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WILD GOOSE ASSOCIATION

PROCEEDINGS

OF THE

SIXTH ANNUAL CONVENTION

HELD IN

SEATTLE, WASHINGTON
12-14 OCTOBER 1977

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PREFACE

These proceedings include the official introductions and technical papers presented at the Sixth Annual Convention of the Wild Goose Association.

This convention was held in conjunction with FISH EXPO 77, the Eleventh Annual International Convention of the American Fishing Industry. The location was the beautiful city of Seattle, Washington. Wild Goose Association headquarters were in the Edgewater Inn while FISH EXPO 77 was held at the nearby Seattle Center Coliseum.

Wild Goose Association technical sessions were conducted on Thursday, 13 October in the Island Room of the Edgewater Inn. On Friday, 14 October, the Wild Goose Association technical session was conducted in the Shaw and Fidalgo Rooms, Coliseum North Court, Seattle Center. The facilities used by the Association on Friday were graciously provided by the sponsors of FISH EXPO 77 and coordinated by Captain R. Barry Fisher, Chairman of the FISH EXPO 77 Seminars and Workshops.

The theme of this convention was "Loran-C Comes to the West Coast." Some of the papers presented at the convention and included in these proceedings are supportive of the theme while others describe uses of Loran-C in other areas of the United States and scientific research pertaining to Loran-C. A total of one hundred eleven persons registered for the convention. However, all the sessions were open to FISH EXPO 77 attendees and, therefore, all sessions had significantly larger numbers in attendance than the number registered.

A SYSTEMATIC METHOD OF LORAN-C ACCURACY CONTOUR ESTIMATION - LCdr. David H. Amos, USCG, and Cdr. Donald A. Feldman, USCG; U.S. Coast Guard Activities, Europe . 131

SUCCESSIVE-CYCLE PHASE-DISTORTION EFFECT ON LORAN C/D ACCURACY - Mr. Robert L. Frank, Electronic System Consultant 149

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Session Chairman: Mr. Daniel A. Panshin
School of Oceanography
Oregon State University

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WEST COAST LORAN-C - THE PROMISE AND THE PRODUCT - Capt. Alfred P. Manning, USCG, 13th Coast Guard District 165

DEVELOPMENT OF CHARTING CORRECTIONS FOR LORAN-C CHARTS IN THE COASTAL CONFLUENCE ZONE - Mr. Randolph J. Doubt, Defense Mapping Agency Hydrographic Center 167

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MANUAL TO AUTOMATIC - OUTGUESSING THE NUMBERS GAME - Mr. Clyde B. Kirlin, Clyde B. Kirlin, Inc.; and Mr. Ernest Wilson, Wilson Communications/Electronics . 189

WELCOME TO THE SIXTH WGA CONVENTION

John M. Beukers
President, Wild Goose Association

At last year's banquet we announced that this year's convention would take place in Seattle to coincide with Loran-C coming to the West Coast. We planned this with some trepidation because the habitat of most members goose is on the East Coast. The added expense plus the difficulties of organizing a convention from the East Coast gave us a challenge. It gives us great satisfaction to see such a good turnout and I welcome you to the Sixth Annual Convention of the WGA.

I wish to acknowledge the splendid work done by the organizers of the convention, the arrangements and technical program. This gives me the opportunity to reintroduce the Chairman - Red Frederick - Committee

Tom McCarty	The Technical Program
Dan Panshin	Interface with Fish Expo & Sea Grant
Bob Dugan	Local Arrangements

I would like to make one important comment before I turn the proceedings over to the Chairman of this morning's session. Last year, at the convention, the WGA was criticized - and we took this constructively - for being divorced from the user, a technical entity unto its own, and being governed and directed from Washington. We took this commentary seriously since it is contrary to our Charter and certainly does not express the goals and objectives of the President and Board of Directors. We consider the WGA's most important function is to communicate - to the User - to the Government - to the Press - to the Manufacturer. As demonstration of this I bring to your attention this year's Journal which is totally user oriented. It contains a report and analysis of Loran-C receivers on the market today and provides updated chain and charting information.

Equally significant is our presence here today. By arrangement and cooperation with Fish Expo we are running back to back with a joint session tomorrow. Our reasons for doing this are twofold. One - to communicate directly with the user and give the user the benefit of a unique gathering of Loran-C operators, technologists and manufacturers. Secondly, it has enabled members who found a conflict between the WGA Convention and Fish Expo last year to be able to benefit from both conventions. Again I bring your attention to tomorrow's joint session which will not be held in this room but in the Shaw and Fidalgo Rooms at 0900 in the North Court, Seattle Center.

Again welcome, we hope your stay will be rewarding and enjoyable. I now turn the meeting over to our Chairman for this morning's session.

A CASE HISTORY OF REDUCING LORAN CHAIN CROSS RATE INTERFERENCE BY USING A BALANCED PHASE CODE

RANDALL V. GRESSANG, GERALD G. IVERSON, RONALD A. MCCLELLAN

ABSTRACT:

During testing of the USAF AN/TRN-38 LORAN C/D Chain in the Southeast United States, it was found that the AN/TRN-38 Chain caused serious cross rate interference to the East Coast LORAN C Chain. This interference was severe enough on 2 March 1977 to cause the operation of the Eglin AFB Monitor of the East Coast LORAN C Chain to be disrupted.

The cross rate interference problem was alleviated by adapting to LORAN-D balanced phase codes as proposed by Roland and Feldman, Pakos and Potts at the Fourth Annual WGA Technical Symposium, and selecting a rate to use with the balanced phase codes as described by Feldman, Pakos, and Potts. The use of a balanced phase code alone was sufficient to result in no discernable interference on the Eglin AFB Monitor recordings.

I. INTRODUCTION

During testing of the USAF AN/TRN-38 LORAN C Chain in the Southeast United States, it was found that the AN/TRN-38 Chain caused serious cross rate interference to the East Coast LORAN C Chain. This interference was severe enough on 2 March 1977 to cause the operation of the Eglin Air Force Base Monitor of the East Coast LORAN C Chain to be disrupted. This occurrence of cross rate interference is only one example of a cross rate interference problem encountered in the operation of a "Minichain" within the service area of a standard LORAN C Chain. A similar case of the "Minichain" interfering with the standard LORAN C Chain was encountered during the testing of the AN/TRN-21 LORAN D Chain in the Southeast Unites States. Examples of the standard chain interfering with the "Minichain" are interference to the Hill Air Force Base Minichain and the Ft Hood Minichain from the West Coast LORAN C Chain.

II. CROSS RATE INTERFERENCE

Cross rate interference is the name given to the effect upon a LORAN receiver of received LORAN pulses which are on a rate different from the rate the receiver is tracking. The pulses on the second rate arise from an adjacent LORAN Chain, from a "Minichain" within the service area of the chain being used, or from a chain within whose service area the "Minichain" being used is located. The effect of the pulses at the second rate on the receiver may be in the form of an offset in the time difference numbers, or a "Sine Waving" oscillation in the time difference numbers. These effects are caused by the periodic coincidence of the pulses at the two rates in the phase tracking loop. It is also possible for this periodic coincidence of pulses on the two rates to cause a cycle slip in the envelope settling of the receiver, or "Sine Waving" or an offset in an envelope tracking loop. In extreme cases, cycle selection may not be possible, or it may not be possible to complete the receiver search process and acquire the desired signals.

III. METHODS OF REDUCING CROSS RATE INTERFERENCE

The possibility of cross rate interference was recognized during the development of LORAN C and its effects were studied analytically and experimentally (1), (2), (3). Several methods of reducing cross rate interference were identified and its basic characteristics were defined in these studies, but no single best method of reducing cross rate interference was identified. The technique adopted for reducing cross rate interference at that time was to select chain repetition rates which were relatively non-interfering. This technique had practical benefits in that no changes in LORAN system specifications or signal formats were required, and action was required only by the operator of the transmitters. A second technique sometimes employed also is to slightly shift the center frequency of one of the chains, which is possible if that chain is not synchronized to UTC.

With the expansion of LORAN C coverage to include the entire coastal confluence zone, the development of LORAN D by the United

States Air Force, and the development of commercial "Minichains" for special applications, the possibility of cross rate interference is increased due to the larger number of adjacent or overlapping chain coverage areas. Because of the increased potential for interference, the LORAN C rate structure was expanded.

In addition, additional studies of cross rate interference were performed (4) (5). These studies identified the use of a balanced phase code in conjunction with careful rate selection as offering the best possible cross rate interference rejection. The change from the standard phase code to a balanced phase code, while increasing protection against cross rate interference, would result in reduced protection against long delay skywaves. A balanced phase code would also require changes in the receiving equipment to enable it to decode the new phase code, and might possibly require changes in the logic of the search algorithm of an automatic LORAN receiver. Because of the required receiver changes, the balanced phase code technique is not attractive for use by standard LORAN C chains. However, for a "Minichain" with short baselines where skywave problems are not present and there are relatively few specialized users, adoption of a balanced phase code for reducting cross rate interference is very attractive.

IV. AN/TRN-38 CROSS RATE INTERFERENCE ALLEVIATION

The use of a balanced phase code by a "Minichain" to reduce cross rate interference has now been successfully implemented. The West Coast Chain interference with the Hill Air Force Base and Ft Hood minichains was alleviated by rate changes of the Hill Air Force Base and Ft Hood chains. The AN/TRN-21 interference with the East Coast LORAN C Chain was alleviated by shifting slightly the AN/TRN-21 center frequency and by rate selection. However, in the case of the AN/TRN-38 interference to the East Coast LORAN C Chain, rate changes did not alleviate the interference, and the center frequency could not be easily shifted. Therefore, the use of a balanced phase code by the AN/TRN-38 in conjunction with rate selection was adopted to alleviate the cross rate interference. This paper will describe the balanced phase codes used and the results of a field test of the effectiveness of the balanced phase codes.

Two different balanced phase codes were developed for LORAN D and field tested. A balanced phase code is one which has an equal number of 0 degree and 180 degree phase pulses. The condition does not specify a unique phase code, but only constrains the set of possible phase codes. An additional condition placed upon the phase codes considered was that the average cross correlation with the LORAN C phase code be zero. This condition also narrows the set of feasible codes but does not specify a nique code. The codes developed repeated after two group repetition intervals. Both codes are presented in Table 1. In Table 1, a + indicates a LORAN pulse with 0 degree phase, and a - indicates a LORAN pulse with 180 degree phase.

Phase code number one is an adaptation of a LORAN C balanced phase code presented by Roland (4). Phase code number two was developed using the optimized phase code function conditions presented by Feldman, Pakos, and Potts (5). In addition, the algorithm for determining desireable group repetition intervals presented by Feldman, Pakos, and Potts was used to determine which rate would yield the least interference. The AN/TRN-38 at present can only generate GRIs corresponding to the old rate structure. As the East Coast LORAN C Chain, having rate 9930 (SS-7), was the chain with which mutual interference was to be minimized, the example worked out by Feldman et al. showed that no feasible rate existed above 5000. The algorithm was applied to the LORAN D rates below 5000, and it was determined that no rate below 5000 satisfied all three conditions of the algorithm, but rate 4960 (S-4) came closest to satisfying all the conditions.

The interference from LORAN D observed at the Eglin Air Force Base LORAN C Monitor consisted of "Sine Waving" and offsets in the phase track, and envelope tracking disturbances which disabled the envelope track of the monitor receiver. The strengths of the signals from the various stations at Eglin are presented in Table 2 (The Dana and Jupiter Signal Strengths were estimated from ocilloscope traces; the other signal strengths were derived from single pulse field strength measurements). The LORAN D secondary phase code was observed to cause more interference than the LORAN D master phase code. Several rates were tried (including rates 3970 (L-3) and 3930 (L-7)) with no apparent affect upon the interference. Phase code number one was then implemented in conjunction with using rate 4960 (S-4) and the effect of the LORAN D signals upon the LORAN C Monitor was reduced to being virtually undetectable except for seeing the LORAN D pulses on the ocilloscope display of the RF.

V. EXPERIMENT TO VERIFY CROSS RATE INTERFERENCE ALLEVIATION

Since the AN/TRN-38 testing required a demonstration of a transmitter dual rate capability, an experiment was constructed to see if use of one of the balanced phase codes would permit dual rate AN/TRN-38 operation without interfering with the Eglin LORAN C Monitor. For this experiment, the strip chart recordings made by the Monitor of TDW, TDZ and Master Phase were to be examined to see if a quantitative measure of the interference could be determined. This experiment was also expanded to include a quantitative comparison of both balanced phase codes against the standard phase code, and a comparison of the effect of a rate change. A total of 8 combinations of rate and phase code were transmitted, with each combination being transmitted continuously for at least four hours. The 8 combinations and the results of

Table 1 Balanced Phase Codes for LORAN D

NOTE: + = 0 Degree Pulse Phase

− = 180 Degree Pulse Phase

Balanced Phase Code Number One

Master Phase Code

Interval One

+ + + − − − − + + − + + − + − −

Interval Two

+ + − + − − + − + − − − − + + +

Secondary Phase Code

Interval One

+ − + + − + − − + + + − − − − +

Interval Two

+ − − − − + + + + + − + − − + −

Balanced Phase Code Number Two

Master Phase Code

Interval One

+ − + − − + − + − + − + + − + −

Interval Two

+ − − + − + + − − + + − + − − +

Secondary Phase Code

Interval One

+ − − + − + + − − + + − + − − +

Interval Two

+ + + + − − − − − − − − + + + +

Table 2 LORAN CHAIN SIGNAL STRENGTHS AT EGLIN AFB, FLORIDA

East Coast LORAN-C Chain

Master Carolina Beach, N. Carolina	3500 microvolts per meter
Secondary W Jupiter, Florida	4000 microvolts per meter
Secondary Z Dana, Indiana	1250 microvolts per meter

AN/TRN-38 LORAN C/D Chain

Master Anniston, Alabama	2500 microvolts per meter
Secondary A Raiford, Florida	3000 microvolts per meter
Secondary B Kisatchie, Louisiana	1800 microvolts per meter

Typical background noise in the LORAN Band at Eglin AFB is 560 microvolts per meter RMS.

examining the Monitor station recordings are shown in Table 3.

Examining Table 3 it will be seen that the TDW and TDZ Monitor strip chart recordings had a normal appearance when balanced phase codes were used. The sine waving when the standard phase code was used was from 60 to 100 nanoseconds in phase, and from .8 microseconds to a continuously drive envelope servo.

When the master cycle recordings are examined, it is now possible to see some differences between the two balanced phase codes and between the rates. Phase code number one with the 4960(S-4) rate resulted in the least effect on the master phase recording, but the 3970 (L-3) rate with phase code number one resulted in a very similar effect. However, none of the cases where a balanced phase code was used resulted in a significant amount of interference in the master phase recordings nor was there any large difference in the interference on the master phase recording between the two balanced phase codes or as rate was varied when balanced phase codes were used. The lack of discrimination in interference between balanced phase codes and rates is probably mainly due to the ad hoc nature of the method used to detect cross rate interference.

VI. CONCLUSION

In conclusion, a serious cross rate interference problems which arose in condunction with AN/TRN-38 testing was resolved through the use of balanced phase codes by the AN/TRN-38, and through the use of specially selected rates. The use of a balanced phase code to relieve cross rate interference confirmed the analysis of References 4 and 5. However, the confirming experiments were not sensitive enough to unambiguously identify the effect of various combinations of balanced phase code and rate.

TABLE 3 CROSS RATE INTERFERENCE TEST RESULTS

CONDITION AN/TRN-38 CHAIN	MASTER CYCLE EGLIN LORAN C MONITOR	TDW		TDZ	
		ENVELOPE	CYCLE	ENVELOPE	CYCLE
Phase Code 1 Rate SL 1	40 nanoseconds sine waving	Normal	Normal	Normal	Normal
Phase Code 1 Rate SL 1 One transmitter dual rated on SL 1 and SH 7	50 nanosecond sine waving	Normal	Normal	Normal	Normal
Phase Code 1 Rate S4	20 nanosecond sine waving	Normal	Normal	Normal	Normal
Phase Code 2 Rate S4	40 nanosecond sine waving	Normal	Normal	Normal	Normal
Phase Code 2 Rate L3	45 nanosecond sine waving	Normal	Normal	Normal	Normal
Phase Code 1 Rate L3	25 nanosecond sine waving	Normal	Normal	Normal	Normal
Standard Phase Code Rate L3	80 nanosecond sine waving	-.4 microsecond offset	60 nanosecond sine waving	.8 microsecond sine waving	80 nanosecond sine waving
Standard Phase Code Rate S4	100 nanosecond sine waving	Continually driven off signal	100 nanosecond sine waving	.8 microsecond sine waving	60 nanosecond sine waving

REFERENCES

1. Collins Radio Co., "Final Engineering Report for Cross-Chain Interference Study", 17 July 1964, U. S. Coast Guard Contract TCG-59, 380-2A

2. ITT Federal Labs., "Final Engineering Report Cross-Rate Interference Study", November 1963, U. S. Coast Guard Contract TCG-59, 380-1A

3. Sperry Gyroscope Co., "Final Report, Cross-Chain Interference Study", April 1964, U. S. Coast Guard Contract TCG-59, 380-A

4. Roland, W. F., "LORAN-C Phase Code and Rate Manipulation for Reduced Cross Chain Interference", Wild Goose Association Fourth Annual Technical Symposium Proceedings, 16 and 17 October 1975

5. Feldman, D. A., P. E. Pakos, and C. E. Potts, "On the Analysis and Minimization of Mutual Interference of LORAN-C Chains", Wild Goose Association Fourth Annual Technical Symposium Proceedings, 16 and 17 October 1975

INTEGRATED AVIONICS SYSTEM WITH LORAN-C FOR THE US COAST GUARD MEDIUM RANGE SURVEILLANCE PROGRAM

BY

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GOVERNMENT AVIONICS DIVISION

COLLINS AVIONICS GROUP, ROCKWELL INTERNATIONAL

SECTION 1

INTRODUCTION

The Medium Range Surveillance (MRS) program will provide the US Coast Guard with a new fleet of surveillance aircraft which may be used in a number of different missions. These aircraft, designated the HU-25A, will be provided by Falcon Jet Corp, as a derivative of their Falcon 20G two-engine business jet. Collins Avionics Group of Rockwell International is subcontractor to Falcon Jet Corp. for the design and integration of the MRS avionics system.

The MRS program makes use of off-the-shelf systems and equipments wherever applicable, including Collins commerical designs and government furnished equipment (GFE) where avaiable. The systems design task therefore has emphasized the integration of a large number of existing equipment designs with some new equipment developments to provide a system operational capability suitable for the varied missions of the US Coast Guard. The integrated system is to be certified under the Federal Aviation Regulations; this prepares the HU-25A for anticipated USCG missions using operating rules for the US and ICAO airspace in which it must operate.

As system integrator, Collins Avionics is performing the mission analysis, system synthesis, hardware and software implementation, and test verification for the MRS avionics system. This paper is being presented to report on these tasks, and to relate to the technical navigation community the technology status of a state-of the-art navigation system being designed for production and fleet operational use. Of particular interest to the Wild Goose Association audience will be the utilization of Loran-C in the system. To present the Loran-C implementation in the right perspective, the applied systems design criteria will be described in both technical and operational terminology. Avionics system capabilities as structured to support the Coast Guard in several of the mission types will be discussed. Anticipated operational requirements will be amplified as principle design criteria for the integrated MRS avionics system. In order to introduce these operational requirements, we will now overview the general mission definitions and summarize the implicit system requirements.

The mission definitions used for the avionics system are: Search and Rescue, Enforcement of Laws and Treaties, (e.g. enforcement of the newly adopted 200-mile limit for economic management of natural resources), Marine Environmental Protection, Marine Science Activities, and associated logistics and support applications of the Coast Guard.

Analysis of the scenarios associated with these missions discloses commonality of system requirements in the following areas:

1. Significant operating time under conditions of adverse weather and low visibility at low altitude.
2. Frequent diversion from one mission to another for emergency situations.

3. Diversity in navigation and communication tasks results in frequent high peak loading on a limited crew size.
4. Search and law enforcement missions require substantiated data of high integrity.
5. Safety of air crew and public during all operations.

Compliance with these common requirements results in functional capabilities which assist the crew in attaining effectivity of the planned mission. Some of the functional capabilities provided by the integrated system are:

1. Centralized multisensor position determination and navigation for on and off-shore operation.
2. Automated intercept and rendezvous guidance.
3. Automated flight plan management including automatic search pattern generation.
4. Flight guidance and aircraft control throughout the mission flight regimes, including Category II approaches.
5. Communications on all maritime and aeronautical frequencies for government, civil and private operators.
6. Automated interfaces between search radar and navigation management functions.
7. Multiple crew station access to control and display of communication, navigation and radar data.

The functions are being designed and integrated with an emphasis on flight crew human factors which considers both normal and degraded operating conditions as well as an emphasis on technical performance for the mission.

Loran-C is the most accurate navigation data source that will be available throughout much of the expected mission. A four-state Kalman filter mechanization is employed in the Loran-C position determination algorithm. Consideration was given to a Kalman filter with more error states. However, the accuracy requirements of this system did not justify the additional computational complexity. As will be shown later, the mathematical models used for design and analysis are those appropriate to the primary need for reliable, accurate and verifiable position determination throughout the mission.

This concludes the introduction to the general MRS program and mission operational objectives for the HU-25A. In the following Section 2 we will overview the system itself and illustrate its functional architecture. Section 3 will discuss the importance of system design for operational acceptability. Section 4 discusses the design analysis of the navigation task, and the specific use of Loran-C within the system. The concluding Section 5 will summarize hardware and software implementation of the RNAV system.

SECTION 2

MRS AVIONICS SYSTEM OVERVIEW

With the overall scope of the operational requirements of the system identified, this section will introduce an overview of the avionics system and identify its functional content.

The system make-up reflects the need for immediate dispatch and return capability with minumum restrictions because of weather. The system includes navigation, communication, flight guidance, and autopilot. With the aircraft and systems certified to Category II minimums routine all weather operations can be provided at all civil and military airports

Extended operations over remote land and ocean is provided by the statistical combination of Loran-C, inertial, and other supporting sensors. The system also includes the GFE APS-127 multimode radar. This radar with its specialized capability for search maintains a high probability of detection even in high sea states. Integration of the radar with the navigation system provides for logging and isolation of radar detected objects and increases all weather, day and night, search effectiveness.

