Inc.
2345 Turner Road
Salem, OR 97302
503-581-8101

Offshore Navigation, Inc.
5728 Jefferson Highway
PO Box 23504
Harahan, LA 70183
504-733-6790

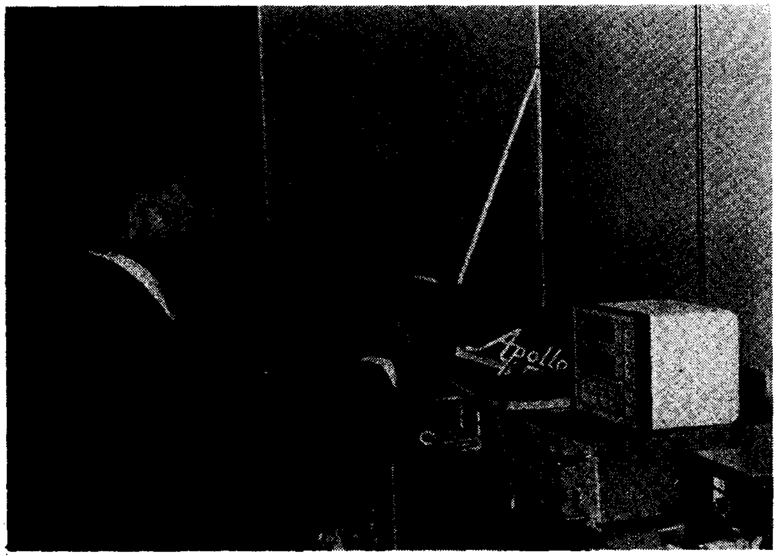
PATHCOR Division
Technology Products, Ltd.
2101 East Broadway
Tempe, AZ 85282
602-968-2818

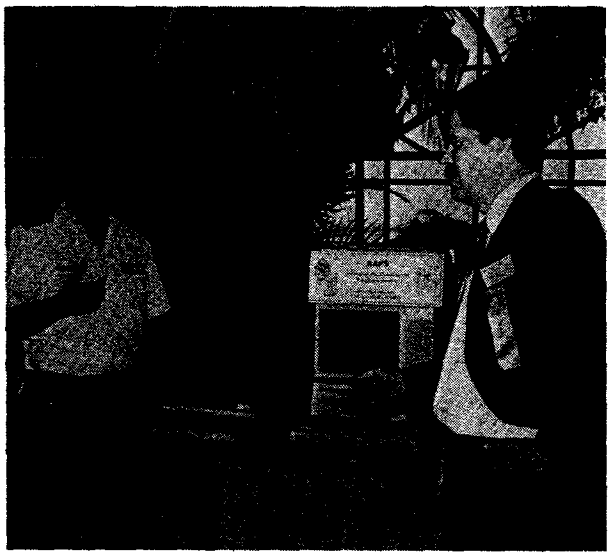
Raytheon Marine Company
676 Island Pond Road
Manchester, NH 03103
603-688-1600

Si-Tex
P.O. Box 6700
Clearwater, FL 33518
813-535-4681

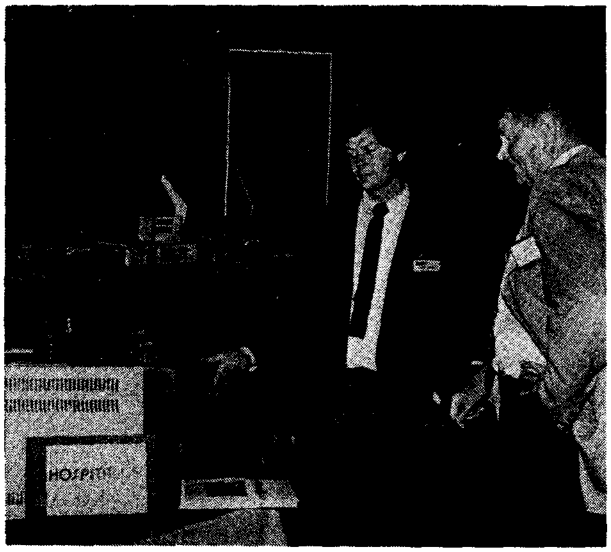
Teledyne Systems Company
19601 Nordhoff Street
Northridge, CA 91324
818-886-2211