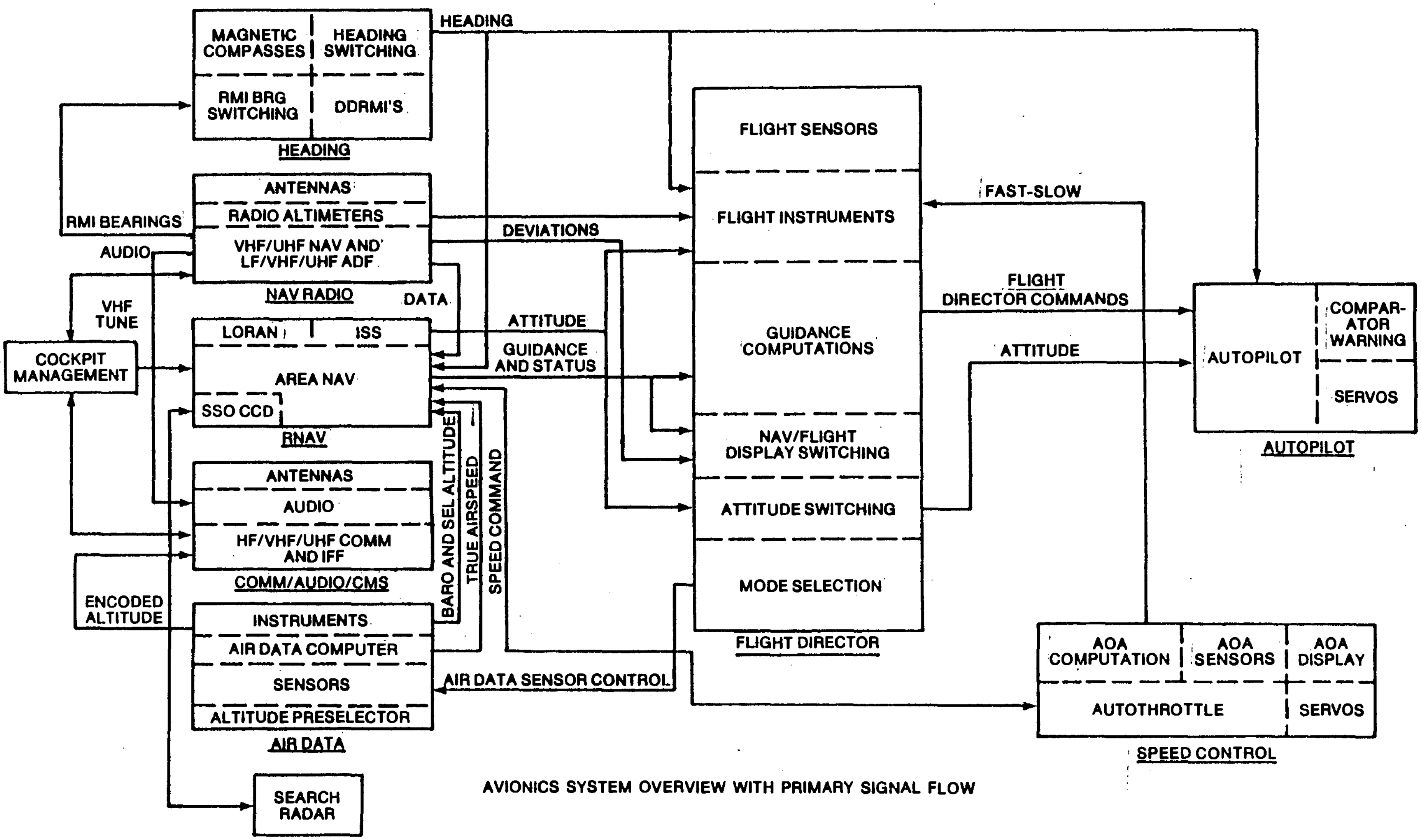
Flight crew management of the large number of communication and radio navigation aids is simplified by an integrated radio management function. The integrated system is being designed with the objective to automate flight management to the extent compatible with flight management effectivity and aircraft safety. Thus the crew workload associated with routine flight management duties is eased to allow more emphasis on the search and patrol duties.

Figure 2-1 presents an overview diagram of the system and shows the primary signal flow. A brief discussion will follow on each on the functional groupings. included in the diagram. These groupings are used to organize the system functions, and do not depict all of the hardware partitioning. The MRS avionics hardware consists of 142 line replaceable units.

AREA NAVIGATION (RNAV)

The basic area nav system includes the Navigation Computer Unit (NCU) for overall digital processing of the navigation and flight management functions. A Control Display Unit (CDU) provides an alpha-numeric keyboard, a CRT readout, and controller functions with multifunction keys for pilot control and interfacing with the system. The bulk data storage source for the system is the Flight Data Storage Unit (FDSU) which employs a magnetic tape cartridge for inputting current nav aid and flight plan waypoint data during Initial Program Load (IPL).

The RNAV subsystem functions include Loran and inertial sensor system (ISS) for complete overwater navigation service. Utilizing the Loran and ISS information, along with navigation inputs from VOR and DME, the R-NAV provides global great circle navigation, automated flight management through preselected three-dimensional waypoints, and steering guidance to allow coupled autopilot



AVIONICS SYSTEM OVERVIEW WITH PRIMARY SIGNAL FLOW

FIGURE 2-1.

and autothrottle control throughout the flight. The RNAV system also provides navigation interfaces with the Multimode Search Radar through the Surveillance System Operator's Cockpit Control Display (SSO CCD). Additional detail on the RNAV functions will be presented in the later sections of this paper.

NAVIGATION RADIO

Radio navigation includes VHF navigation (VOR/LOC) and DME, Marker Beacon, TACAN, and radio altimetry capabilities, as well as Loran, which is included under the RNAV. An LF-ADF and UHF/VHF-DF provide radio bearing information for homing operation over a wide range of frequencies.

COMM/AUDIO

Communication coverage is provided over a complete spectrum of frequencies for the monitoring of distress transmissions from, or communicating with, all military, civil, and domestic aircraft operators, as well as military, commercial, or private maritime operators.

Communication is also provided with military, ATC, and civil defense networks. Frequency bands include VHF, UHF, HF, and VHF-FM. IFF transponder capability is provided on L band. The communication equipment ties into an audio system which serves both pilots, the SSO, and the search observers.

COCKPIT MANAGEMENT SYSTEM

A Cockpit Management System (CMS) provides integration of tuning, control, and display of the overall set of MRS communication and navigation radios. All of the radios, except for LF-ADF, can be tuned from centralized Cockpit Control Displays (CCD's) at the pilot, copilot, and SSO stations. The CCD's provide the flexibility of presetting anticipated needed frequencies into the system for various of the radios for rapid recall and tuning initiation by channel number later in the flight. The CMS is interconnected with the RNAV system to provide for computer control of the navigation radios where needed.

FLIGHT DIRECTOR

The flight director system functions include all primary flight control displays, the flight mode selection and computation, and the primary flight sensors, such as basic gyros and accelerometers. Flight guidance modes include those which integrate mission RNAV profile steering into control of the aircraft, as well as TACAN, VOR, and ILS tracking service, and a selection of air data modes for longitudinal and altitude axis control of the aircraft. The computed guidance commands are displayed on the Attitude Director Indicator command bars for flight director steering assistance to the pilot in flying the aircraft manually, and the guidance commands are supplied to the autopilot for coupled flight control.

Dual flight director system redundancy is provided with displays for both the pilot and copilot. Reversionary switching functions permit cross feeding various sensor signals to still facilitate a complete set of displayed information for each pilot even after failure of certain gyro sensors.

AUTOPILOT

The basic autopilot, with yaw damper, provides automatic control of the aircraft, with coupling to mission guidance or with basic control modes. The integrated autopilot/flight-director system provides Category II approach capability.

SPEED CONTROL

The speed control functions include automatic throttles for holding a selected speed reference based on either angle of attack or airspeed, and for mission profile thrust management for fuel efficiency. Speed monitoring service also is provided.

AIR DATA

An air data computer provides TAS and baro-corrected altitude for RNAV computations. Basic altimeter, vertical speed, and mach/airspeed display data for the left side of the cockpit are supplied by the air data computer to electrically driven instruments. Right-side air data displays are pneumatically driven.

HEADING

The heading subsystem provides gyro-stabilized magnetic heading sensing for navigation and flight control. Heading, distance, and selected radio bearings are displayed on the integrated digital distance radio magnetic indicator.

SECTION 3

MISSION OPERATIONAL CAPABILITY

With the MRS aircraft program defined to accommodate the general US Coast Guard mission applications, a key part of the MRS avionics system design and integration task was identified from the beginning as one of assuring mission operational effectiveness and crew acceptability. Indeed, the integration of many off-the-shelf equipments which previously had not been used together into a new system, and the installation integration of the sizable avionics suite into a modest sized derivative aircraft are major avionics engineering tasks. The program also includes finalizing the development of new equipments for speed control, cockpit management, data processing, and aircraft integration of the system. However, operational design and human factors engineering have remained a primary element of the engineering program for assuring overall program success and satisfaction.

DESIGNING FOR OPERATIONAL ACCEPTABILITY

It is our goal for the MRS avionics program to provide maximum operational capability and flexibility consistent with the contracted scope of the program. With the flexibility given to the designer through the use of a programmable computer, CRT displays, flexible keyboards, a multimode flight system, and highly capable supporting sensors such as Loran-C; there can be the tendancy to complicate system design for the sake of technically stimulating possibilities. The consequence of such an approach could be an operationally difficult, or even uncertifiable system for the flight crews.

For the MRS program, the Coast Guard has elected to procure an FAA-certified aircraft and avionics system. Industry guidelines that have developed in working with the FAA, including the Federal Aviation Regulations (FAR's) and other FAA advisory documents, are therefore being applied in the design of the MRS systems. Within the framework of the principles of these established practices and requirements, special provisions for the missions are being incorporated.

The MRS avionics design team is composed of a balance in expertise represented by experienced human factors, systems, and hardware design personnel. With a system design emphasis on making sure that primary and typical mission requirements are best satisfied, the team will integrate and verify the system on the basis of operational acceptability and usability. System operation is being designed to be understandable by the pilot at all times so that in the event of malfunctions, correct action and reversionary control will be initiated. The ultimate operational criteria, therefore, is that flight safety and mission completion must be assured.

In the MRS system, automaticity is provided to ease crew workload related to routine useage. Automatic navigation and flight management functions are provided, along with autopilot and autothrottle functions for automatic flight control. However, extensive basic data and complementary information is displayed to the pilot for cross checking, monitoring, and reversionary control. Display of basic flight parameters such as air data, aircraft attitudes, and course deviations and bearings to the varied radio references, are available full time to both pilots. Automatic cross-monitoring assistance is provided on certain critical parameters. A full complement of flight control and navigation mode annunciations is provided to the pilots. In-line monitoring assists in identifying equipment failures with flag annunciation and aural warning, and with certain automatic system disconnections.

In the event system component malfunctions are identified, means for system reversionary reconfiguration is provided. Means of selecting alternate redundant sensors is provided. Reconfiguration to alternate modes of control, or to less automatic means of control is available. For example, autopilot maneuvering modes may be used rather than the coupled navigation profile control, or manual control with flight director service can be used when autopilot control is not operable.

New levels of operational automaticity are carefully examined to assure that the pilots can stay on top of the automatic operations. Only if multiple redundancy and automatic reconfiguration to standby channels in event of failures is provided, (such as is done for certificated automatic landing systems) can automatic functions be designed without provision for intimate pilot monitoring and immediate manual takeover. Single channel (single string) automatic functions must be kept straight forward enough to permit the pilot to assess the performance results with the data displayed to assure that he takes intervening action when necessary.

Overall design of the MRS avionics operational concept has proceeded with the ground rule that the system organization should be consistent with flight priorities and the frequency with which various navigation/flight control processes must be attended. Figure 3-1 shows a depiction of the nav/flight control process as it is typically viewed by an operational pilot. Automatic system functions are organized in the same manner as the pilot would execute the functions, allowing his supervisory assessment of, and manual intervention in, any part of the process when necessary. Figure 3-1 is organized to show that the position determination and navigation functions at the left of the diagram are those which require attention less frequently, whereas functions more to the right side of the diagram such as flight navigation, flight guidance, and flight control, correspond to areas needing increasing amounts of pilots attention.

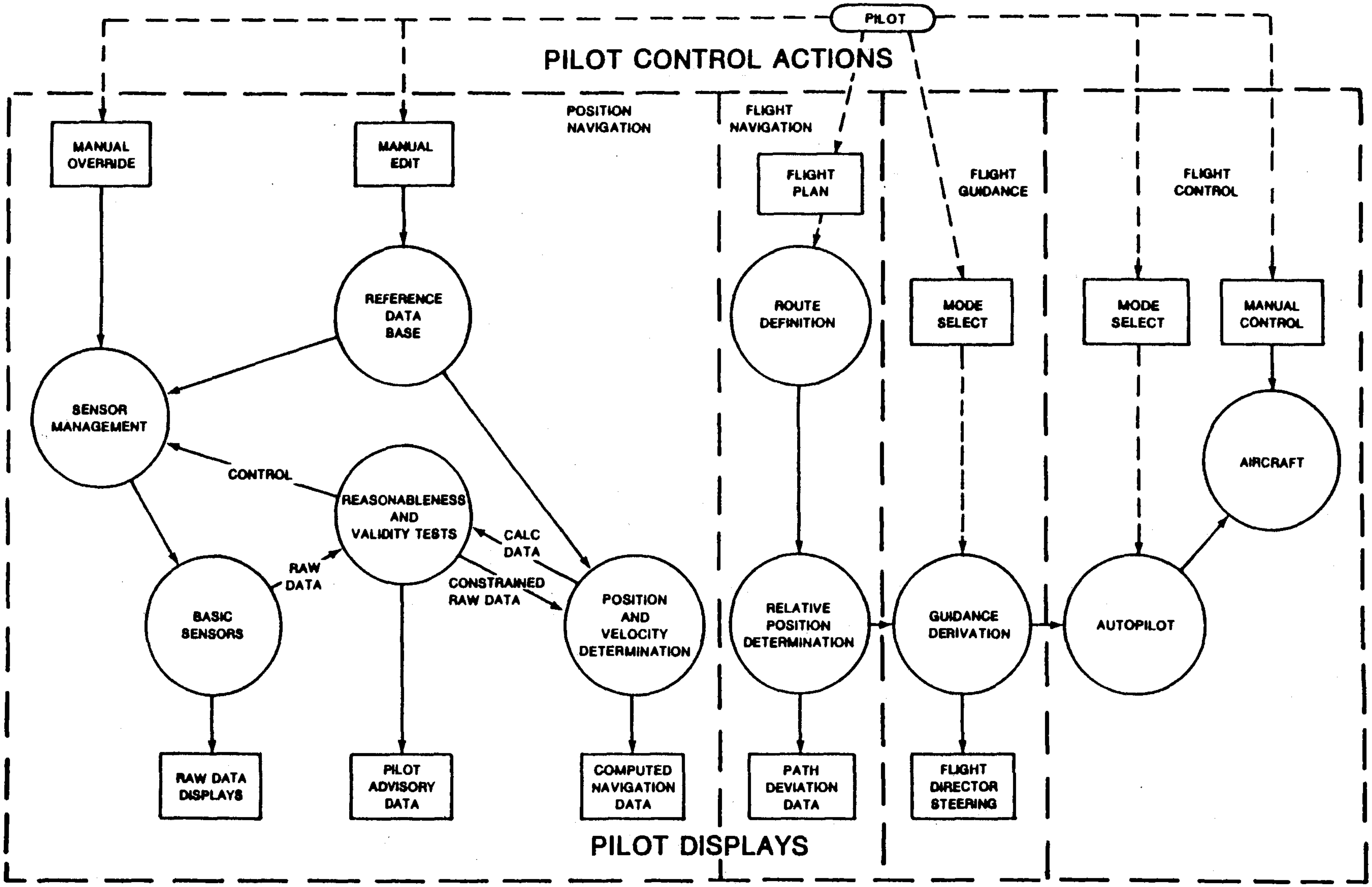
SPECIFIC MRS OPERATIONAL CAPABILITIES

This section of the paper will present some of the specific MRS operational features that have resulted from our operational design studies.

Area Navigation

The pilot's operational interface with the RNAV system is through the multipurpose CDU which uses a number of "pages" on the CRT display to display status and data, and to label the current role of the multi-function select buttons used to insert data or used to select various RNAV operational modes. The CDU and its page organization is depicted in figure 3-2.

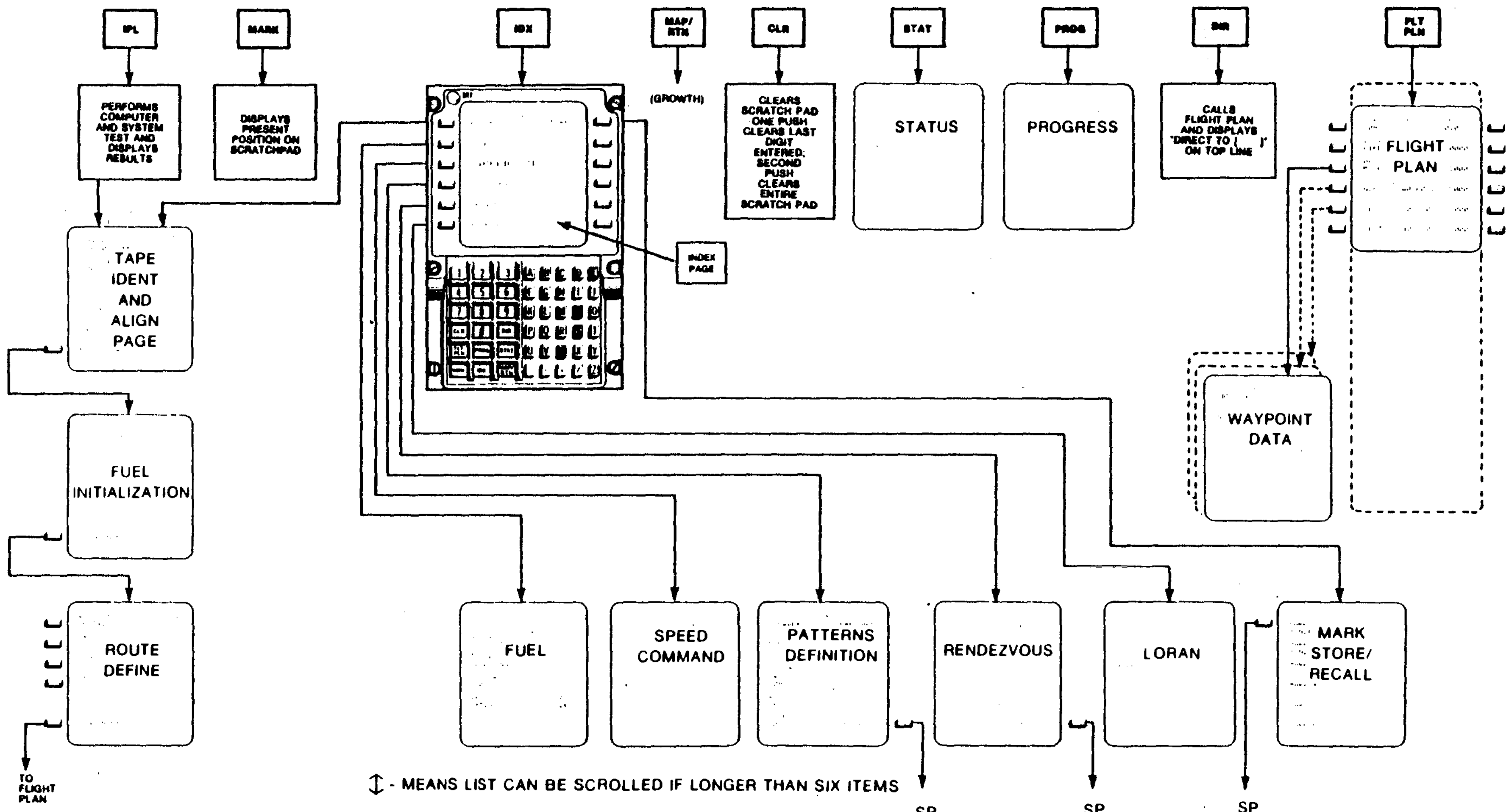
Various individual CDU pages of figure 3-2 are reproduced later for more legibility and detail. Figure 3-2 does purport to show that certain of the pages are immediately accessible by depressing dedicated keys within the primary keyboard of the CDU. These keys are represented by the legends in the squares along the top of figure 3-2; they call up pages associated



THE NAV/FLIGHT CONTROL PROCESS

FIGURE 3-1

CDU PAGE ACCESS



↕ - MEANS LIST CAN BE SCROLLED IF LONGER THAN SIX ITEMS

SP - MEANS ITEM SELECTED WILL AUTOMATICALLY APPEAR ON THE SCRATCH PAD AND THE FLIGHT PLAN IS DISPLAYED.

FIGURE 3-2.

with the following functions: Flight Plan, Progress, Status, and Index.

Secondary pages are accessible only through a primary page, which must first have been selected before the secondary page is accessible through a multifunction select button along the side of the CRT display. Examples of the secondary pages are the individual Waypoint Data detail pages selectable from the Flight Plan page. Each waypoint listing on the Flight Plan page becomes a label for the multifunction button for use in selecting the corresponding detail page. Other secondary pages are accessible through the Index page, which is a listing of other secondarv pages attainable with the multifunction buttons; they are associated with the following functions: Start (initialize) Fuel Monitoring, Speed Command, Search Patterns, Rendezvous, Loran, and Mark (Radar or "marked" visual waypoints.)

Having briefly overviewed the pilots operational interface with the RNAV system at the CDU, certain details of the RNAV operational capability as organized through particular CDU pages, now will be discussed.

Flight Plan:

The flight plan as viewed by the pilot includes both the lateral and vertical profiles that are to be flown. The flight plan in the lateral axis consists of geographical points that can be generically named for ease of recognition. These geographical points are known as waypoints. The flight plan may also consist of navaids, latitude/longitudes, or points defined by radials and distance from other stored waypoints. The flight plan represents a preplanned series of fixes between which navigation, in the classical sense, is to be executed in a route sequence. The flight plan also shows altitude information to the pilot. When specific altitudes are not specified, profiles will be generated and indicated to the pilot as the flight plan. A flight plan example page from the CDU is shown in figure 3-3.

The positional information that supports the flight plan data is resident in mass storage and is retrieved when the pilot chooses to connect the flight plan definition to the actual positional data. In the route retrieval case, where geographical points have been strung together, altitudes can also be specified as part of the data to be retreived as a flight plan.