U.S. Coast Guard Academy
New London, CT 06320
203-444-8547


Apollo



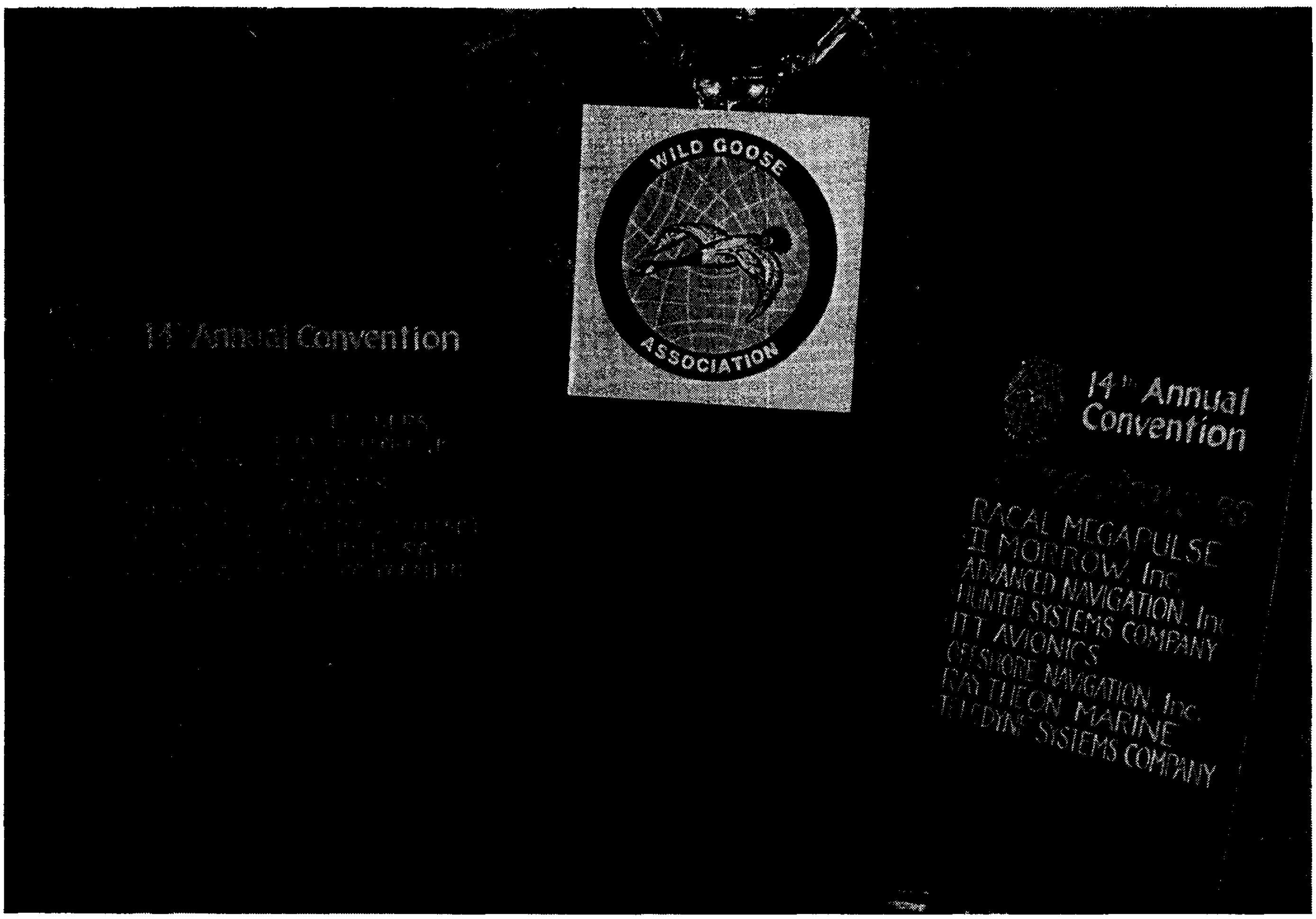

TASC


HOSPIT


KAMAN TEMPO

1985 WGA CONVENTION

SPONSORS



RACAL MEGAPULSE
II MORROW, Inc.
ADVANCED NAVIGATION, Inc.
HUNTER SYSTEMS COMPANY
ITT AVIONICS
OFFSHORE NAVIGATION, Inc.
RAYTHEON MARINE
TELEDYNE SYSTEMS COMPANY

WGA AWARDS - 1985

THE FOLLOWING AWARDS WERE PRESENTED AT THE ANNUAL CONVENTION HELD IN SANTA BARBARA, CALIFORNIA IN 1985.

MEDAL OF MERIT

THE MEDAL OF MERIT IS AWARDED TO A PERSON OR PERSONS FOR A PARTICULAR CONTRIBUTION OF OUTSTANDING VALUE TO THE DEVELOPMENT OR FOSTERING OF LORAN. THIS AWARD IS NORMALLY GIVEN ONLY AFTER THE EXCEPTIONAL NATURE OF THE CONTRIBUTION IS CLEARLY RECOGNIZED.

JAMES I. MERANDA

See citation next page

SERVICE AWARD

THIS SERVICE AWARD IS GIVEN TO MEMBERS WHO DISTINGUISH THEMSELVES BY SERVICE TO THE WILD GOOSE ASSOCIATION

CARL ANDREN
President
Wild Goose Assocation
1984-1985

LARRY SARTIN
Chairman, 1984 Convention

ROGER HASSARD
Chairman 1984 Technical
Symposium

BERNARD AMBROSENO
Journal Editor, 1980-1984

FRANK RADIN
Art Direction &
Mechanical Design of
Journal, 1982-1984

PAPER AWARD

THE PAPER AWARD IS GIVEN TO A MEMBER OF THE WILD GOOSE ASSOCIATION FOR THE BEST PAPER PUBLISHED ON THE GENERAL SUBJECT OF LORAN

LT. RICHARD J. HARTNETT, USCG
LT. RONALD T. HEWITT, USCG

"The U.S. Coast Guard's Loran-C
Remote Operating System"

Wild Goose Association

CITATION on the award of the MEDAL OF MERIT to

JAMES I. MERANDA

The Medal of Merit of the Wild Goose Association is awarded to James I. Meranda in recognition of his extensive contributions to the development and fostering of Loran, including pioneering work on digital microcircuit Loran-C receivers and the reduction of costs by use of hard-limiting signal processing.

As early as 1962, at Sperry Gyroscope Company, he was a major contributor to the digital design of the first digital microcircuit receivers AN/ARN-76,78, 85, and a few years later the first manpack Loran receiver. He suggested the use of hard limiting in certain areas of the former and all of the latter designs and devised the application details. In his subsequent work at Teledyne, Litcom, Beukers Laboratories and other companies, his ideas were spread in the Loran community, and ultimately were a major contribution to the reduction of costs of commercial receivers. His work is documented by a number of patents and published papers, and many unpublished reports.

The Wild Goose Association gratefully acknowledges these and other valuable contributions which have been a significant factor in the promotion of Loran to the important state it enjoys today.