There are two basic types of flight plan definitions:

1) Site or route data definition. This data definition supports the flight plan in pre-defined areas.
2) CONUS type data definition. This data definition supports the impromptu or cross country type flights.

Waypoint:

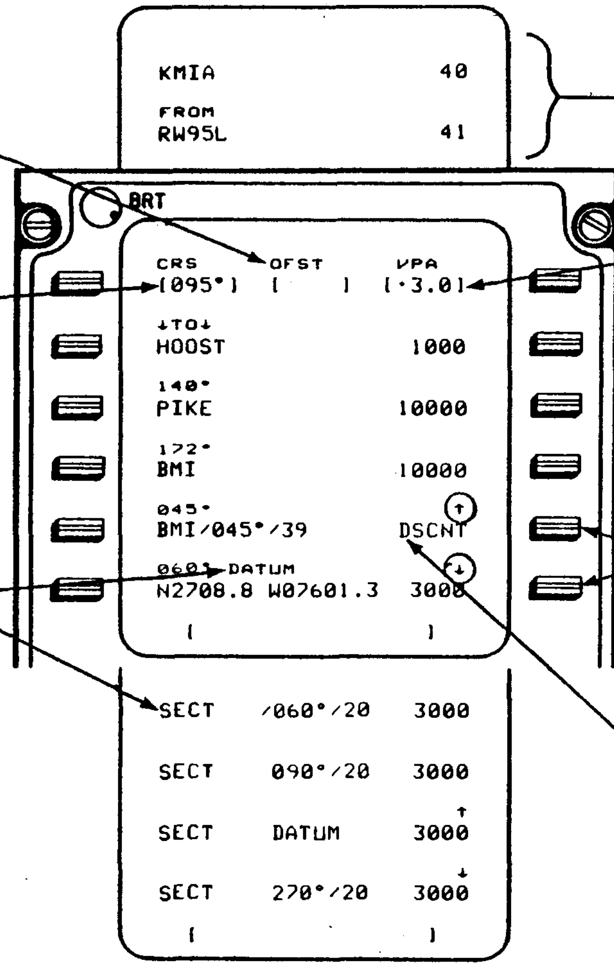
The detail information about specific waypoint identifiers such as its geographical location in lat/long coordinates, distance and course from the aircraft, and arrival time are available for pilot scrutiny. Any waypoint information that is contained in the data base is addressable by the pilot. The information is formatted and presented in the form shown in the CDU Waypoint Data page illustrated in figure 3-4.

FLIGHT PLAN FEATURES

A LATERAL PARALLEL OFFSET CAN BE MADE BY ENTRY OF L OR R (LEFT OR RIGHT) AND THE NUMBER OF MILES CROSSTRACK DISTANCE DESIRED (E.G. R5). TO CANCEL OFFSET INSERT "L0", "R0", 0 OR MINUS.

COURSE TO THE "TO" WAYPOINT. COURSE MAY BE CHANGED BY ENTERING A NEW COURSE ON SCRATCH PAD AND INSERTING WITH TO LINE KEY

IF A SEARCH PATTERN IS ENTERED TO THE FLIGHT PLAN, THE WAYPOINT AT WHICH THE SEARCH INITIATED IS LABELED DATUM AND IS RETAINED IN THE FLIGHT PLAN UNTIL PATTERN EXIT.



"FROM" WAYPOINTS ARE RETAINED IN THE FLIGHT PLAN UP TO A LIMIT OF 5

VERTICAL PATH ANGLES ARE NOMINALLY SET AT ±3.0 DEGREES FOR CLIMBS AND DESCENTS, OR 0.0° FOR LEVEL FLIGHT (E.G. BETWEEN PIKE AND BMI). VPA MAY BE PILOT MODIFIED. VPA MAY VARY BETWEEN 2° AND 6° ON DESCENTS DEPENDING ON WINDS.

LINE KEYS ARE USED TO SCROLL THE FLIGHT PLAN UP OR DOWN AS INDICATED BY SMALL CIRCLED ARROWS

DSCNT INDICATES A DESCENT PROFILE BETWEEN BMI AT 10,000 AND DATUM AT 3,000 FEET. AIRCRAFT WILL REMAIN AT 10,000 FEET UNTIL INTERCEPTING THE 3° PATH TO THE ALTITUDE AT DATUM.

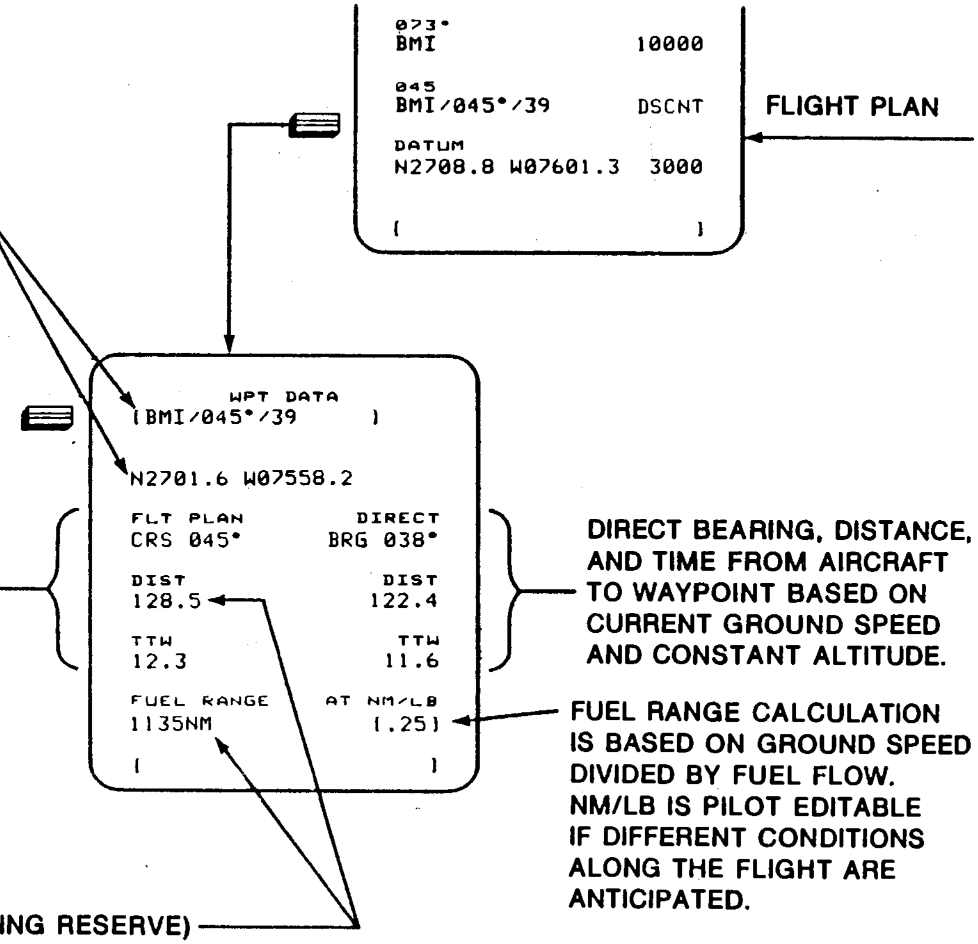
FIGURE 3-3

WAYPOINT DATA

ACCESS WAYPOINT DATA BY SELECTING ANY FLIGHT PLAN LINE KEY (SCRATCH PAD MUST BE CLEARED).

WAYPOINT NAME AND POSITION
A NON-FLIGHT PLAN WAYPOINT/NAVAID/AIRPORT/ WAYPOINT-BRG-DIST/OR LAT/LONG MAY BE ENTERED.

ALONG FLIGHT PLAN COURSE, DISTANCE, AND TIME-TO-WAYPOINT BASED ON CURRENT GROUND SPEED. CONSTANT ALTITUDE IS ASSUMED. DASHES (---), MEANING NO COMPUTED DATA, APPEAR FOR WAYPOINTS NOT IN THE FLIGHT PLAN.



DIRECT BEARING, DISTANCE, AND TIME FROM AIRCRAFT TO WAYPOINT BASED ON CURRENT GROUND SPEED AND CONSTANT ALTITUDE.

FUEL RANGE CALCULATION IS BASED ON GROUND SPEED DIVIDED BY FUEL FLOW. NM/LB IS PILOT EDITABLE IF DIFFERENT CONDITIONS ALONG THE FLIGHT ARE ANTICIPATED.

COMPARISON OF FUEL RANGE (NOT INCLUDING RESERVE) WITH CUMULATIVE DISTANCE ALONG THE FLIGHT PLAN INDICATES APPROXIMATE PORTION OF THE PATROL THAT CAN BE COMPLETED WITH FUEL REMAINING.

FIGURE 3-4

Progress:

Flight progress information is information related to aircraft performance to the current leg of the flight plan. A typical CDU Progress page is shown in figure 3-5. Typical information that the pilot can observe is "TO" lateral and vertical points, lateral deviation from the projected course, vertical deviation, wind direction/distance, groundspeed, air speed, and time to the fuel alert. The aircraft's present position in lat/long is also available.

VNAV:

The MRS approach to the coupled VNAV problem is one that makes sense from an energy management viewpoint. Climb profiles are flown in an air-mass flight control mode, and descent profiles are flown at a fixed angle that would typically correspond to idle thrust. For the climb profile, the pilot captures the RNAV altitude from a flight control mode such as IAS Hold. The RNAV system flies the profile until a top of descent point is reached. The aircraft is commanded by the RNAV system to fly the coupled VNAV path to the descent altitude specified in the flight plan. VNAV flight is illustrated further in figure 3-6.

Special Patterns:

The special patterns for the MRS program consist of Ladder, Sector, Expanding Square and Holding. The RNAV system provides to the pilot the ability to define the starting point, altitude, and dimensions of the search area. Once the initial conditions are satisfied, the pattern waypoints are continually generated by the correct pattern algorithm as the pattern is being flown. The waypoints generated are labeled to provide the pilot with orientation as to where the aircraft is within the pattern. The Expanding Square example is illustrated in figure 3-7.

Rendezvous:

The rendezvous calculation provides the pilot with a waypoint that can be navigated to as a flight plan entry to assist in intercepting a vehicle in distress. The pilot is required to supply basic information for the calculations. These include the last known position, heading, speed of the target vehicle, and time of fix. The rendezvous calculations are iterative and as new information about the target is inserted, the algorithm will produce a updated point. The current rendezvous algorithm is concerned only with interception in the horizontal plane. Illustration of the CDU page associated with rendezvous is shown in figure 3-8.

PROGRESS PAGE

— A SUMMARY OF PROGRESS ALONG THE FLIGHT PLAN AND DISPLAY OF CURRENT CONDITIONS AND PERFORMANCE

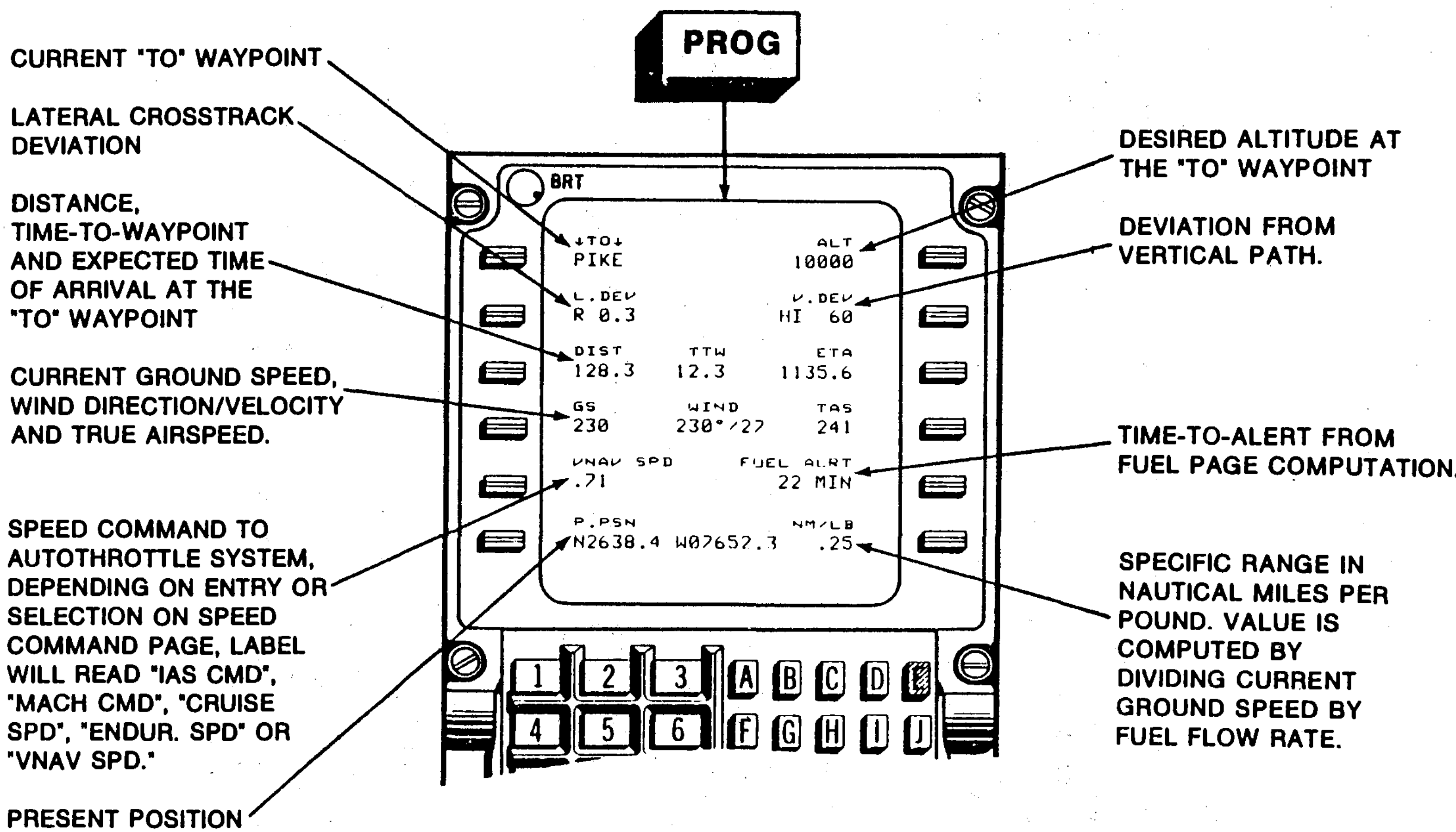
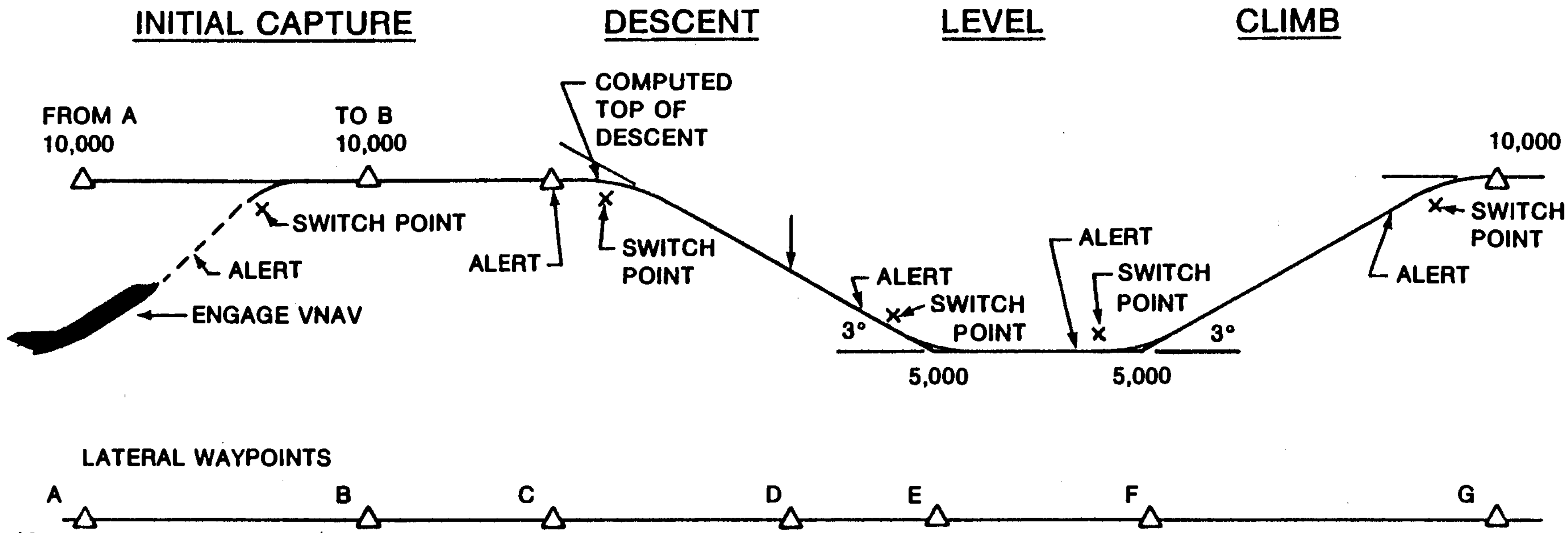


FIGURE 3-5

V-NAV



THE FLIGHT CREW ESTABLISHES ATTITUDE AND SPEED TO INTERCEPT VNAV PATH. UPON ENGAGING VNAV, AIRCRAFT WILL CONTINUE ON ESTABLISHED CLIMB UNTIL REACHING SWITCH POINT FOR VNAV PATH CAPTURE. 10 SECONDS PRIOR TO SWITCH POINT VNAV ALERT IS ANNUNCIATED.

THE COMMAND BUG ON THE VSI WILL ALWAYS INDICATE THE VERTICAL SPEED REQUIRED TO ACHIEVE THE FIRST ALTITUDE SPECIFIED IN THE FLIGHT PLAN.

IF THE COMPUTED TOP OF DESCENT WAS PRIOR TO WAYPOINT C, THE ALTITUDE ASSOCIATED WITH C WOULD BE REPRESENTED AS A DESCENT . THIS APPLIES TO ALL VERTICAL DESCENT LEGS EXCEPT THE CURRENT DESIRED "CLIMB TO" ALTITUDE.

```
FROM
A                      10000

CRS      OFST         VPA
[087]°   [   ]    [ 0.0]°
↓TO↓
B                      10000

C                      10000

D                      DSCNT
                           ↑
E                       5000
                           ↓
F                       5000
[                          ]

G                      10000
```

FIGURE 3-6

EXPANDING SQUARE

① SELECT INDEX PAGE

② SELECT "PATTERNS" ON INDEX

③ SELECT "EXP SQ"

④ ENTER TRACK SPACE

⑤ SELECT "INSERT." "EXP. SQ AT" WILL APPEAR ON THE SCRATCH PAD WITH THE FLIGHT PLAN DISPLAYED.

⑥ INSERT EXPANDING SQUARE AT DATUM POINT. DATUM POINT WILL BE LABELED "DATUM" AND REMAIN IN THE FLIGHT PLAN UNTIL EXIT OF PATTERN. EXIT PATTERN BY SELECTING DIRECT KEY (DIR) AND THEN SELECTING A WAYPOINT THAT FOLLOWS PATTERN POINTS IN THE FLIGHT PLAN LIST. COURSE OF THE FIRST LEG WILL BE THE SAME AS THE COURSE TO DATUM.

THE LIST OF PATTERN POINTS WILL BE CALCULATED FOUR WAYPOINTS AHEAD OF THE CURRENT LEG. PATTERN PARAMETERS CAN BE MODIFIED AND RE-ENTERED TO THE DATUM POINT. "DIRECT TO DATUM" WILL RESTART THE PATTERN.

AN ALTITUDE ENTERED TO ANY PATTERN POINT SHALL APPLY TO ALL WAYPOINTS OF THE PATTERN.

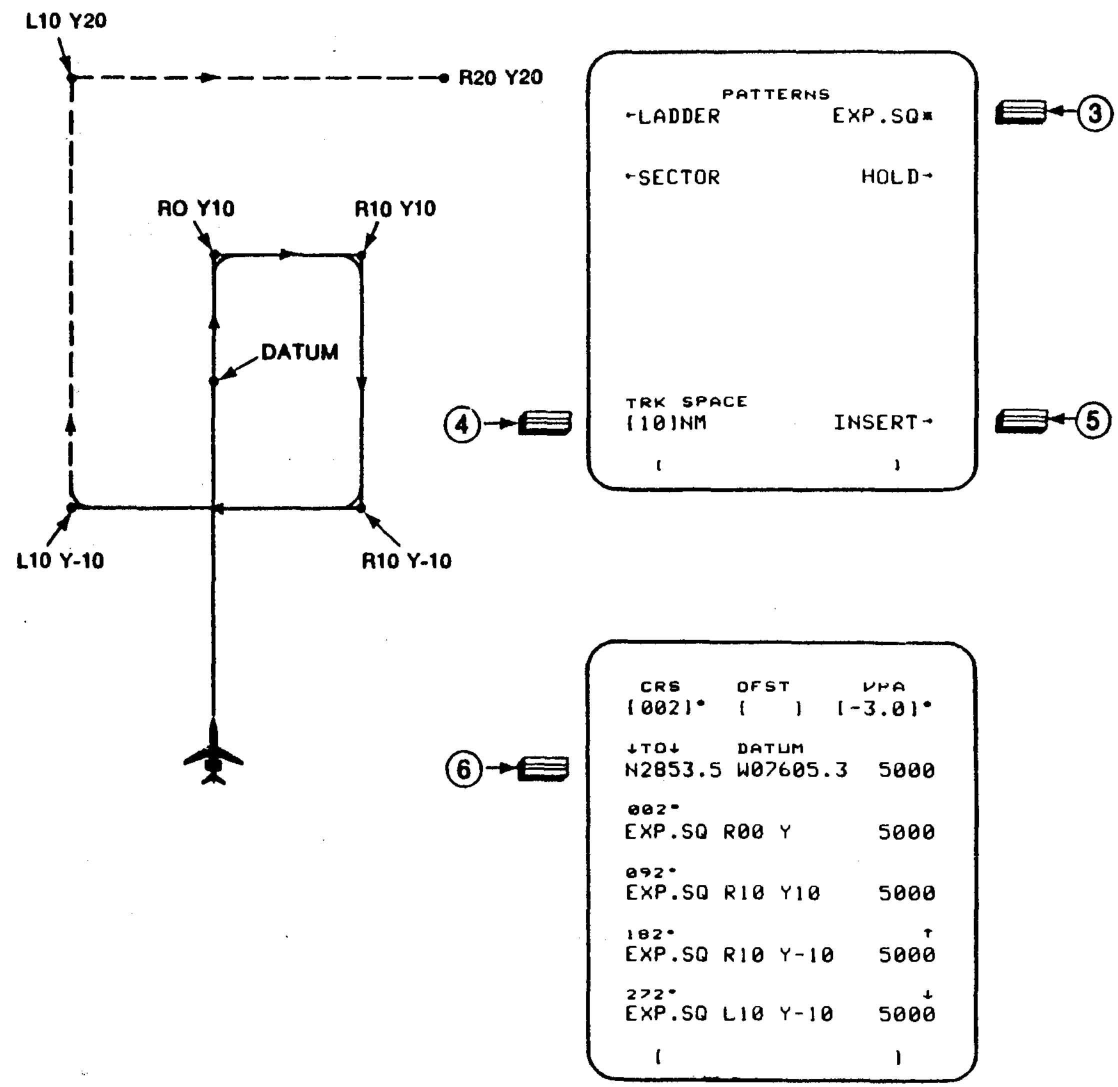


FIGURE 3-7

RENDEZVOUS

— ALLOWS COMPUTATION OF AN INTERCEPT POINT FOR AIRCRAFT IN DISTRESS

(1) ACCESS RENDEZVOUS PAGE VIA INDEX

(2) ENTER LAST FIX POSITION EITHER BY LAT/LONG OR WAYPOINT/RADIAL/DISTANCE

(3) ENTER REPORTED HEADING

(4) ENTER REPORTED TRUE AIRSPEED

(5) ENTER TIME OF POSITION REPORT IF DIFFERENT THAN PRESENT TIME.

(6) ENTER OWN ESTIMATED TAS FOR ON GROUND CALCULATION. WHEN OWN AIRCRAFT IS AIRBORNE, ACTUAL TAS WILL BE USED.

(7) SELECT "INSERT" KEY. "RENDZ" WILL BE DISPLAYED ON SCRATCH PAD OF FLIGHT PLAN FOR INSERTION INTO THE FLIGHT PLAN. RENDEZVOUS POSITION IS CONTINUALLY RECOMPUTED BASED ON OWN AIRCRAFT PROGRESS TOWARD THE INTERCEPT. IF A MORE CURRENT POSITION REPORT IS RECEIVED, PARAMETERS CAN BE RE-ENTERED.

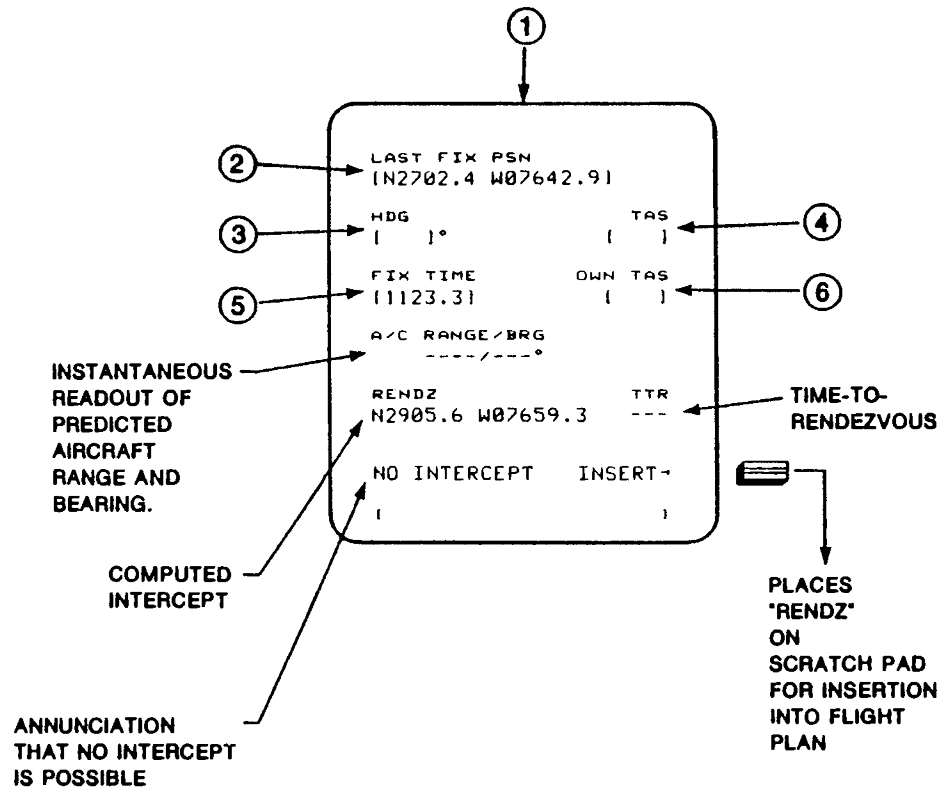


FIGURE 3-8

Loran:

The RNAV subsystem receives input from the Loran sensor as status, chain identifiers, and time differences. The control of the Loran set for MRS is accomplished by a dedicated control head.

The RNAV subsystem provides visibility of the chain selected and coding delays for the secondaries. The CDU page which display the Loran information is shown in figure 3-9. The RNAV subsystem has the capability of tracking the sensor in sky wave and allows the pilot to correct (update) the sensor data.

Flight Control

The MRS flight control system includes integrated autopilot and flight director capability with common guidance computations used for both automatic and manual control. The primary flight director indicators are the Attitude Director Indicator (ADI) and the Horizontal Situation Indicator (HSI) for integrated display of aircraft attitudes, steering commands, and navigation course deviation information. Control panels for HSI navigation display selection, guidance mode selection, and autopilot engagement are provided, along with a complete set of mode annunciation readouts for confirming the active and pre-armed modes of the flight control system. The available flight control modes are as follows:

Heading Select
Navigation (LNAV, Tacan, or VOR/LOC)
Approach (with Category II capability)
Vertical Navigation
Altitude Preselect
Altitude Hold
Vertical Speed Hold
Indicated Airspeed Hold
Mach Hold

Speed Control

The autothrottle system for MRS provides conventional speed control based on either angle of attack or indicated airspeed for the lower speed flight regimes during low level search or patrol runs, ILS approaches, or holding patterns. Individual modes are available to allow the pilot to select either angle of attack or airspeed as his speed reference, and then dial in the specific speed he wishes the system to attain.

Additional speed control thrust management functions are available for managing the fuel efficiency of the flight. Historically, the pilot has taken present conditions of gross weight, outside air temperature, and altitude, referred to performance charts in the flight manual, and some time later has come up with what speed or altitude he should fly for maximum range or endurance. For accurate fuel management, such computations have to be repeated frequently

LORAN PAGE

— DISPLAYS NET AND
TIME DELAYS AND
ALLOWS INPUT OF TIME
DIFFERENCE CORRECTIONS.

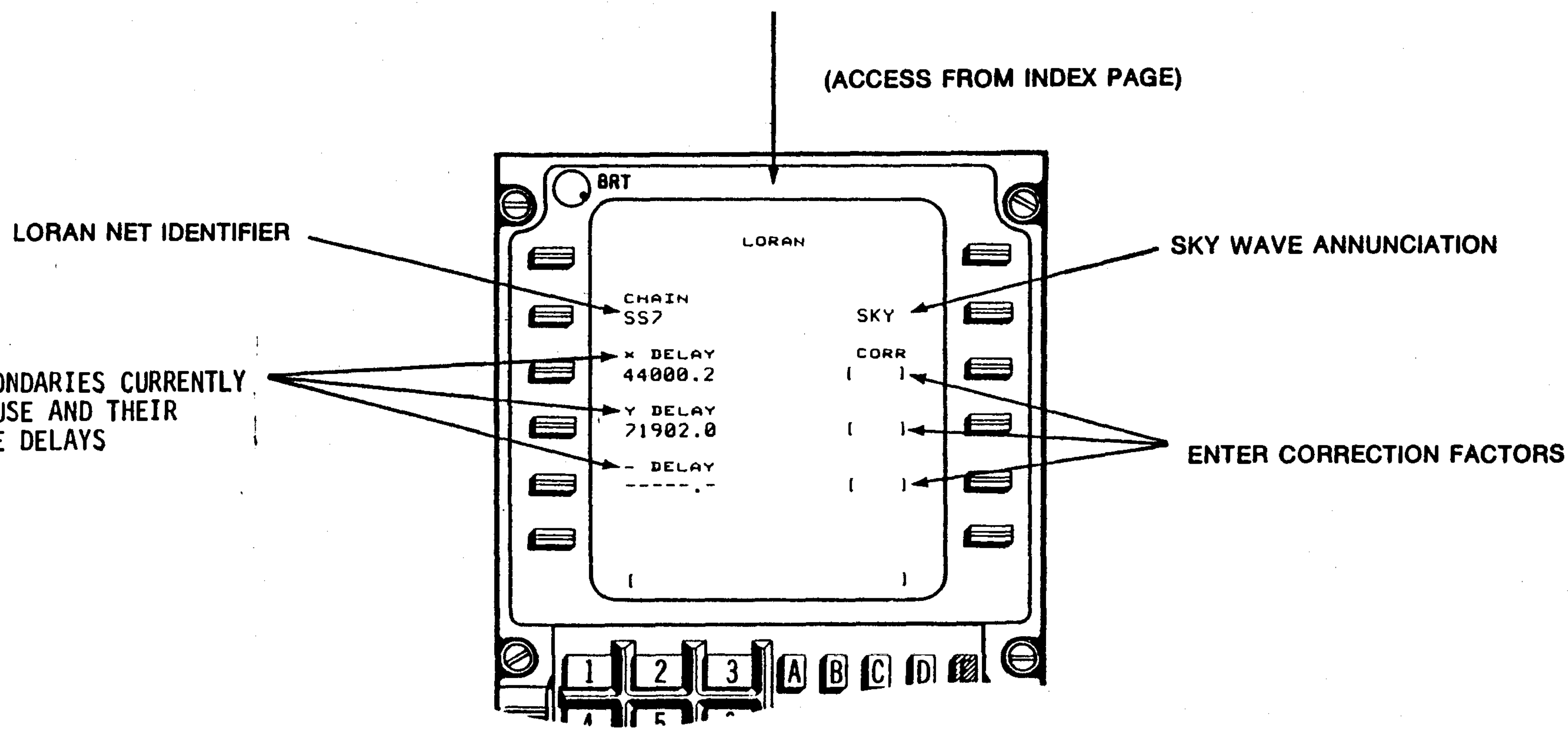


FIGURE 3-9

throughout the flight. In the MRS system, the thrust management computations for fuel efficiency are automatically provided in the same way the pilot would do them, and is continually available. The system provides maximum range airspeed, maximum endurance airspeed, and optimum range altitude as displayed parameters. The pilot may engage the autothrottle to automatically hold the desired fuel efficient airspeed.

Associated with the fuel efficiency management function is the managing and monitoring of fuel quantity. In the MRS system, a visual "FUEL ALERT" is displayed whenever fuel quantity remaining becomes less than the fuel required to return from present position to destination with a pilot determined reserve. Required return fuel is computed based on single engine maximum range performance and includes climb, cruise, and descent fuel. The Time-To-Alert display enables the aircraft commander to read his time remaining on station.

FISH PATROL SCENARIO

It was previously stated that a primary design emphasis has been to assure that the typical Coast Guard mission was well accommodated. Therefore, it is of interest to look at a possible patrol mission and the modes of capability available to execute it. Postulated diversions from the route will also be introduced.

The pre-planned fish patrol which the Coast Guard might use is shown in Figure 3-10. The pre-planned route is shown in solid lines and the unplanned diversions show as dashed lines. The patrol represents flight out of the Air Station at Cape Cod through a successive series of navigation waypoints labeled FP A01, FP A02, etc., with final return back to the Air Station.

The control of the aircraft immediately after takeoff begins with the Autopilot in the Heading mode. The autopilot maneuvering mode is used to intercept the first leg of the RNAV flight plan. At the time of intercept, the autopilot switches to the pre-armed LNAV mode and becomes coupled to the lateral guidance signals from the area navigation system. Continuous automatic lateral tracking through all of the pre-planned flight legs is thereby provided.

In the vertical axis immediately after takeoff the autopilot is typically engaged in the Airspeed Hold mode for climbout. When the resultant path of the aircraft intercepts the first leg of the pre-planned vertical nav profile, the autopilot automatically couples to the pre-armed VNAV guidance and commences tracking the vertical profile. In a typical patrol, the vertical profile may include letdown to some lower altitude by the time the first fish patrol waypoint is reached for low level patrol and surveillance.

Return to base can also be made under coupled autopilot and RNAV control. The RNAV route can be pre-planned to intercept the ILS pattern serving the air station after which a final approach to the ILS runway can be executed under autopilot control.

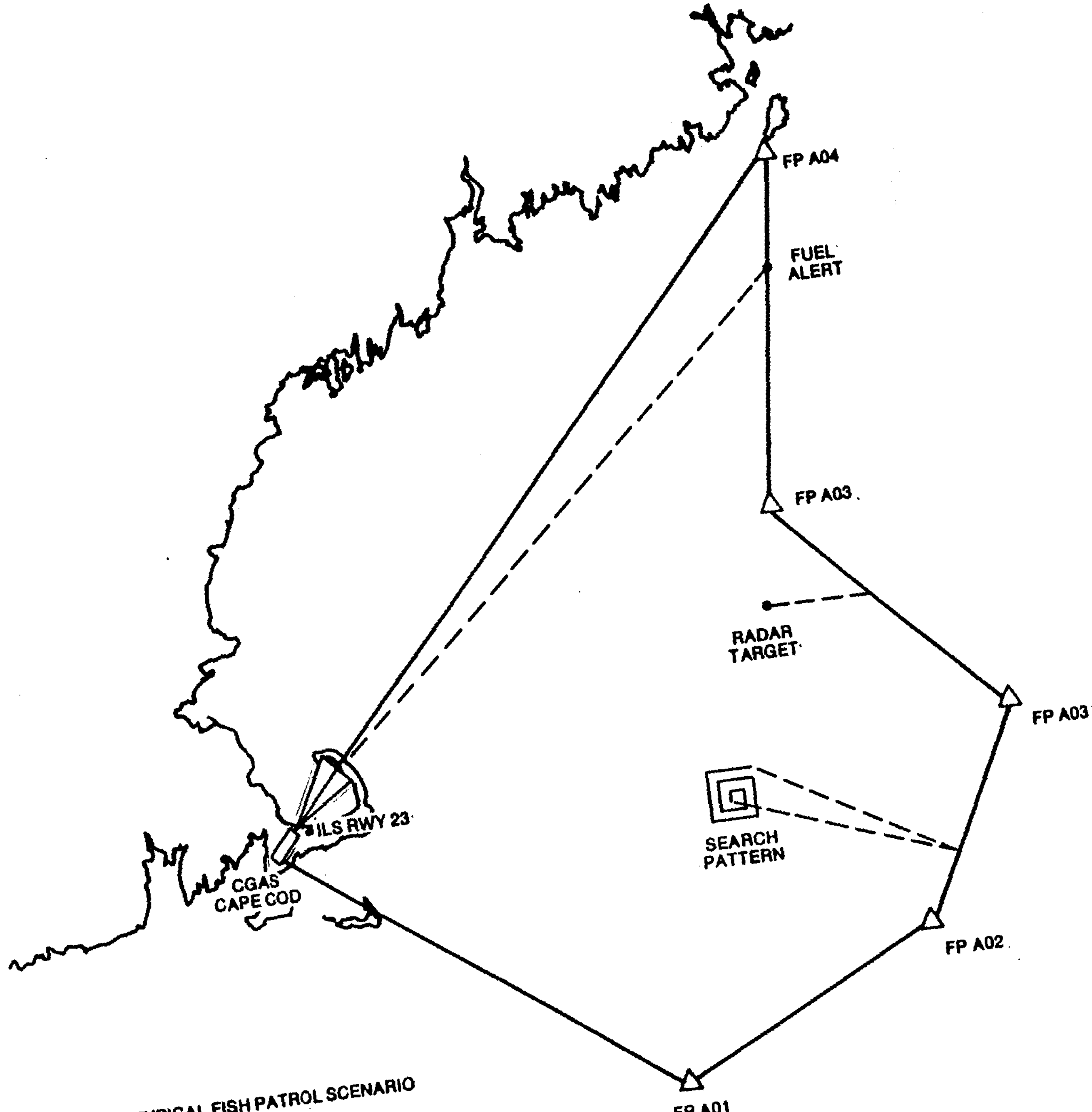


FIGURE 3-10. TYPICAL FISH PATROL SCENARIO

Figure 3-10. also highlights a number of possible diversions from the preplanned fish patrol which the system can assist the pilot in handling. In the first unplanned instance, the crew has diverted from the route, after identifying the lat/long for later resumption of the patrol, to head directly to the reported latitude and longitude of a ship in distress. When the aircraft arrives at the reported latitude and longitude, a pre-selected preprogrammed expanding square search pattern is provided by the RNAV system. The search pattern, one of several types available to the pilot, provides the basis for an automatically controlled and computed segment of flight in the area of the reported vessel in distress. After contact with the vessel is made, and assistance is given, the pilot can command the system to return directly to the preplanned patrol at the point of previous deversion.

A second unplanned event depicted in figure 3-10. is a diversion to a Search Radar contact. In this case, the latitude and longitude corresponding to an image on the radar screen is entered into the RNAV with the aid of cursors on the screen, and appropriate computer interfaces through the Surveillance System Operators Cockpit Management control and display. The pilot may then command the system to fly directly to that lat/long for closer inspection of the radar target; he also may elect to again return to the patrol at the point the diversion was made.

As previously introduced, fuel monitoring and management assistance is provided in the MRS mission. The third unplanned event in figure 3-10. is a Fuel Alert, as might occurr because of the diversions. Being alerted that only a contingency amount of fuel remains beyond that needed to return to base, the pilot then would normally execute a "Direct To" home base.

SECTION 4

NAVIGATION WITH LORAN

The MRS RNAV system employs classical dead-reckoning in conjunction with a Kalman estimator. The system outputs estimates of the aircraft position and velocity in latitude and longitude coordinates. The calculations are performed employing a spherical earth model with corrections for earth oblateness. A block diagram showing the relationship between the Kalman filter, Loran, other radio sensors, inertial system, air data system and the dead reckoning computations is shown in Figure 4-1. The Kalman filter iteration rate is once every two seconds.

When radio data are available, the Kalman filter estimates the position and velocity errors which are modeled in the state vector and applies corrections to the RNAV position and velocity equations. The effects of geometric dilution of precision (GDOP) on the Loran-C measurements are modeled implicitly within the sensor error model utilized in the filter. Thus the filter weights velocity reference data more heavily for poor geometric conditions. When radio data are not available the system performs dead-reckoning computations still employing the inertial system as the velocity reference. When the inertial system and radio data are absent, the system performs dead-reckoning computations and the Kalman filter supplies velocity error information based on the last available inertial data to these computations. The differences between the actual measurements and the a priori estimates of the measurements are subjected to dynamic reasonableness testing by a comparison of these differences with the a priori estimate of the measurement statistics. The resulting navigation solutions for position and velocity using Loran-C integrated with an inertial or air data velocity reference provides a substantial improvement in accuracy over VOR/DME navigation for the off-shore operations of the MRS aircraft.

DEAD RECKONING MECHANIZATION

The output of the velocity reference is integrated by the high speed navigation program to provide position and velocity information. Two velocity biases, ΔV_e (east) and ΔV_n (north), are added to the measured east and north velocities, V_{em} and V_{nm}, for the dead reckoning calculations. The Kalman filter estimates the errors in ΔV_e and ΔV_n, and controls them whenever radio data is available.

The basic dead reckoning equation used for latitude is:

$$\phi(t_n) = \phi(t_{n-1}) + \frac{(V_{nm} + \Delta V_n)\Delta_t}{R_{eo}}$$

and for longitude is:

$$\lambda(t_n) = \lambda(t_{n-1}) + \frac{(V_{em} + \Delta V_e)\,\Delta t}{R_{eo}\cos\phi\,(t_n)}$$

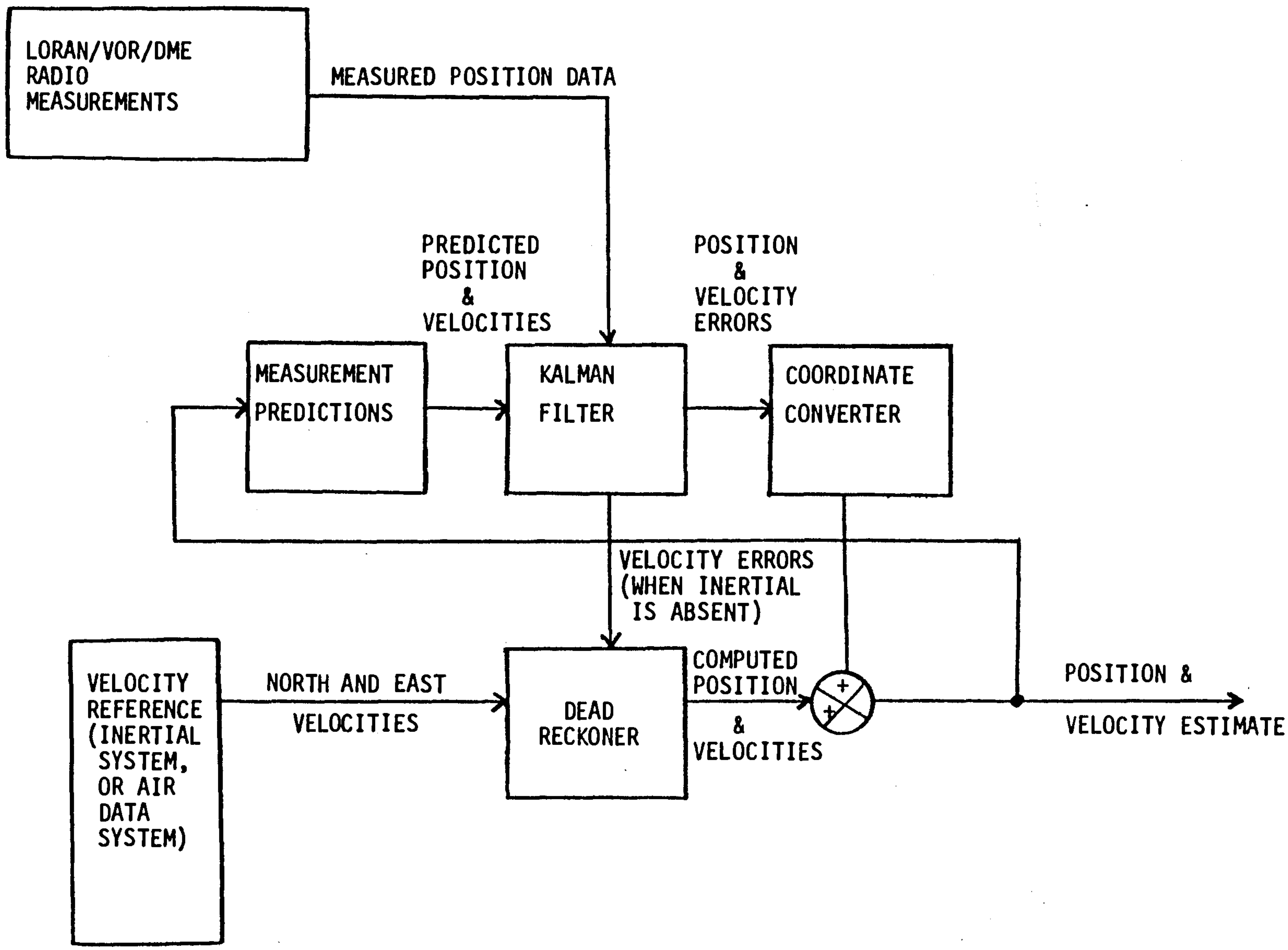


FIGURE 4-1 POSITION AND VELOCITY ESTIMATION BLOCK DIAGRAM

R_{eo} is a nominal earth radius at the surface, t_n and t_{n-1} refer to the current and previous executions of the fast navigation loop, and $\Delta t = t_n - t_{n-1}$.