Awarded this 24th day of October, 1985,

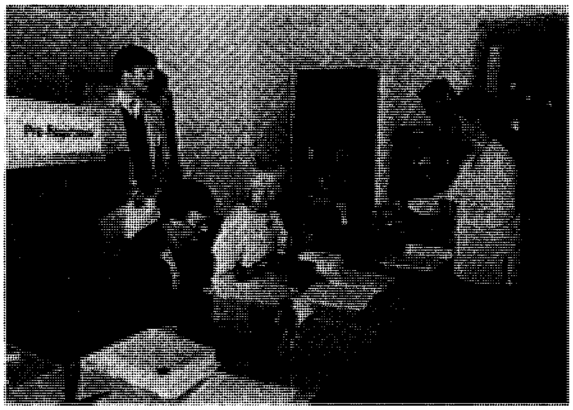
Carl S. Andren, President.

1972

1985 WGA CONVENTION SCENE PHOTOS

THE PLACE

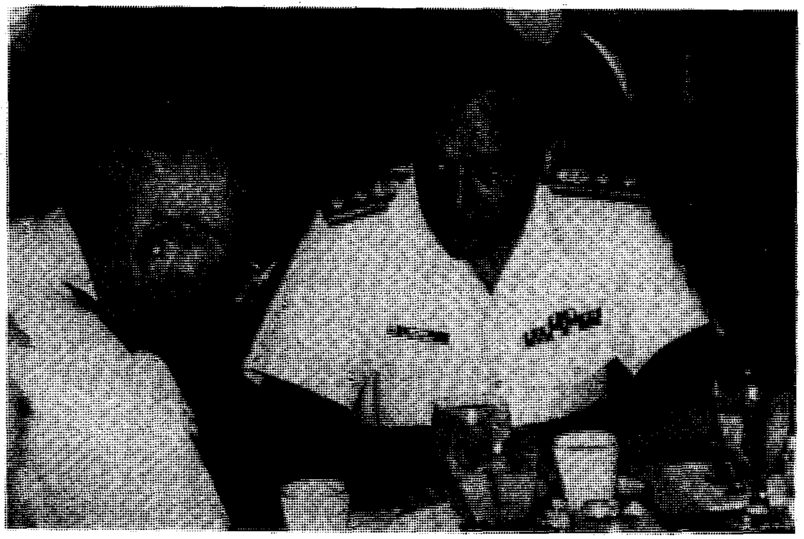
CHECKING IN



JOHN'S LAST MINUTE CHORES

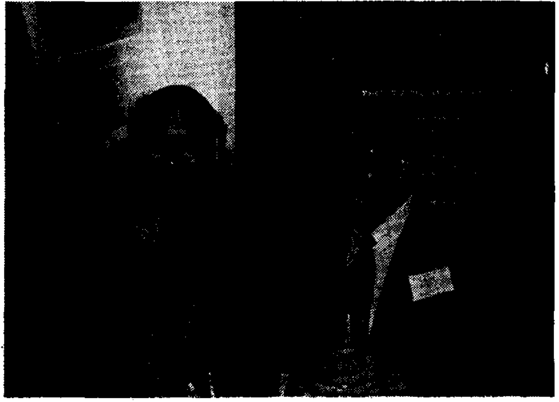
THE WGA BOARD AT WORK

SPEAKERS BREAKFAST



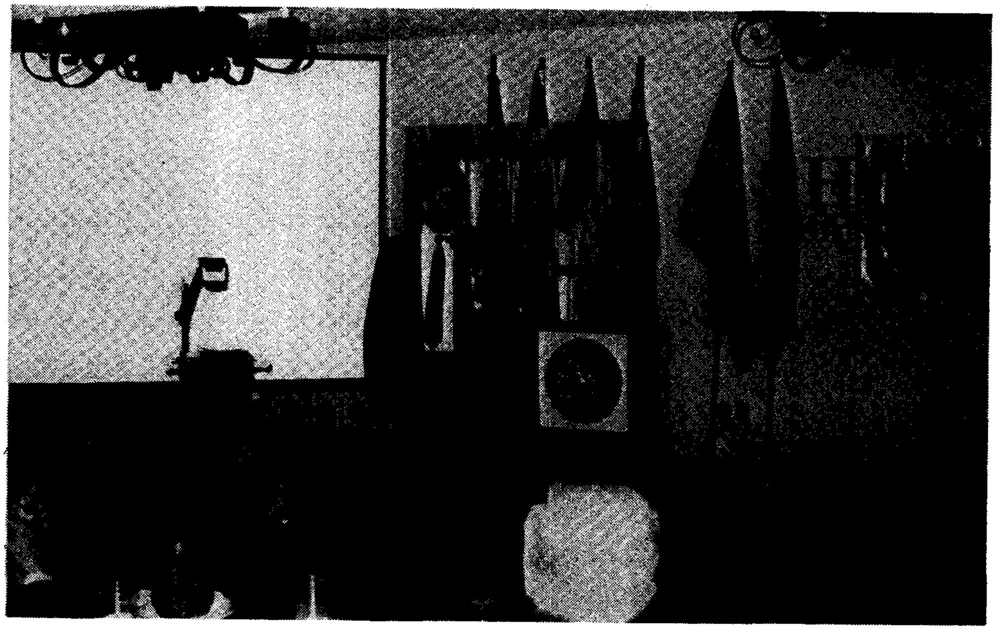
COAST GUARD PLANNING

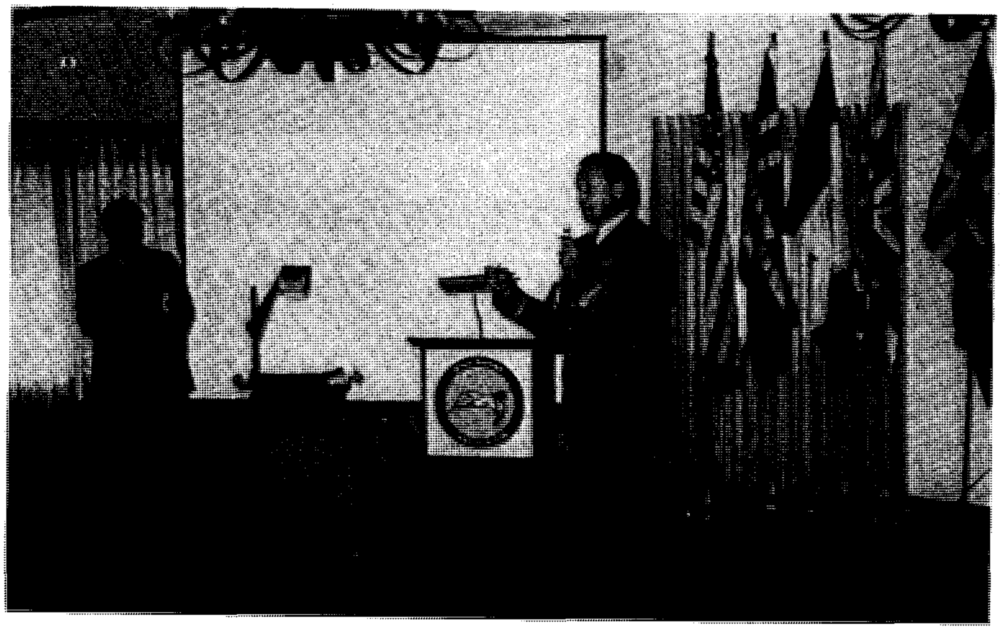
THE RECEPTION




U.S. COAST GUARD
PARADES THE COLORS

THE "PRES" LEADS OFF

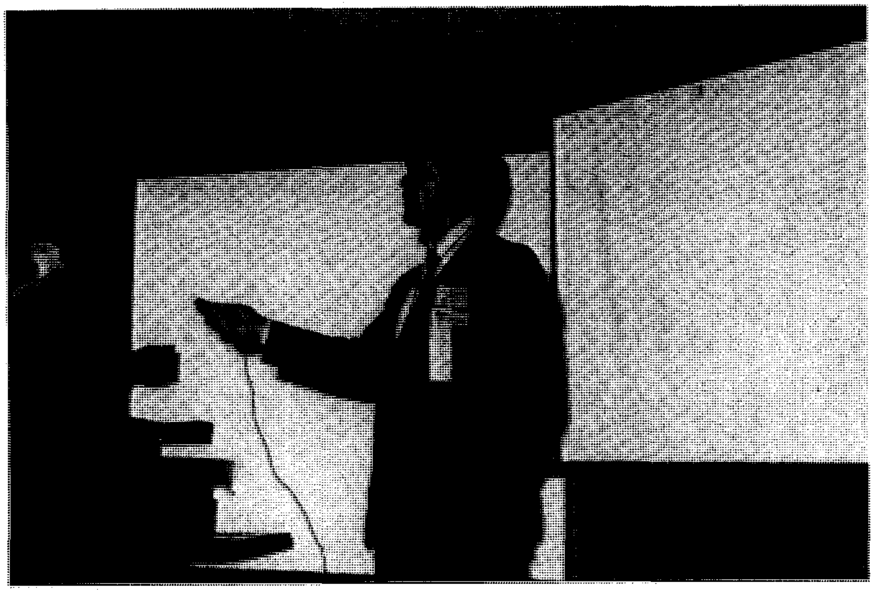


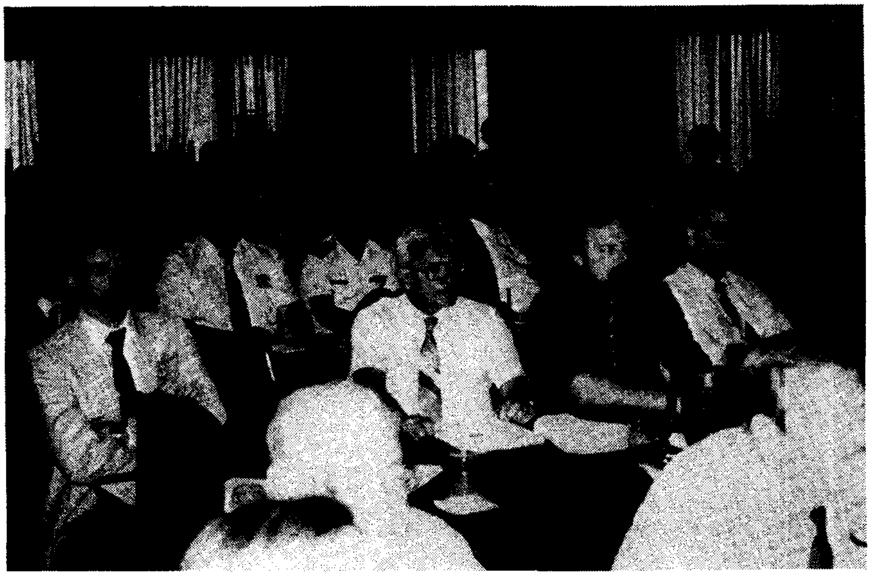

THE KEYNOTE

TECHNICAL SESSIONS

JIM GETS IT STARTED

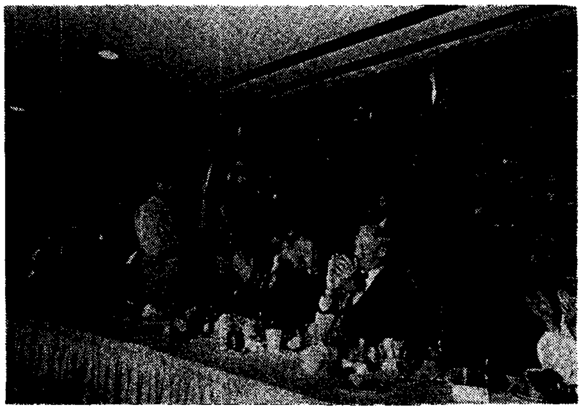
LARRY DELIVERS





THE AUDIENCE

THE LUNCHEONS AND BANQUET



REGISTERED ATTENDANCE

WILD GOOSE ASSOCIATION 14TH ANNUAL TECHNICAL SYMPOSIUM