For the case of air data velocity reference, the measured quantities are true airspeed, V_a, and magnetic heading, ψ_m. Thus for this case

$$V_{nm} = V_a \cos (\psi_m + \Delta\psi)$$

$$V_{em} = V_a \sin (\psi_m + \Delta\psi)$$

where $\Delta\psi$ is the magnetic variation at the present location.

For the case of ISS velocity reference the dead reckoning equations are modified somewhat:

$$\phi(t_n) = \phi(t_{n-1}) + \phi_{ISS}(t_n) - \phi_{ISS}(t_{n-1})$$

and

$$\lambda(t_n) = \lambda(t_{n-1}) + \lambda_{ISS}(t_n) - \lambda_{ISS}(t_{n-1})$$

where ϕ_{ISS} and λ_{ISS} are latitude and longitude read from the ISS. The basic difference caused by the ISS in the dead reckoning equations is that the effects of ΔV_n and ΔV_e are not included for ISS velocity reference. The change in calculation is done to prevent errors in ΔV_n and ΔV_e from propagating during an extended radio outage. Thus, during a radio outage, latitude and longitude change is slaved to ISS latitude and longitude change.

KALMAN FILTER

Basically, the Kalman filter mechanization is a statistical weighting and error propagation device. It performs an error analysis of system performance and uses the results of this analysis to combine the navigation sensor information in an optimal manner. The filter operates on error differences between the navigation system's indicated position and velocity and externally measured position and velocity. On the basis of these differences, the filter estimates and corrects navigation system errors.

ERROR STATE MODEL

The navigation errors are modeled in a four element state error vector. These elements are: east position error, north position error, east velocity error and north velocity error. No error states are modeled separately for inertial platform tilt, bias or drift. The MRS RNAV position and velocity estimate is essentially slaved to radio data whenever it is available.

The error state model is assumed to be of the form

$$\dot{\chi} = A\chi + w$$

where χ is the error state vector

$$= \begin{bmatrix} \text{East Position Error} \\ \text{North Position Error} \\ \text{East Velocity Error} \\ \text{North Velocity Error} \end{bmatrix} = \begin{bmatrix} \delta R_e \\ \delta R_n \\ \delta V_e \\ \delta V_n \end{bmatrix}$$

w is the state model noise vector, white noise with covariance Q and

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

This model gives a simple transition matrix

$$\phi = \begin{bmatrix} 1 & 0 & T & 0 \\ 0 & 1 & 0 & T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$ where T is the Kalman iteration interval.

SENSOR MODELS

The navigation sensors, DME, VOR, and Loran are all assumed to provide scalar observations to the Kalman filter of the form

$$y = M\chi + v$$

v is the white noise on the measurement with covariance V

M is the 1 x 4 measurement matrix.

Definition of the observations for each sensor is as follows:

Sensor	Observation	Observation Variance	Measurement Matrix
DME	$y = R_c - R_m$	V_{DME}	$[-e_E, e_N, 0, 0]$
VOR	$y = \rho_{VOR}[\gamma_c - (\gamma_m + \Delta\psi_s)]$	$V_{VOR} = (\rho_{VOR}\sigma_{VOR})^2 + V_{DME}$	$[-\cos\theta, \sin\theta, 0, 0]$
Loran	$y = (\rho_{GM} - \rho_{SM}) - (\Delta\rho_M - \Delta\rho_{PROP})$	$V_{Loran} = \begin{cases} V_{GW}, & \text{ground wave} \\ V_{SW}, & \text{sky wave} \end{cases}$	$[\sin\theta_s - \sin\theta_m, \cos\theta_s - \cos\theta_m, 0, 0]$

Where the following definitions hold:

R_c	=	Computed DME slant range
R_m	=	Measured DME slant range
e_E, e_N	=	East and north components of a unit vector along the line of sight from the aircraft to the DME station.
V_{DME}	=	DME measurement covariance
ρ_{VOR}	=	Distance along the surface of the earth from the aircraft to the VOR station
γ_c	=	Computed inbound bearing to the VOR station with respect to true north.
γ_m	=	Measured inbound magnetic bearing to the VOR station
$\Delta\psi_s$	=	Magnetic variation at the VOR station
θ	=	The true bearing from the VOR station to the aircraft
V_{VOR}	=	VOR measurement covariance
σ_{VOR}	=	Assumed VOR rms angular error
$\Delta\rho_m$	=	C * TD where TD is the Loran time of arrival difference and C is the velocity of propagation
ρ_{GM}, ρ_{SM}	=	The computed geodesic ranges from the aircraft to the Loran master and secondary respectively
$\Delta\rho_{PROP}$	=	A Loran propagation correction which may be taken from a manual entry
θ_M, θ_S	=	True bearings from the aircraft to the Loran master and secondary respectively

KALMAN MEASUREMENT UPDATE

For the equations below, assume that a scalar observation, y, is available along with the corresponding measurement matrix, M, and measurement variance, V. P represents the covariance matrix and x the error state vector.

First the reasonableness check is made. Define

$$G = PM^T \text{ (a 4-component vector)}$$

$$D_1 = MG$$

$$D_2 = D_1 + V$$

The measurement residual is

$$\delta y = y - Mx$$

Inasmuch as $E(\delta y^2) = MPM^T + V$, then $D_2 = E(\delta y^2)$. Thus a δy^2 that significantly exceeds D_2 is judged to be unreasonable, i.e., the residual must satisfy

$$\delta y^2 < K_R D_2$$

to be accepted. $K_R = 16$ is a plausible choice (corresponds to a "4-sigma" test).

If δy is reasonable, processing continues with the gain computation. Let

$$D = \max\ (D_2, K_G D_1)$$

Then, the Kalman gain vector is

$$B = G/D$$

This procedure serves to limit the on-axis gain to $1/K_G$.

The error state is then updated via

$$X^+ = X^- + B\delta_y$$

where X^- denotes the error state prior to update and X^+ is the error state after update. (X^+ becomes X^- for processing the next measurement.) The corresponding covariance matrix update is

$$P^+ = (I-BM)P^-(I-BM)^T + VBB^T$$

It can be shown that this reduces to

$$P^+ = P^- - \frac{D_3}{D^2} GG^T$$

where

$$D_3 = 2D - D_2$$

and P^- and P^+ denote the covariance matrix before and after update respectively.

KALMAN TIME UPDATE

After all measurements have been processed, the state vector and covariance matrix must be propagated forward in time to the beginning of the next Kalman cycle. The covariance matrix is propagated via

$$P_{N+1} = \phi P_N \phi^T + Q$$

where

$$Q = \begin{cases} Q_{ISS}, & \text{If ISS is being used} \\ Q_{AD}, & \text{If Air Data is being used.} \end{cases}$$

Q_{ISS} and Q_{AD} are constant matrices. The error state is propagated via

$$X_{N+1} = \phi X_N$$

WHOLE VALUE CONTROL

Upon gaining control for each execution of the Kalman program, the best estimate of the error state vector, x, is applied to quantities in the fast nav program via

$$\phi^+ = \phi^- - \frac{\delta \hat{R}_n}{R_{eo}}$$

$$\lambda^+ = \lambda^- - \frac{\delta \hat{R}_e}{R_{eo} \cos \phi^+}$$

$$\Delta V_n^+ = \Delta V_n^- - \delta \hat{V}_n$$

$$\Delta V_e^+ = \Delta V_e^- - \delta \hat{V}_e$$

$$\hat{X} = 0$$

The last equation for $\hat{X}$ reflects the fact that after removing the estimated errors, the best estimate of the error state vector is zero.

The Loran measurement error covariance matrix is not diagonal, i.e., the time difference errors for a given measurement frame are correlated. For two time differences, the correlation coefficient is about 0.5. For software flexibility, the Loran Time Delays are processed one at a time (as are all other measurements). The Kalman filter has been designed to ignore these error correlations. The measurement variance is weighted slightly greater than it would be otherwise, thereby approximately accounting for these correlation effects.

SENSOR MANAGEMENT

All sensor input data used in navigation computations first passes validity, then consistency and reasonableness checks. VOR/DME station selection logic permits usage of the stations providing the best geometric coverage at all times, while avoiding the VOR cone of confusion and the DME station close proximity error zones. Loran-C chain selection is managed manually at the Loran Control Indicator by the crew. The NCU then performs logic checks on the Loran data and compares chain selection data from the Loran receiver with chain identification data resident in the NCU memory. When the proper Loran stations are identified, validity, consistency and reasonableness checks are performed. The test for reasonableness is a check on the magnitude of the difference between the measured and the predicted value as computed by the Kalman filter state estimate. This difference is compared with the best current estimate of the measurement covariance to obtain the reasonableness result.

SECTION 5

RNAV SYSTEM IMPLEMENTATION

RNAV SUBSYSTEM HARDWARE

The RNAV Subsystem hardware includes a navigation computer unit (NCU), inertial sensor system (ISS), Loran system, control/display unit (CDU), signal conditioner-digitizer unit (SCDU), and a Flight Data Storage Unit (FDSU). The subsystem has a digital interface that conforms to ARINC 571, internal interfaces with ISS and Loran, and other analog and digital interfaces, such as TACAN, Air Data, VOR/DME, etc. The FDSU is on the Digital Input-Output Concentrator (DIOC) bus. The CDU is on a 1553A bus. Figure 5-1 is a Block Diagram which outlines the RNAV subsystem and the equipment that are interfaced by RNAV subsystem.

Navigation Computer Unit (NCU)

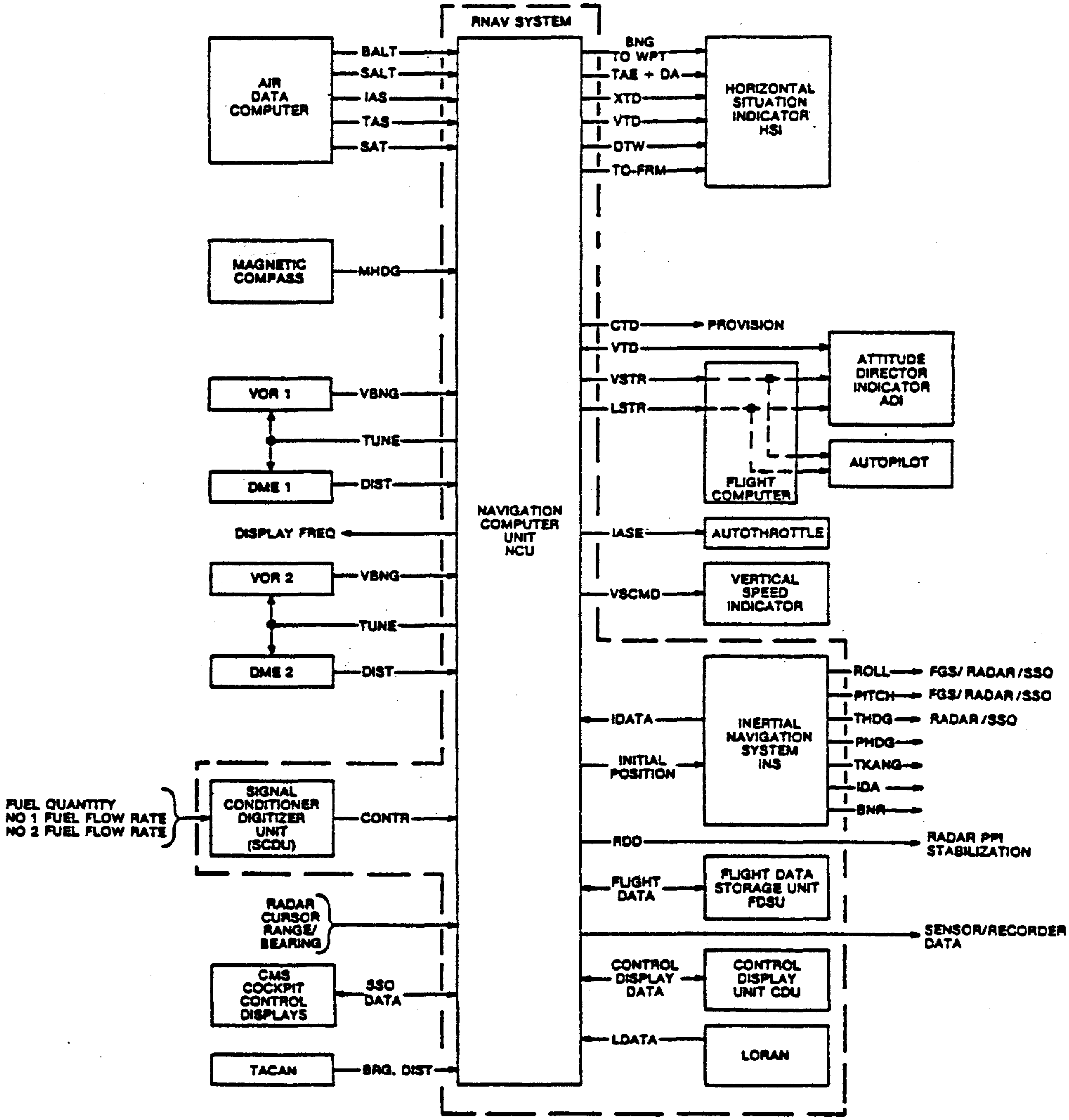
The NCU is a high speed, general purpose digital computer. The NCU contains a digital processor, interface electronics, memory, and a power supply. It is a binary, whole number and fractional, electronic reprogrammable machine using a wide temperature range memory. I/O circuits and memory are designed with modular units to facilitate changes required for specific system configurations and expansion. The NCU, designated the 8564C-5, is a new generation of a family of Collins Adaptive Processing System (CAPS) processors designed for navigation and flight control systems programs.

The NCU characteristics are as shown in Table 5-1.

The arithmetic logic and control unit (ALCU) contains the combinational logic required to realize the arithmetic and logic-oriented operation codes. Scratchpad register logic is provided and is accessible by the program as index registers, accumulators and instruction buffers. The scratchpad register is accessible as the first 16 words of memory.

The control portion of the processor includes the logic circuitry necessary to provide NCU control functions, such as program sequencing, decoding instructions, calculating effective addresses, fetching operands and storing results, and processing interrupts. The program control word, maintained by the control section, is a status word that sets the processor status, i.e., the hardware/software interface, for any given program. The program control word provides for program initiation and switching control with this one set of data.

The aircraft systems coupler (ASC) contained within the NCU contains analog and digital converters for navigation sensor data, converters/drivers for navigation output data, and control logic for routing data internally to/from the digital input/output concentrator.



RNAV SYSTEM WITH RELATED INTERFACES

FIGURE 5-1

Characteristic	Requirements
Computer Type	Stack processor
Data Word	16 bits
Byte Size	8 bits
Addressing	Literal, direct, indexed, component and paged
Instruction Word	8, 16, 24, 32- 40-bits
Memory Type	Ferrite Core, PROM
Memory Size	40,960 words of 16 bits
Nominal speed in Microseconds	
-Memory Cycle	1.0
-Memory Access	0.4
-Add (Memory Format)	1.0
-Multiply (32 x 32)	7.0
-Divide	8.0 (Typical)
-Clocks	10 MHz (Basic)
-I/O Rates (Maximum)	125,000 bits per second
-Instructions	100
Input power (includes ASC)	380 watts, 115 VAC, 400 Hz nominal

Table 5-1. MRS Navigation Computer Unit Characteristics
Type 8564C-5 (CAPS-5)

The ASC control logic and internal digital I/O interface selects the navigation input data in a predetermined sequence for periodic serial transmission on the output data line to the digital I/O coupler and subsequently to the memory. Navigation outputs are monitored with the status included with the navigation input data.

The control logic and internal digital I/O interfaces also receive navigation data periodically on the input data line from the digital I/O concentrator. The external digital navigation output data is serially transmitted, and the analog navigation output data are converted to proper form by the output converters/drivers. The high level warning outputs provide navigation output parameter validity to the corresponding users.

The digital I/O concentrator (DIOC) provides the input/output path for the FDSU. The I/O concentrator has a direct interface to memory (DMA) and a control interface to the processor. Input/output transfers consist of data records of 64 16 Bit words between the FDSU and memory.

Inertial Sensor System (ISS)

The Inertial Sensor System (ISS) selected for the MRS program is a version of the Litton LTN-71. It is designed and configured to conform to ARINC 571. The ISS consists of an Inertial Sensor Unit (ISU), Align/Display UNIT (ADU), and a Battery Unit (BU). The ISS contains an inertial platform, a computer, I/O platform electronics, and power supplies such that it can provide aircraft attitude, latitude, longitude, and ground speed following a self-contained ground alignment. Initial alignments are restricted to latitudes ranging from N 75 degrees to S 75 degrees, but navigation and attitude outputs are available to all latitudes and all aircraft attitudes.

Latitude and longitude are supplied to the ISS from the NCU, or by means of the ADU for alignment. Following ground alignment, the ISS provides latitude, longitude and aircraft velocity vector information to the NCU, stabilization inputs to the APS-127 radar, and attitude reference to the other aircraft equipment.

The system is configured such that the ISU is completely self-contained with respect to providing the align and navigation functions, provided initial present position is available during alignment. The ISU contains all necessary computation functions associated with alignment, navigation, and control functions.

Loran Receiving System

The Loran receiving system selected for the MRS program is the NSI ADL-81. It automatically acquires, synchronizes, and tracks Loran-C signals from any Loran C chain and outputs the measured time differences (TD's) to the Navigation Computer Unit. The receiver is capable of simultaneously tracking a Master and up to three secondaries of a single Loran C chain. The TD's are output to the NCU via a two-wire data bus in accordance with ARINC Characteristic 419-1. The Loran receiving system consists of:

a) Loran Receiver Unit
b) Loran Control Indicator
c) Loran Antenna Coupler

A fully-independent Loran navigational capability is provided, accessible by means of the Loran Control Indicator.

Control and Display Unit (CDU)

The CDU is an updated version of the CDU employed in the Collins ANS-70A RNAV system. It is capable of controlling the area navigation system and monitoring or displaying data such that the system operational and functional requirements may be carried out.

CDU Functions

The CDU provides the following functions:

- Capability for the pilot to address the computer with full alpha plus numerics
- System initialization by inputting position data to the NCU and commanding the NCU to transmit this to the inertial sensor.
- Selection and display of route identifiers, flight plan, destination, and Site ID's.
- Selection and display of course, waypoint data and altitudes.
- Selection and display of system status displays.
- Selection and display of inflight route changes and all pertinent data.
- Manual waypoint entry for routes not contained in the FDSU.
- Indication that the NCU has failed. Indication that transmission between the CDU and NCU has failed.
- Indication when any NAV unit or sensor fails and a tabular list of all failed NAV units or sensors.
- Indication that the crossing of the "TO" waypoint is imminent.
- The capability of parameter entry of special patterns.

Flight Data Storage Unit (FDSU)

The FDSU is the Collins 8848D-2 used in the Collins ANS-70A RNAV System. It provides a capability of transferring stored navigation data from a magnetic tape cartridge directly to the NCU.

The FDSU consists of a magnetic tape storage unit utilizing high quality magnetic tape.

The FDSU has the following characteristics:

- Storage Capacity	12×10^6 bits
- Data density	2208 bits/inch maximum
- Data rate	25 kilobits/second nominal
- Access time	75 seconds maximum/track from center of tape
- Random Bit Error Rate	1×10^{-7}
- Tape life	2500 accesses (each side)
- Input power	23 watts stby, 20 watts operating 115 volts, 400 hertz

RNAV SUBSYSTEM SOFTWARE

The MRS RNAV software is partitioned by functional task into eleven modules:

- o Real Time Executive
- o Applications Initialization
- o Navigation Foreground
- o Navigation Background
- o Kalman Filter
- o CDU Service
- o Flight Data Manager
- o Flight Data Loader
- o Utilities
- o CMS Interface
- o Flight Data File Update

This modular software organization has allowed independent development, debugging and testing of each software module. With well established module interfaces, it allows changes to be made within a particular module without causing changes to be made in other modules. Top-down structured programming techniques are employed utilizing HIPO (Hiearchial-Input-Process-Output) diagrams during the design phase. These techniques, together with the AED high level language facilitate the manageability of the software development tasks.

Real Time Executive

The function of the real time executive (RTE) is to provide overall control of the software system. It allocates computer resources for all the computing processes and controls the response to all interrupts. It provides the applications software with interfaces to guide the RTE in the control of these functions.

The RTE performs the following functions:

- o System initialization
- o Interrupt response control
- o User interface
- o Executive utilities
- o Process control
- o Program load
- o FDSU I/O control
- o 1553A bus I/O control

Applications Initialization

The Applications Intialization module performs the following functions:

- A sequence of procedure calls to initialization routines that are provided by other major software functions.

- An interface with the RTE via SCHEDULE statements that initiates the execution of other applications processes.

Navigation Foreground

The Navigation Foreground module is a grouping of algorithms that have high priority execution rates and are exercised at least every 200 milliseconds. These include:

- Interface with the Aircraft Systems Coupler (ASC) to input and process system discretes and sensor data.

- Provide the best estimate of current aircraft position and velocity by combining inertial or air data/compass dead reckoning outputs with position and velocity error estimates provided by the Kalman Filter.

- Calculate lateral deviation parameters for the current leg of the flight plan.

- Provide the lateral steering command that is required to capture or track the current desired path.

- Calculate vertical deviation parameters for the current desired vertical path.

- Provide the vertical steering command that is required to capture or track the current desired vertical profile.

- Maintain navigation parameters that are used for CDU and Instrument Display.

- Interface with the ASC to output the current state of RNAV parameters that are used by the MRS Flight Control and Autopilot Systems.

Navigation Background

The Navigation Background module includes those tasks necessary for the navigation function normally performed on a relatively low frequency basis. This module performs the following functions:

- Navigation Flight Plan maintenance
- VOR/DME SElection
- Rendezvous Calculations

- o Fuel Monitoring/Alert
- o Cruise Control

Kalman Filter

The Kalman Filter module is described under the Navigation With Loran section of this paper.

CDU Service

The CDU Service module performs the following functions:

- o Service keyboard inputs -
  - Poll keyboard
  - Function selection
  - Process scratchpad fields
  - Radar cursor entry processing
- o Refresh display -
  - Output scratchpad keys
  - Output scratchpad messages
  - Build display pages
  - Blinking control
- o CDU Utilities -
  - Write function
  - Page service code translation
  - Scratchpad error routines

Flight Data Manager

The Flight Data Manager module performs the following functions:

- o Manages access to the Reference Waypoint Stack -
  - Stored waypoint database
  - Pilot defined waypoints
- o Manages access to the Flight Event Table -
  - Sequences of flight events (waypoints, altitudes, pattern points, holding patterns, etc.)
  - End of database coverage
- o Manages access to Flight Database -
  - Waypoint data
  - Navaid data
  - Loran C data
- o Flight Plan Editor -
  - Interface with CDU routines
  - Update of flight plan

Flight Data Loader

The Flight Data Loader module performs the following functions:

- o Selection of data from FDSU magnetic tape cartridge unit.
- o Assembly of flight data in NCU core -
  - Site oriented data base; patrol routes, Loran chains, etc.
  - Cross country oriented data base; airport directory, navaids, etc.

Utilities

The Utilities module performs the following functions:

- o Math Package -
  - Basic Trigonometric routines
  - Spherical trigonometric routines
  - Algebraic routines
- o Time and Distance routines

CMS Interface

The CMS (Cockpit Management System) Interface module performs the following function:

- o Supervise CMS I/O transactions

Flight Data File Update

The Flight Data File Update module performs the following functions:

- o Create FDSU encoded magnetic tape
- o Update of FDSU magnetic tape cartridge unit (at regular intervals) -
  - Changes in standard data (VOR, DME, VORTAC, TACAN, Waypoints, Airports)
  - Loran C changes
  - USCG tailored data changes

The Evaluation of Loran-C by a Fully Automatic Receiver-Indicator

Yumio YONEZAWA*
Yuichi MIYOSHI**
Yoshio NISHITANI*

I. Introduction

The authors have published the result of observation of Loran-C signals by a Loran A/C manual receiver-indicator in 1969[1].

This is a preliminary report on the improved accuracy of the receiver. Recently in the U.S., Loran-A is in the process of being phased out to be replaced by Loran-C. The Loran-C receiver now offers higher accuracy and its cost has been going down. So authors tried observation of Loran-C signals using a full automatic receiver-indicator. The evaluation of data at a fixed receiving point for a year's period is underway but this report deals with a few days in February, March, May, and July. We hope to publish the total result in the future.

II. Method of Observation

Using 2 sets of DL-91, MK-2 of Navigation System Incorporated SS3-M, W, X, Y, and Z signals were received by "Auto" mode and tracked by "Normal" mode. Time differences(TDs) were printed out and punched out on paper tape at every constant period.

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III. Distances from Transmitting Stations to Receiving Point

The receiving point used is 35°43'.2N and 135° 19'.0E on a 1/25000 map published by NIHON CHIRI-IN. The distances to receiving point are:

from Master Station	673 n. miles
from W Secondary Station	1161 n. miles
from X Secondary Station	622 n. miles
from Y Secondary Station	612 n. miles
from Z Secondary Station	1519 n. miles

IV. Result and Discussion

Results are tabulated in Table 1 and also plotted into Figures 1, 2, and 3. Table 2 is 1969 results.

a. Mean Time Difference

Table 1 shows that the difference between mean time differences for day and night is almost nil for X and Y. M, X, and Y seem to be ground waves. There is little variation in mean time difference for X and Y throughout this experiment. We can see that they are not effected by seasonal conditions or time of the day conditions and remain rather stable.

W shows a ground wave pattern, too, except for the month of March when sky wave patterns were obtained.

As for Z, the result almost always shows a sky wave pattern where the difference between day and night mean time differences is great. This has to do with the sky wave correction and is discussed later. W in May seems to have a transient pattern changing from sky wave pattern to ground wave pattern.

Comparison of these results with 1969 results shows that the difference of the mean time differences between these two results are less than about 2 micro-seconds except for the one with a 10 microsecond slip. That means a skilled operator can get a good result from even a manual receiver although W and Z could be received and seen on the scope but no time difference was obtain-

TABLE 1 RESULT BY AUTOMATIC RECEIVER

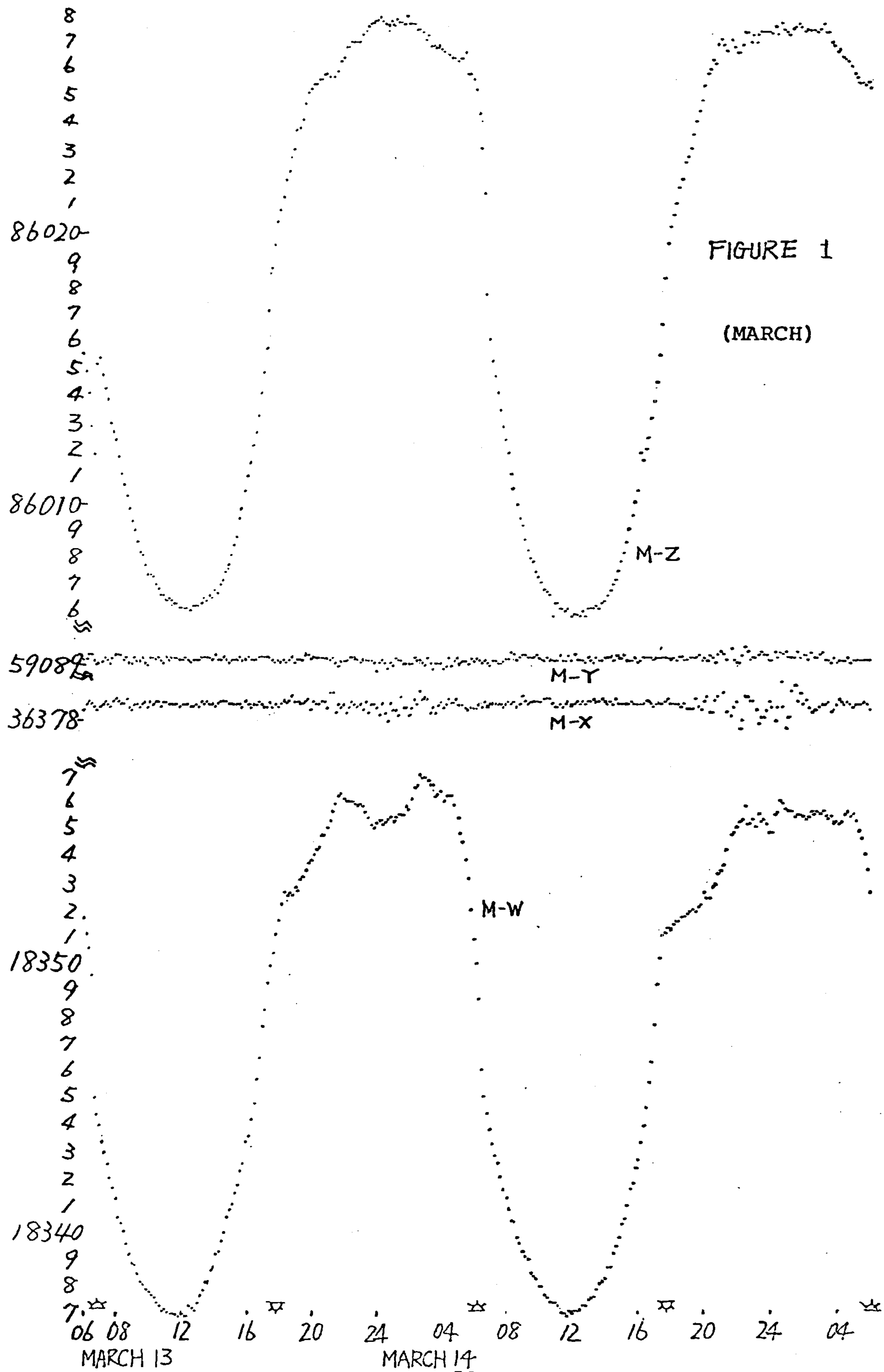
		M - W			M - X		
		DAY	NIGHT	DIFF.	DAY	NIGHT	DIFF.
FEBRUARY	AVERAGE				36378.6	36378.6	0.0
	STAND. ER.				0.15	0.14	
	RANGE MAX.				36379.2	36379.1	
	RANGE MIN.				36378.2	36377.8	
	RANGE RANGE				1.0	1.3	
MARCH	AVERAGE	18341.14	18354.68	13.54	36378.62	36378.56	0.06
	STAND. ER.				0.09	0.26	
	RANGE MAX.	18351.6	18357.0		36378.9	36379.4	
	RANGE MIN.	18336.9	18350.0		36378.4	36377.7	
	RANGE RANGE	14.7	7.0		0.5	1.7	
MAY	AVERAGE	18305.68	18304.99	0.69	36378.71	36378.71	0.0
	STAND. ER.	0.88	0.28		0.13	0.19	
	RANGE MAX.				36379.1	36379.2	
	RANGE MIN.				36378.0	36378.0	
	RANGE RANGE				1.1	1.2	
JULY	AVERAGE	18305.33	18305.02	0.31	36378.66	36378.68	0.02
	STAND. ER.	0.33	0.34		0.15	0.18	
	RANGE MAX.				36379.1	36379.2	
	RANGE MIN.				36378.0	36378.2	
	RANGE RANGE				1.1	1.0	

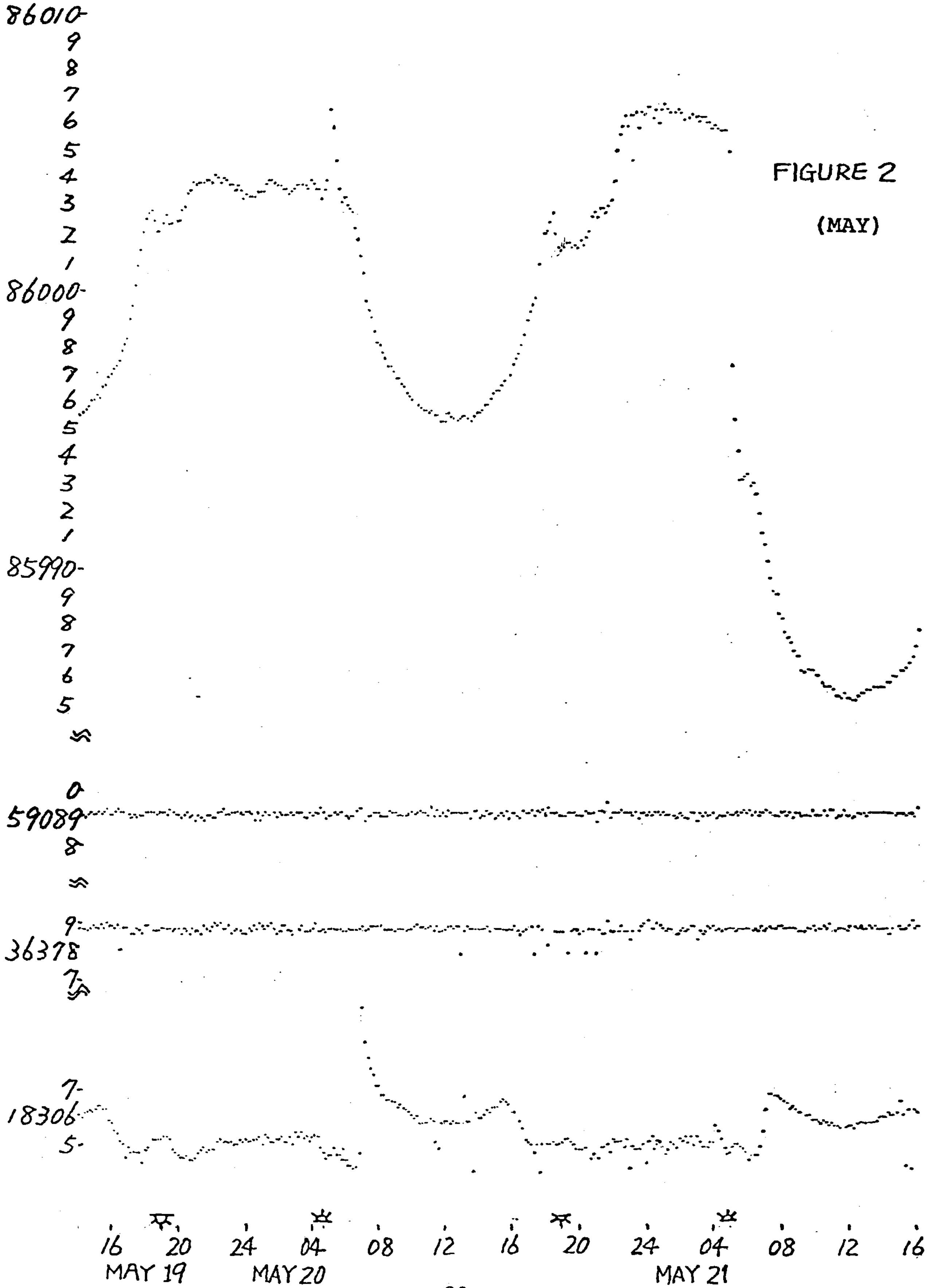
TABLE 1 RESULT BY AUTOMATIC RECEIVER (CONTINUE)

		M - Y			M - Z		
		DAY	NIGHT	DIFF.	DAY	NIGHT	DIFF.
FEBRUARY	AVERAGE	59089.2	59089.2	0.0			
	STAND. ER.	0.12	0.12				
	MAX.	59089.6	59089.7				
	RANGE MIN.	59088.8	59088.7				
	RANGE	0.8	1.0				
MARCH	AVERAGE	59089.24	59089.24	0.0	86010.25	86026.08	15.83
	STAND. ER.	0.09	0.13				
	MAX.	59089.5	59089.7		86024.3	86028.0	
	RANGE MIN.	59089.0	59088.8		86005.8	86020.6	
	RANGE	0.5	0.9		18.5	7.4	
MAY	AVERAGE	59089.09	59089.15	0.06	85997.89	86004.28	6.39
	STAND. ER.	0.09	0.11		2.82	1.51	
	MAX.	59089.4	59089.6				
	RANGE MIN.	59088.9	59088.9				
	RANGE	0.5	0.7				
JULY	AVERAGE	59089.14	59089.14	0.0	85984.83	85984.60	
	STAND. ER.	0.10	0.12		0.79	0.34	
	MAX.	59089.5	59089.5				
	RANGE MIN.	59088.9	59088.7				
	RANGE	0.6	0.8				

FIGURE 1

(MARCH)




86010
86000
85990
59089
36378
18306
16
20
24
04
08
12
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MAY 19
MAY 20
MAY 21

FIGURE 2

(MAY)

FIGURE 3

(JULY)

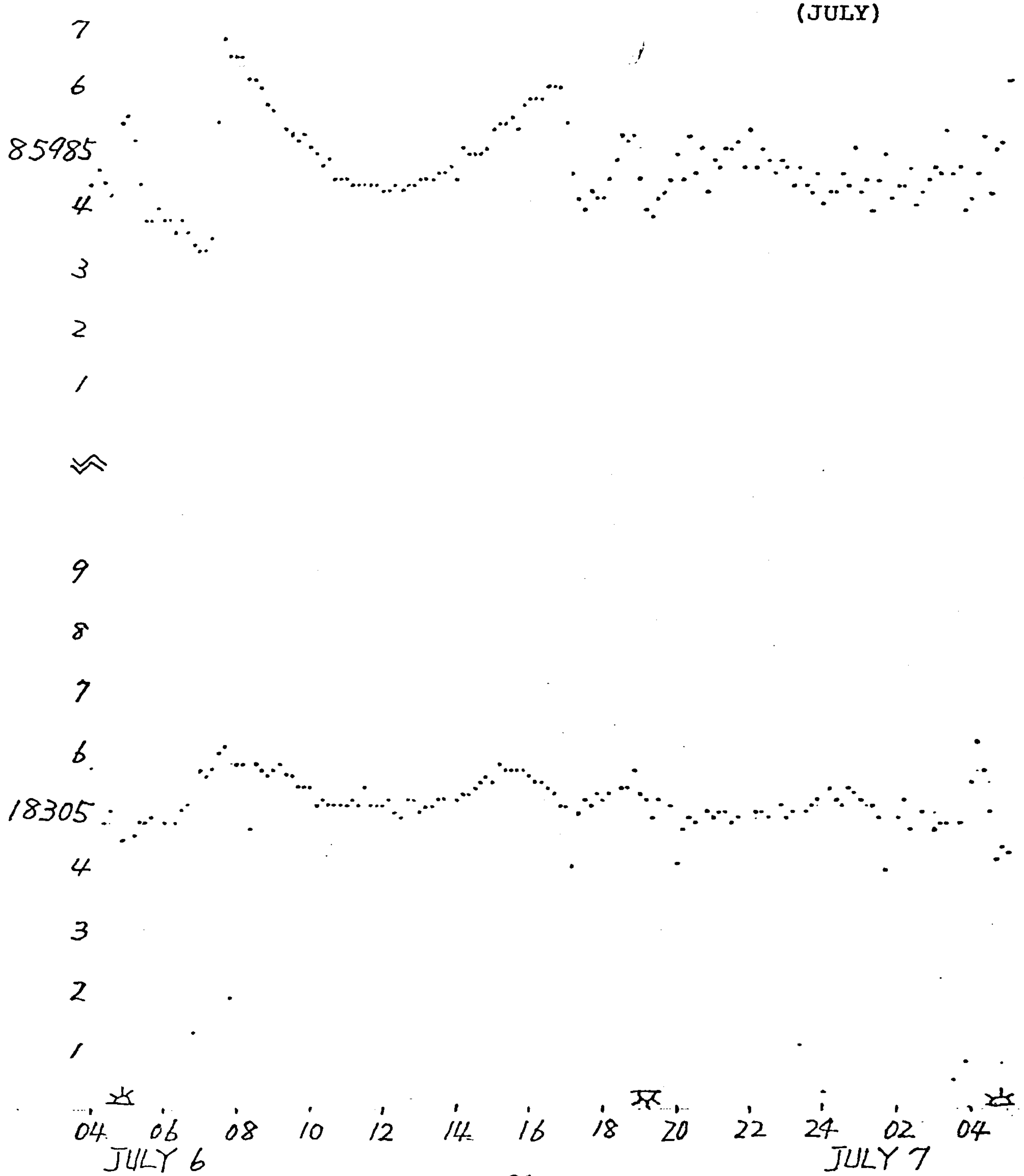

TABLE 2 RESULT BY MANUAL RECEIVER

	M - X			M -Y		
	DAY	NIGHT	DIFF.	DAY	NIGHT	DIFF.
AVERAGE	36377.8	36387.1	19.3	59087.7	59086.9	0.8
STAND. ER.	0.50	0.32 (36380)		0.54	0.53 (59090)	
	0.68	0.48 (36390)		0.27	0.69 (59100)	
	0.73	0.64 (36400)				
		1.18 (36410)				
RANGE MAX.	36409.3	36420.3		59099.4	59110.2	
RANGE MIN.	36369.2	36378.6		59079.0	59080.2	
RANGE RANGE	40.1	41.7		20.4	30.2	
FIXED POSITION	DAY	34-43.1 N, 135-18.0 E FOR DAY AVERAGE				
	NIGHT	34-42.3 N, 135-18.3 E FOR NIGHT AVERAGE				

ed and a 10 microsecond slip could not be avoided.

b. Variation of mean time difference

As can be seen from Table 1, the ranges for X and Y show that the values themselves are very small and there is very little difference between day and night time ranges. Day time ranges seem to be less than night time ranges although the differences are negligible on the whole.

In the mean time, our manual results show very big values for ranges for X and Y mainly due to 10 microsecond slip. This shows the improved accuracy of automatic receiver.

c. Standard Error

Standard errors for X and Y are very small, less than about 0.2 microsecond. Data also show Y is more stable than X, latter signal comes all the way over land.

Comparing these with 1969 results in Table 2, it is seen that the latter results show more dispersion. This means manual results are less accurate in individual cases even though the average mean time differences come close to the automatic receiver values.

d. Correction

Time differences for March are plotted in Figure 1 as typical example. X and Y show ground wave patterns(if it can be called a pattern, it is a straight line). W and Z show sky wave patterns. These sky wave patterns do not coincide with the typical Loran-C sky wave pattern assumed which is a basis for the constant correction values in present sky wave correction[2]. Moreover, W signal looks like an in-between of sky wave and ground wave in May as can be seen in Figure 2. A correction might have to be made according to the more realistic values taking the seasonal pattern change into account.

Another reason for the necessity for a more realistic correction is that the improved capability of receivers results eventually in the expansion of coverage area and consequently in the use outside the ground wave area. In fact, W and Z, which could not be used in the last observation of 1969, can be used with the full automatic receiver at this time.

So, more realistic correction is needed.

e. Fixed Position

Our position is fixed by Loran C Table with mean time difference values for Z and Y such as 34° 43'.2 N and 135° 18'.9 E.