SANTA BARBARA, CALIFORNIA

OCTOBER 23-25, 1985

WILD GOOSE ASSOCIATION 14th ANNUAL CONVENTION

Name	Representing	Address
Alexander, Cdr J.O.	Alexander Marine Trans.	Los Alamitos, CA
Ambroseno, Bernard	Epsco, Inc.	Westwood, MA
Amos, Cdr David	U.S. Coast Guard	Boston, MA
Anderson, Ralph P.		Port Townsend, WA
Andren, Carl S.	Racal-Megapulse	Bedford, MA
Andross, Norman E.	A&N Technology	Santa Maria, CA
Baer, Glen E.	APL/Johns Hopkins Univ.	Laurel, MD
Beran, Commodore A.	U.S. Coast Guard	Long Beach, CA
Beukers, John M.	Viz Manufacturing Co.	Philadelphia, PA
Blizard, Lt JG Matthew M.	U.S. Coast Guard	Groton, CT
Bo, Sigura	Meridian Ocean Systems	Ventura, CA
Boettcher, J.	II Morrow, Europe	Fed. Republic Germany
Bradley, Jerry W.	FAA	Oakton, VA
Bronson, Robert	II Morrow, Inc.	Salem, OR
Burgin, William F.	Si-Tex Marine Electronics	Clearwater, FL
Burket, Paul E.	Oregon Aeronautics Div.	Salem, OR
Butler, John	Canadian Coast Guard	St. Johns, Canada
Cappeto, Rocco	Raytheon Marine	Los Angeles, CA
Carter, David	JAYCOR	Bowie, MD
Cassis, Robert H.	U.S. Coast Guard	Alameda, CA
Cortland, Larry	II Morrow, Inc.	Salem, OR
Culbertson, James F.	Kaman Tempo	Westminster, CA
Culver, Calvin	Micrologic	Chartworth, CA
Dana, Peter H.	Consultant	Georgetown, TX
Danklefs, Ronald W.	Micrologic	Chatsworth, CA
DeGeorge, Bill	ITT Avionics	Nutley, NJ
Dean, Walter N.	ARNAV Systems	Wilsonville, OR
Doughty, Russ	U.S. Coast Guard	Bowie, MD
Dueck, Terry L.C.	Systems Control Technology	Palo Alto, CA
Duhnke, Robert E.	The Boeing Company	Auburn, WA
Edwards, Charles R.	APL/Johns Hopkins Univ.	Laurel, MD
Erikson, Robert H.	FAA Technical Center	Lindenwold, NJ
Fagan, John H.	Synetics Corporation	Reading, MA
Ferer, Harvey	Consultant	Marina Del Rey, CA
Foxwell, David G.	Kaman Tempo	Santa Barbara, CA
Frank, Robert L.	Consultant	Birmingham, MI
Frazier, LCDR Ronald H.	U.S. Coast Guard	Groton, CT
Frost, Albert D.	University of New Hampshire	Durham, NM
Fujino, T.	Si-Tex Marine	Clearwater, FL
Garmany, William J.	ITT Avionics	Livingston, NJ
Gazlay, LCDR R.L.	U.S. Coast Guard	Washington, DC
Ginsburg, Issac	Canadian Coast Guard	Ottawa, Canada
Goddard, Robert	Racal-Megapulse	Bedford, MA
Goodman, Gill R.	U.S. Coast Guard	Novato, CA
Grant, Brian	Journalist	England
Greenleaf, William T.	King Marine Radio Corp.	Clearwater, FL
Gunther, G.T.	U.S. Coast Guard	Woodbridge, VA
Hartnett, Richard	USCG Academy	New London, CT
Hay, Mike	U.S. Coast Guard	Cape May Ct Hse, NJ
Hewitt, Ron	U.S. Coast Guard	Wildwood, NJ