This position is different from the 1969 manual result by 1 minute in longitude in the day time and 1 minute both in latitude and longitude at night. Close agreement is seen for average values for X and Y.

f. Identification of Sky Waves and Ground Waves

To make the identification of the sky waves easier it seems necessary to unify the value for ground wave range although many factors are involved such as receiver capability, transmitting power, and etc. It is generally said that ground waves can be received within 1200 n. miles from the transmitting station. This is also stated in the Loran-C table. The automatic receiver indicator manual assures the ground wave reception within 600 n. miles. In our observation, diurnal pattern for W and Z show a seasonal change. In March they both showed typical sky wave patterns and in May W exhibited ground wave patterns, especially at night. In July, W became a ground wave signal, as can be seen in Table 1 and Fig. 1,2,3. Ground wave range seems to be effected by seasonal change and the operator should be aware of this.

DL-91 automatic receiver has a status lamp (SKY/SYN) to identify sky waves but it's not always accurate. This lamp does not often light even for Z.

g. Slips

At the present location of this receiver (DL-91), Loran C signals are received and tracked well. The manual receiver requires a skilled operator to get the best results and the automatic receiver is no exeption. Although the automatic rarely slips, skill is required to begin tracking. With X and Y no slip was seen in tracking. When slips occur with Z, it is usually around twilight. W signal sometimes slips but soon returns. All in all, adjustment with the automatic receiver is crucial at the beginning of tracking and checking is very necessary.

V. Conclusion

a. We feel it is necessary to continue our observation using the full automatic receiver-indicator to examine sky wave pattern and correction, especially concerning seasonal change. We understand that in the U.S. Loran-C was designed to mainly use ground wave but to expand the versatility of the Loran-C system, sky wave study cannot be avoided.

b. We hope a more reliable device is developed to identify sky waves.

References

1. Yumio Yonezawa and others; The Evaluation of Loran-C by a Manual Receiver-indicator, Navigation,Vol.16,No. 1,1969
2. Gifford Hefley; The Development of Loran-C Navigation and Timing, DOT, 1972

Current Marine Loran-C User Experiences on the East Coast

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Abstract

The degree of success that the East Coast mariner experiences with Loran-C navigation is directly related to the type of receiver that is being used. Mariners using true "low-cost" receivers are obtaining the accuracy, repeatability, and range capability as stated for a particular area. Mariners using combination Loran A/C receivers are experiencing problems utilizing Loran-C. A sizable segment of these mariners do not believe that the true Loran-C receiver has yet become low-cost. Information programs are necessary at all levels within the Loran-C user communities. Examples are given that illustrate recent applications of Loran-C within the CCZ.

Introduction

Our nation has entered a relatively new and promising era of navigation. It began in May 1974, when the Department of Transportation announced its National Plan for Navigation using Loran-C as the government-provided radionavigation system for the Coastal Confluence Zone (CCZ). The effects of that announcement are just now being realized. The West Coast and Gulf of Alaska Loran-C chains have been declared operational for navigational use. The East Coast reconfiguration, Gulf of Mexico, and Great Lakes chains are moving toward completion, and the termination date for Loran-A chains, July 1, 1980, is drawing close. The use of Loran-C in the CCZ, the Great Lakes, the Mississippi River Valley, and much of our inland area, provides an opportunity previously non-existent for both mariners and terrestrial users alike when pursuing the art of navigation.

The East Coast has been uniquely fortunate in having Loran-C available for many years because of its military applications. With the coming of the so-called true "low-cost" receiver, the civilian mariner has begun to use Loran-C as a trusted navigational tool. However, if there are any discords within the Loran-C implementation, it is with the definition of what a "low-cost" receiver should cost and with the level of understanding and information that the mariner has about Loran-C.

Definition: Low-cost Receiver

One of the present drawbacks to a general acceptance of Loran-C is the question of receiver cost. Mr. Gilbert N. Nelson of Simrad has suggested that a rule of thumb of between 5 and 15% of full [vessel] replacement cost be considered minimal for investment in on-board electronic instrumentation. Radionavigation receivers usually rank no higher than third on the instrumentation priority list and, particularly on smaller vessels, are relegated often to the "wish list" for later purchase or to the purchase of a receiver that does not meet the operational characteristics for a true Loran-C receiver as outlined in the U. S. Coast Guard Loran-C User Handbook (CG-462). It is difficult to specifically define the value of a receiver that is indeed low-cost. This value must be determined by the user, and a sizable segment of East Coast mariners have determined that the true Loran-C receiver is not yet low-cost. Their alternative is the combination Loran A/C receiver which is currently very attractive because of its lower cost, because it appears to offer the accuracy, repeatability, and other benefits publicized about Loran-C, and because it appears to provide a reasonable method to circumvent the problem of Loran-A termination while providing a safe method for investment in Loran electronic instrumentation. The combination receiver may cost up to 50% less than the true Loran-C receiver. It is incumbent upon us, the current members of the Loran-C community, to work toward equating the user's and the manufacturer's definition of "low-cost", and to inform this user of the possible consequences of his "compromising" by buying a combination receiver.

Information Problems

The current level of understanding and information among East Coast mariners is another area that demands our attention. The combination of incorrect information coupled with the lack of information available from knowledgeable and easily-accessed sources creates a discouraging outlook at a time when Loran-C should be becoming widely accepted. This problem needs to be addressed at the user level; not with theoretical and technical language but in a language that the user can comprehend.

Current Loran-A users who resist the termination of Loran-A usually have several quick reasons for their resistance: receiver cost, transition problems, and a lack of information about Loran-C. Initial feelings are that they could survive with Loran-A if it were allowed to survive. But continued conversations can expose discontent: increasing Loran-A chain down-time, skywave problems causing day-night time difference discrepancies, and the lack of charts for and reliable coverage in estuarine areas. This user has undoubtedly heard of the advantages of Loran-C but still remembers another recent governmental "improvement" which forced the replacement of AM radiotelephones with VHF and possibly SSB radiotelephones at a cost which was probably less than for what current "low-cost" Loran-C receivers are selling. This transition was made over a five-year period during which time radiotelephone cost decreased and its technology improved. Many Loran users are hoping that similar advantages will occur for them before the Loran-A to Loran-C transition is completed.

Users of combination Loran A/C receivers are inclined to further degrade their own and others confidence in Loran-C when they cannot obtain the accuracy and repeatability publicized for Loran-C. They blame everyone -- the government, Coast Guard, receiver manufacturer and dealer. Excuses then abound, generated from incorrect information. As an example, several mariners told me this summer that they could not use the East Coast Dana(Z) secondary because it was operating at half-power. If they cannot use Dana now, then they may encounter similar problems when the East Coast reconfiguration is completed. They may not be able to receive the new Seneca, NY master or any more than two secondaries at a time. If the existing East Coast Loran-C chain stops transmitting on July 1, 1979 and the East Coast Loran-A chains stop transmitting on July 1, 1980, then this mariner will be unable to utilize Loran radionavigation until he purchases a true Loran-C receiver.

These information problems need to be addressed by all of us here. Dealers and manufacturer's representatives need to be sure that their personnel are knowledgeable and able to authoritatively dispel any incorrect information that the mariner may have. These persons must be able to extol the advantage of Loran-C: its accuracy, repeatability, reliability, ease of operation, its coverage area, and its resistance to weather disturbances and day-night discrepancies. It is not enough, and is potentially damaging, to merely say that Loran-C is what the federal government has decided will replace Loran-A.

The Loran-C user community needs to have more opportunity to see operational receivers whether they be at showrooms, boat shows, or even in service vehicles. There is no substitute for hands-on experience under real conditions, and nothing is so useless as the demonstration of an unoperational receiver or one that is coupled to a simulator which is displaying very pretty but useless numbers. Now is the time to get the key persons from throughout the marine community convinced that Loran-C is the radionavigation system for the future that's available now.

The marine publication media also need to promote the advantages of Loran-C. Advertisements, editorials, and informational columns should stress these advantages and address the Loran-C implementation in a positive manner. Since the U. S. Coast Guard is responsible for the operation of the Loran-C system, it is logical that they should be the primary source of Loran-C information. The Coast Guard publication Local Notice to Mariners (LNM) should devote a brief section of each issue to Loran-C chain information for that particular district including current operational status, on-air performance record, scheduled maintenance times, proposed chain improvements, and in general, any information beneficial to the Loran-C user community. The LNM method of information dissemination would be the most authoritative and most timely method to use and would go a long way towards promoting Loran-C.

The marine user community is being joined by a relatively new terrestrial user community. Many exciting terrestrial applications for the use of Loran-C have been proposed and tested including automatic real-time vehicle monitoring, vehicle locating and routing, and location recording. These users need the same Loran-C operations information as does the mariner. Since these users would not be expected to monitor marine radiotelephone and radiotelegraph frequencies, and even greater burden is about to be placed on the written method of information dissemination. The Coast Guard must be prepared either to increase their LNM mailings to this user group or to develop an alternate method to disseminate Loran-C information to them.

I can easily reinforce these remarks by sharing some experiences that I had last Saturday at the U. S. Powerboat Show in Annapolis, Md. There were 6 Marine electronics dealers in attendance. Only 2 dealers had working receivers. Several dealers displayed a manual Loran-C receiver that utilized a rate selection module that plugged into the front of the receiver. On this module, 9930 was written which is the current East Coast chain rate. One salesman said the 9930 value was the receiver serial number, another salesman said that it was the frequency on which the Loran-C chain operated: 9.930 MHz. I was also informed that the resolution of Loran-C was .2 second, that the master pulse group consists of 1 master pulse and 8 identification pulses, that Loran-C operates on a higher frequency than Loran-A and therefore has more accuracy, that the 4400 line is transmitted from Florida, that the East Coast chain was supposed to be on-the-air this past July, that Loran-A will be around for either 5-6 or 7-8 more years depending on which dealer I talked to, and that the Coast Guard has installed many new Loran-C transmitters, is having many problems with them, and will not say anything about these problems. These pieces of information clearly demonstrate the incorrect information currently being disseminated.

Current User Experiences

The University of Delaware installed two Loran-C receivers (Simrad LC204, Teledyne TDL-601) on its 120 ft. coastal zone research vessel, the R/V Cape Henlopen. Both of these receivers meet the Coast Guard's requirements for a "true" low-cost Loran-C receiver. Utilizing the East Coast chain, the Cape Henlopen sailed its maiden voyage from Morgan City, LA to Lewes, DE in April 1976, with only minimal problems encountered, which were in the baseline extension areas. Since then, the Cape Henlopen has performed a variety of coastal zone research activities along the East Coast and Loran-C has been a necessary aid to each cruise and has convinced many vessel users of its merit. One of the earliest and simplist Loran-C experiments was the launch and recovery of a common unlighted fishing buoy containing no radar reflector, flag, or transponder. The buoy was launched at midnight at a point approximately 45 miles east of the Delaware coast and retrieved at midnight the next night. The Cape Henlopen approached the Loran-C coordinates logged when the buoy was deployed and, as the coordinates were crossed, the buoy was sighted within 50 ft. of the port bow and then hauled aboard as the vessel drifted by. This degree of navigational accuracy has become an expected standard aboard the Cape Henlopen. Buoy arrays containing current monitoring equipment have been deployed for extended periods and then quickly recovered, thanks in part to Loran-C repeatability. Also, vessel operating costs have been reduced since on-station search time is negligible. The Cape Henlopen is currently being chartered for the quarterly collection of baseline data over the Mid-Atlantic continental shelf for part of a Bureau of Land Management study. One aspect of this collection is the study of organism recolonization in the ocean floor sediment. Sediment is collected at a specific location, organisms in the sediment are identified and removed, and then the sediment is returned to the ocean floor in fiberglass trays which are recovered at a later date so that organism recolonization patterns can be evaluated. Loran-C has enabled the Cape Henlopen to return to this specific location and deploy divers who locate these trays in 220 feet of water. Loran-C has indeed become street signs in the ocean for this type of research. The most publicized cruise of the Cape Henlopen was in April 1977, when University scientists, in cooperation with the Monitor Research and Recovery Foundation, completed important environmental and engineering studies at this famous Civil War Ironclad's wreck site.

Using Loran-C coordinates from previous studies on other research vessels, the Cape Henlopen located the Monitor on the second pass over the site. The Loran-C coordinates obtained compared excellently with the previous coordinates with the difference between the respective coordinates being less than the length of the Monitor. Current measurements and piston-coring experiments were then completed in the immediate wreck area with Loran-C coordinates documenting the experiment locations. On the return cruise to Delaware, the Cape Henlopen recovered another current meter deployed earlier off the Delaware coast and again had comparable Loran-C repeatability.

The University of Delaware is also collecting baseline data over the Georges Bank continental shelf for part of another Bureau of Land Management study. In order to assure that the vessels used for this study would meet the navigational requirements for station positioning, a Loran-C receiver (Simrad LC204) was purchased and has been installed on the vessel used for each cruise. The maneuvering board method used for buoy positioning as described in the January-February-March 1973 issue of Coast Guard Engineer's Digest was adopted. This method consists of locating the specific station at the center of a maneuvering board chart and drawing the hyperbolic Loran-C lines of position (LOP) for that area on the chart. Since the station radius is .5NM, the LOP's are assumed to be approximately straight lines on the chart. The chart is covered with a sheet of plexiglass with the vessel's location then plotted with a grease pencil. This method has been very successful and has exceeding our expectations for being able to keep all station sampling with the .5NM radius.

Aircraft using Loran-C for the surveillance of ocean dumping, oil slicks, and current fronts have been coordinated with shipboard sampling aboard the R/V Cape Henlopen for ground truth correlation. Accuracies and repeatabilities obtained by the aircraft were comparable to shipboard values. The major difficulty encountered in airborne Loran-C is very similar to the mariner's difficulty which is the lack of information concerning Loran-C chain operation. Again, the Coast Guard must be prepared to provide Loran-C information to this user community.

Not all users require the same degree of navigational accuracy. The master of an oceangoing tanker, the commercial fishermen, the yacht owner, and the scientist all require various degrees of accuracy. The important point is that Loran-C has been proven to be an effective radionavigational aid capable of meeting their navigational needs. Examples of the use of Loran-C in scientific studies are used here since their requirements tend to be the most demanding.

Conclusions

The current experiences of marine Loran-C users on the East Coast are directly related to the equipment being used. The examples above readily document the capability of Loran-C radionavigation when used to its full potential by a true Loran-C receiver. The East Coast reconfiguration should improve the mariner's use of Loran-C by eliminating bothersome baseline-extension problems in critical navigational areas and by improving grid crossing angles. Mariners who use a combination Loran A/C receivers are experiencing problems utilizing Loran-C. Both groups are plagued by incorrect information and a lack of information. Information programs must be initiated at all levels within the Loran-C user communities if the full potential of Loran-C is going to be realized by the people that it is designed to serve.

APPLICATION OF LORAN-C FOR A UNIQUE COLLISION AVIODANCE SYSTEM

by
General John D. Lavelle, USAF Retired
Richard J. Jacobi

This paper describes a unique Loran-C system, developed to protect motorists who use the Lake Pontchartrain Expressway, from being assaulted by incompetent tugboat captains. Sometimes these assaults have been repulsed, at other times motorists have skillfully avoided them, but on occasion they have been highly successful, resulting in situations like this. Figure 1. (Two lives and three vehicles were lost in this accident. Note the tractor-trailer on the fallen bridge slab.) The cause of this accident was "unqualified tugboat Captain".

Background

The Greater New Orleans Expressway Commission operates the 24-mile long, two-span causeway bridge across the center of Lake Pontchartrain, a lake where there is extensive commercial shell dredging 24 hours a day. There have been several instances over the past years when tugs and barges involved in this commercial dredging operation have crashed into the bridge with resultant severe damage to the bridge. On ten occasions one or more bridge slabs have been knocked down and twice, immediately after collisions, vehicles have been driven off the bridge into the water. Most of the occupants were killed. Figure 2 shows photographs taken after another accident resulting in motorist fatalities. In this case a bus with 8 passengers was involved. The skid marks from the bus bouncing off the fallen slab can be seen just to the left of the man standing on the slab. In this case, the damage was caused by an empty barge pushed by a tugboat. The cause of the accident was listed as "the crew was asleep."

There are as many as 35 barge-tugboat crossings under the expressway every day. In 22 years there have been 19 collisions with the expressway, resulting in 9 motorist deaths. No tugboat crew member has sustained any injury. Apparently, this is because the tugboat pushes rather than tows the barge. It should be pointed out that only a barge under tow, or push, has enough momentum and mass to cause sufficient structural damage to the pilings to result in displaced or fallen slabs.

3 VEHICLES PLUNGE OFF WRECKED LOUISIANA SPAN

—Associated Press

Rescue boats stand by a section of a 60-foot high bridge that fell into a narrow neck of water connecting Lake Pontchartrain and Lake Maurepas near New Orleans yesterday. Several sections of the bridge collapsed after being struck by a barge carrying a load of sea shells. A tractor-trailer truck (center) and two cars plunged off the bridge. The truck landed on one of the spans but the cars disappeared in swift-moving water 56 feet deep. State police divers hunted for the vehicles but did not find them. Another effort is planned for today. The number of persons in the cars was unknown. The truck driver and his rider were injured. The bridge spans Manchac Pass on U.S. 51 between New Orleans and Hammond, La.

Figure 1. Newspaper clipping of tugboat-barge collision with Lake Pontchartrain Expressway

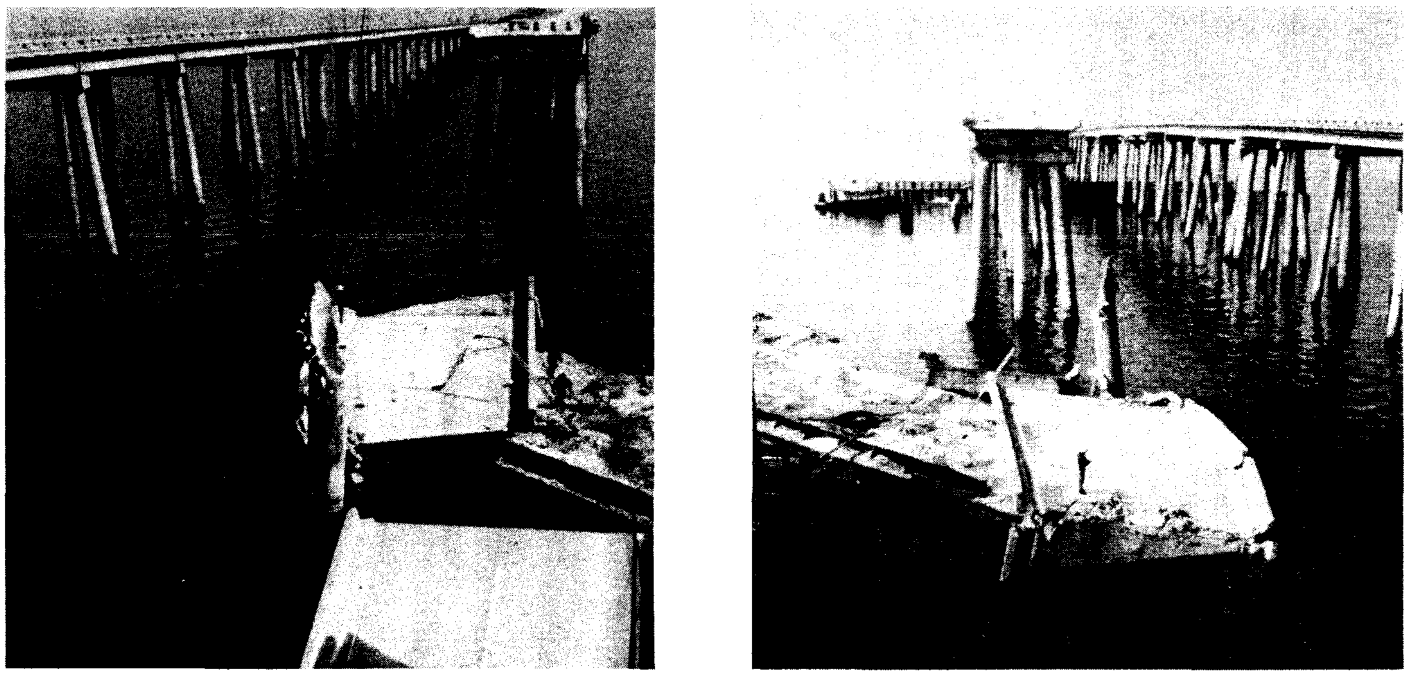


Figure 2. Photographs of tugboat-barge collision with Lake Pontchartrain Expressway

The expressway is the longest concrete bridge structure in the world consisting of two separate two-lane causeways each 24 miles long. There are two high bridges for vessel traffic to pass under, located 8 miles from each shore. One of these bridges has bascule leaf openings for passage of high structures such as derricks, drilling rigs, high sail boats, etc. The other is fixed. Figure 3 shows a tugboat pushing an empty barge through one of the bridge openings. The barges, when fully loaded, hold about 300 tons of shells in a mound about 30 feet high. The important characteristics of the Lake Pontchartrain Expressway are shown in Figure 4.

A summary of the accidents to the expressway and the location of the impact points is depicted in Figure 5. Note that there is no consistency in the location, direction or cause of the accidents. Except for an accident caused by a hurricane and a sinking tug under the bridge, all accidents were caused by tugboat crew errors.

The above conditions identify two problem areas. The first problem is one of immediately identifying bridge damage and activating a motorists warning system to reduce the probability of vehicle accidents after waterborne vessels have collided with the bridge. The second problem is to greatly reduce the likelihood of waterborne work vessels colliding with the bridge. Figure 6 summarizes the role that Decisions and Designs played in this area. Since this study was commissioned by the Greater New Orleans Expressway Commission, who has responsiblility only in the area of the first problem, we were originally advised that 85 percent of our effort should be spent on the prevention of bridge vehicle accidents and only 15 percent on reducing the probability of waterborne vessels ramming the bridge.

In the original study we identified approximately 30 ideas for slabout warning systems, obtained from previous studies and/or proposals. We added a few more of our own and then reduced the number to 13 feasible systems upon which we did a preliminary cost and effectiveness analysis. These slabout warning systems are summarized in Figure 7. Our base system was a break wire between each slab, connected by multi cables to a central processor. This system appeared feasible and was proposed by one of our larger national electronic firms, though it was greatly under priced at just over a million dollars.