Name	Representing	Address
Higginbotham, Lloyd		Acton, MA
Hinton, Greg	Technology Projects, Ltd.	Tempe, AZ
Honey, Frederick Jr.	Marine Technology, Inc.	Long Beach, CA
Honey, John F.	Marine Technology, Inc.	Long Beach, CA
Hopkins, John	Navigation Development Svcs	Northridge, CA
Illgen, John D.	Kaman Tempo	Santa Barbara, CA
Johannessen, Paul R.	Racal-Megapulse	Bedford, MA
Johnson, Vernon L.	ITT Avionics	Nutley, NJ
Keeler, Captain N.H.	U.S. Coast Guard	Washington, DC
Kelly, James D.	TASC	Reading, MA
Kies, Captain Phillip J.	U.S. Coast Guard	Long Beach, MS
Klein, James	Rockwell	Marion, IA
Lally, Vincent E.	National Ctr for Atmo Res.	Boulder, CO
Lauther, B.G.	U.S. Coast Guard	Washington, DC
Lazenby, Daniel L.	Kinton, Inc.	Baileys Crossroads, VA
Lilley, Dr. R.W.	Ohio Univ Avionics Eng Ctr	Athens, OH
Longman, Chick	FAA	Washington, DC
MacKenzie, Franklin D.	TSC	Needham, MA
Mantel, Stan	APL/Johns Hopkins Univ.	Laurel, MD
Marchal, A. William	Offshore Navigation, Inc.	New Orleans, LA
Marshall, Duane	Racal-Megapulse	Bedford, MA
May, Bill	U.S. Coast Guard	Woodbridge, VA
Maynard, Kurtis	John E. Chance & Assoc	LaFayette, LA
McCall, Daryl L.	Ohio Univ Avionics Eng Ctr	Athens, OH
McKeown, Robert	ITT Avionics	Montclair, NJ
McGann, Edward L.	Racal-Megapulse	Bedford, MA
Meranda, Jim		Temecula, CA
Millan, CDR Harold E.	U.S. Coast Guard	Alameda, CA
Miller, Robert	Kaman Tempo	Albuquerque, NM
Mooney, Francis W.	TSC	Marblehead, MA
Moroney, Michael	U.S. Department of Trans.	S. Hamilton, MA
Muellenhoff, William P.	Tetra Tech Inc.	Corvallis, OR
Nichols, T.G.	Raytheon ESD	Santa Barbara, CA
Oliver, Robert E.	Delco	Goleta, CA
Pealer, Nevin A.	Systems Control Technology	Washington, DC
Perchik, Garry	ITTAV	Nutley, NJ
Polhemus, William L.	Polhemus Associates	Cambridge, VT
Poppe, Martin C.	Cambridge Engineering	Cambridge, VT
Puzon, C.V.	MCI	Washington, DC
Ridley, Wallace R.	U.S. Coast Guard	Marlboro, MD
Rogoff, Mortimer	Navigation Sciences	Bethesda, MD
Roland, Capt W.F.	U.S. Coast Guard	Honolulu, HI
Roll, Ronald G.	APL/Johns Hopkins Univ.	Laurel, MD
Saether, Kolbjorn	Norwegian Def Comm Org	Oslo 1, Norway
Sargent, VADM Thomas R.	U.S. Coast Guard (Ret.)	Lake San Marcos, CA
Schnitger, Wallace		Huntington Beach, CA
Scull, David C.	DOT/RSPA	Alexandria, VA
Seery, Sam	II Morrow, Inc.	Salem, OR
Shuey, Martin W.	AOPA	Frederick, MD
Sigurdsson, Haraldur	Gen Dir Posts & Telecom	Iceland
Slagle, CWO3 Daniel C.	U.S. Coast Guard	Groton, CT
Solomon, Hal	Systems Control Technology	Los Altos, CA