DDI performed an engineering analysis of the candidate systems with technical and cost comparisons. Figure 8 shows the relative ranking of those 13 slabout warning systems. The two systems, 8 and 9, with the best performance and least cost utilized vibration sensors arrayed in zones along

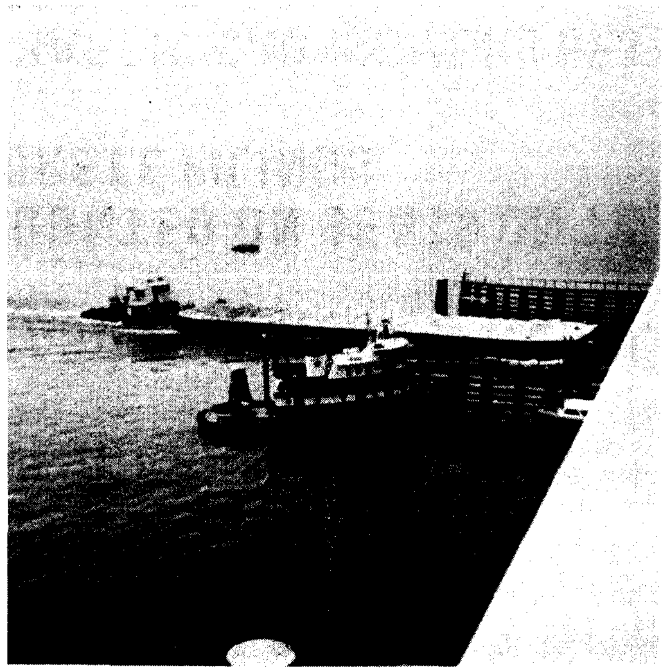


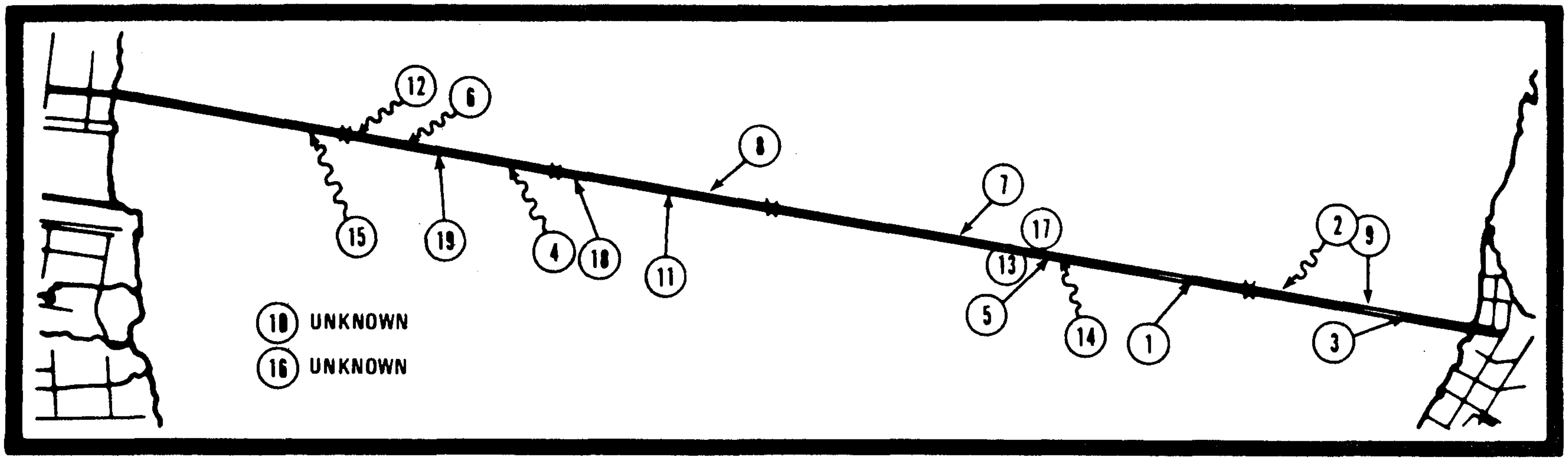
Figure 3. Normal crossing under Lake Pontchartrain high bridge

Causeway Construction

- PRESTRESSED CONCRETE SLAB CONSTRUCTION
- SLAB – TWO-LANE ROADWAY WITH INTREGAL SAFETY RAILS
- OLDER WEST CAUSEWAY – 2200 SLABS, 56′ LONG
- NEWER EAST CAUSEWAY – 1500 SLABS, 84′ LONG
- SLABS MOUNTED ON BENTS ON TWO OR THREE CONCRETE PILINGS
- SEVEN TRAFFIC CROSSOVERS BETWEEN THE CAUSEWAYS
- AVERAGE BARGE/TUG CROSSINGS, 35 PER DAY
- 19 SERIOUS VESSEL BRIDGE ACCIDENTS IN 22 YEARS

Figure 4. Lake Pontchartrain causeway construction highlights

Vessel - Causeway Accidents



Date	Damage	Cause	Date	Damage	Cause
1. 55	2 FALLEN SLABS	POOR NAVIGATION	11. 67	OLD SPAN – 2 SLABS FALLEN	ASLEEP
2. 55	DAMAGED PILINGS	LOOSE BARGE; BROKEN FROM MOORING BY WEATHER	12. 67	MINOR TO PILINGS	?
3. 56	2 FALLEN SLABS	FELL ASLEEP	13. 67	NONE	SINKING TUG ABANDONED BY CREW UNDER CAUSEWAY
4. 58	DAMAGED PILINGS	ENGINE FAILURE	14. 69	NEW SPAN – 3 SLABS FALLEN	WEATHER
5. 60	2 FALLEN SLABS, 1 DAMAGED SLAB	POOR NAVIGATION	15. 69	DAMAGED SLAB & 2 BENTS	WEATHER
6. 61	DAMAGED PILINGS FOR 1.5 MILES	LOOSE BARGE BROKE FREE DUE TO WEATHER	16. 69	NONE	UNKNOWN
7. 62	1 FALLEN SLAB	CREW ERROR	17. 70	DAMAGED STEEL BRACING	CREW ERROR
8. 64	4 FALLEN SLABS	OPERATOR FAINTED OR PASSED OUT	18. 74	3 FALLEN SLABS	ASLEEP
9. 64	2 FALLEN SLABS	ASLEEP	19. 76	DAMAGED SLAB	?
10. 65	DAMAGED PILINGS				

Figure 5. Lake Pontchartrain Vessel-Causeway Accident summary

DDI Under Contract With David Volkert, Associates
for
Greater New Orleans Expressway Commission

TASKS:

- REVIEW ALL PREVIOUS PROPOSALS TO THE COMMISSION
  DETERMINE WARNING SYSTEMS

- PERFORM ABBREVIATED ANALYSIS TO DETERMINE
  IS THERE A FEASIBLE SOLUTION

- DEVOTE EFFORT AS FOLLOWS:
  - SLABOUT WARNING SYSTEM – 85 PERCENT
  - VESSEL COLLISION AVOIDANCE SYSTEM –
    15 PERCENT

Figure 6. DDI Task Summary

Slabout Warning Systems Considered

SENSOR TYPE	VARIATIONS	DATA AND CONTROL TRANSMISSION
BREAKWIRE	6	MULTICONDUCTOR CABLE SINGLE CABLE RADIO
VIBRATION	3	RADIO
LASER BEAM	1	RADIO
PNEUMATIC TUBE	1	NONE
CABLE MONITOR	1	SINGLE CABLE
MICROWAVE	1	RADIO
	13	

Figure 7. Slabout Warning System Considered

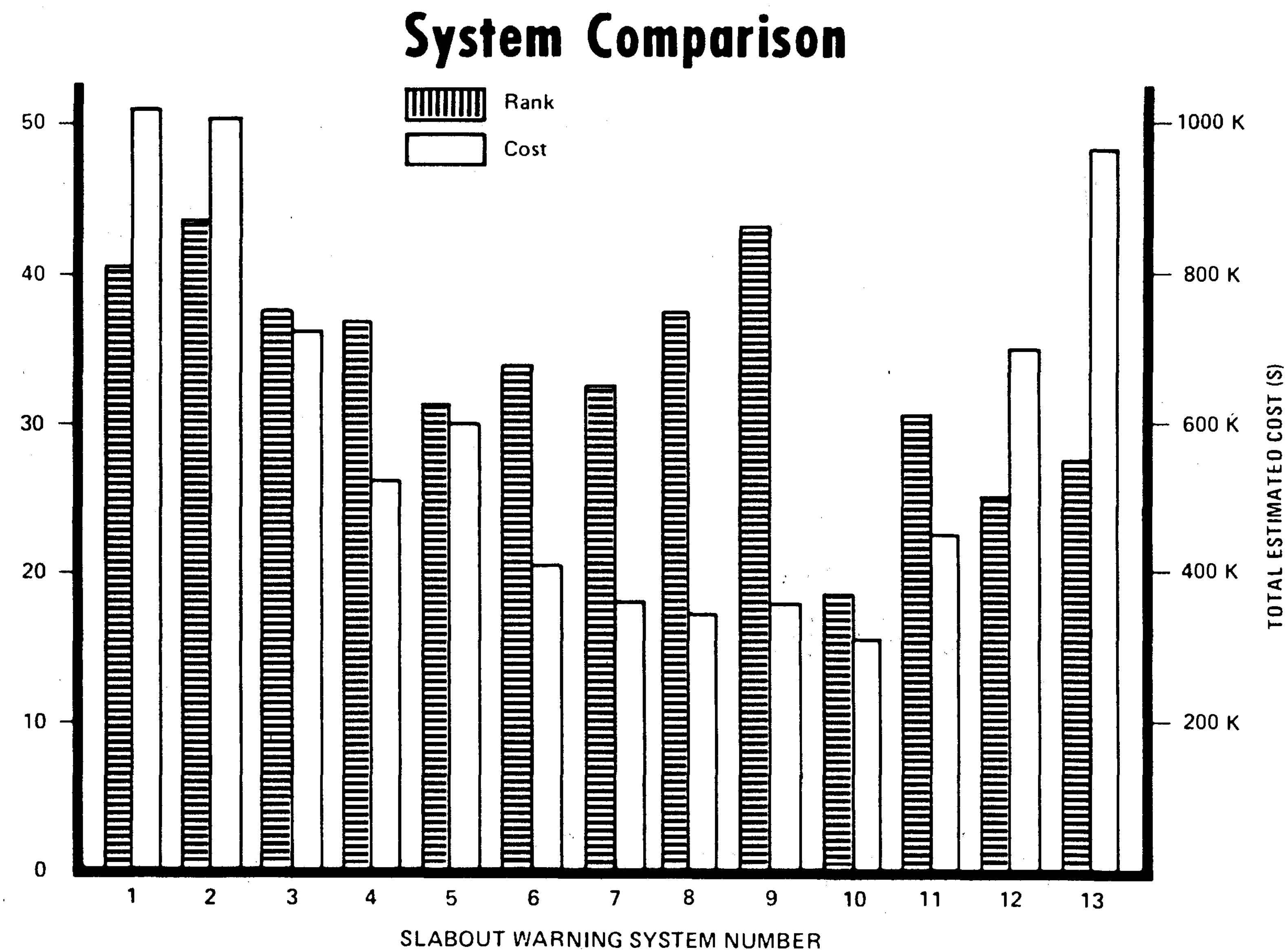


Figure 8. Slabout Warning System Comparison

the expressway. The sensors reported by radios which would be powered off the batteries that operated the navigation hazard lights on the bridge. False alarms, reliability and upkeep costs plagued all the systems.

It was obvious to all of us that looking at how to handle the situation after the accident was not the best solution to the problem.

We then looked at three systems designed to reduce the probability of a tug/barge-bridge collision in what we called a Collision Avoidance System. These three systems are shown in Figure 9. We looked first at a vessel tracking system similar to what the Coast Guard is in the process of installing now in busy ports like Seattle, San Francisco, New Orleans, and New York. We then looked at a modified version of the vessel tracking system to make it a monitoring rather than a tracking system. This allowed us to eliminate the operator and to incorporate a computer which could be programmed to initiate an alert message when a tugboat approached too close to the bridge. In the last system, we added a Loran-C receiver to each tug and automatically retransmitted the Loran T.D.'s to a shore station. The specific Loran T.D.'s were compared with a predetermined unsafe set of Loran T.D.'s, to provide a warning of a possible collision situation. Knowing that the cause of almost all the previous accidents had been due to the irresponsibility of the tugboat crew, it was proposed that the crew be taken out of the loop and the system be entirely automatic. These three systems were analyzed and the comparisons shown in Figure 10. The conceptual Loran-C system appeared to be more effective and less costly than the radar systems. Figure 11 summarizes our findings in the initial study. We determined that a Slabout Warning System was feasible, however, it would be very costly. In addition, we were concerned about potential false alarms, system reliability and the cost of system maintenance. Therefore, we recommended that alternative solutions be considered. Specifically, we recommended that since the Loran-C system appeared to offer the best potential solution, that the Greater New Orleans Expressway Commission have the conceptual Loran-C system that we described, developed in more detail to make sure that it was a feasible alternative. We further felt that this should probably be done through the US Coast Guard and the Department of Transportation.

The GNOEC accepted our recommendations, but asked us to further develop the Loran-C conceptual system to establish and prove its feasibility. The GNOEC position was that before they would approach the US Coast Guard, they wanted to be able to hand the Coast Guard at least the preliminary

System Configurations

SYSTEM	TECHNIQUE	OPERATION
VESSEL TRACKING SYSTEM (VTS)	SURVEILLANCE RADAR	CONTINUOUS OPERATOR MONITOR OPERATOR-TUGBOAT COMMUNICATIONS
MODIFIED VTS	SURVEILLANCE RADAR WITH TUG BORNE RADAR BEACONS	COMPUTER WARNING OPERATOR-TUGBOAT COMMUNICATIONS
LORAN-C VESSEL POSITIONING SYSTEM	LORAN-C WITH TUG BORNE RETRANSMITTERS	COMPUTER WARNING OPERATOR-TUGBOAT COMMUNICATIONS

Figure 9. Collision Avoidance System Configurations

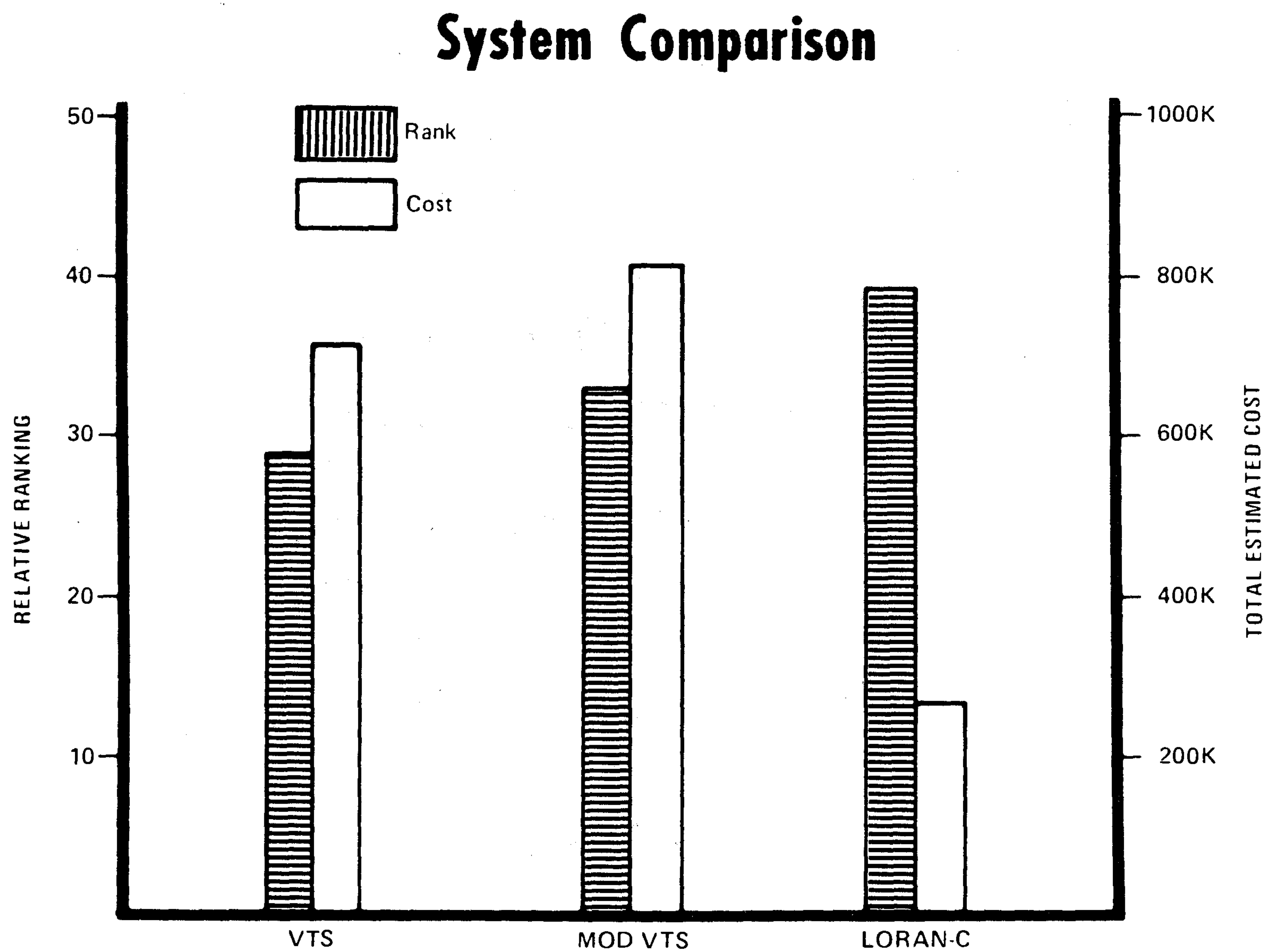


Figure 10. Collision Avoidance System Comparison

Findings

- SLABOUT WARNING SYSTEM
  - *Feasible*
  - *Costly*
  - *Consider Alternatives*
- COLLISION AVOIDANCE
  - *Practical Solution*
  - *Loran-C Appears Preferred*
- DEVELOP LORAN-C SYSTEM FURTHER
- DOT/U.S. COAST GUARD RESPONSIBILITY

Figure 11. Summary of Important Study Findings

design for a complete Loran-C Collision Avoidance System for Lake Pontchartrain.

We then performed a follow-on study to develop a Loran-C system design in sufficient detail to support the GNOEC in their efforts to get the US Coast Guard to establish a Loran-C Collision Avoidance System on Lake Pontchartrain. The study was to:

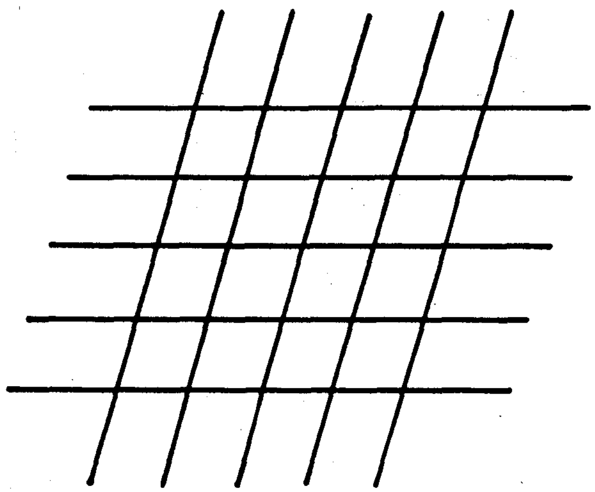
- o Define a Loran-C vessel positioning system to the degree necessary to prove the concept was workable.
- o Produce a system operational plan.
- o Define the necessary interface and computer program requirements to provide automatic warning.
- o Develop detailed cost data and a schedule for development and installation of a Loran-C system.

Driving the detailed design was the never relaxed, stringent requirement that the final system had to be fully automated. In the initial study it was found that past serious accidents were almost one hundred percent crew related, therefore it was essential that the Collision Avoidance System operate without crew involvement. We therefore fell back on a technique first pioneered by some of the people here at this convention, of automatically remoting the Loran T.D.'s to a central receiver. All data processing and responsibility for all required emergency actions would be placed at the central station.

The proposed system is based on using the Loran-C low frequency navigation system currently in operation along the coastal waters of the United States to monitor tugboat operations on Lake Pontchartrain. See Figure 12. The East Coast chain of Loran-C master and slave transmitters provide good coverage over Lake Pontchartrain and contiguous waters. The Gulf of Mexico chain, which will be operational in 1978, should provide alternate and even more accurate coverage over the Lake area. In a Loran accuracy test on Lake Pontchartrain, made by the US Coast Guard, 17 positional fixes were taken. All of them exceeded the accuracy requirements of the proposed Collision Avoidance System. The reliability of the Loran-C system, with dual chain coverage, effective in July of 1978, should be extremely high.

In 1972, the Secretary of Transportation designated the Loran-C as the preferred navigation system for use in the US coastal confluence zone in the National Plan for

Loran-C Low-Frequency Navigation System



- PONTCHARTRAIN COVERAGE EXISTS
  - *East Coast*
  - *Gulf Coast*
- MEETS ACCURACY REQUIREMENTS
- HIGHLY RELIABLE
- DOT DESIGNATED SYSTEM
- COMMERCIAL RECEIVERS AVAILABLE

Figure 12. Loran-C Low-Frequency Navigation System

Navigation (NPN).

So, there is Loran coverage in the problem area, with tested and verified accuracy, and soon to have redundant coverage. It is the designated navigation system for US Coastal Waterways and commercial receivers are available and should soon be available at a comparatively much lower cost.

This proposed system requires each particular tugboat, operating on Lake Pontchartrain, to have a Loran-C receiver installed and functioning continuously while on the lake. The Loran positional data from this receiver would be coupled to a VHF marine transceiver and automatically transmitted to a central station. Figure 13 shows the functions and equipments required on a tugboat. A Loran-C receiver, a VHF transceiver, data converter and a klaxon are all that is required on a tugboat. The communications link between the tugboat and the central station would be a VHF radio marine transceiver similar to those already installed on the tugboats. All data would be transmitted in a digital format and in short burst messages. To keep within standard maritime services transceiver equipment requirements an Amplitude Modulation Frequency Shift Keyed (AM-FSK) method of transmission and reception will be used at a 300-bit-per-second data rate. This system can be made to operate on any commercial or government VHF marine channel. The communications link would function automatically, both on the tugboat and at the central station, and would not require operator attention.

Figure 14 shows the functions and equipments of the central station. The equipment consists of a Loran-C receiver and antenna, a converter unit connected to a VHF marine transceiver, a control unit, a computer, a display unit, a hard copy printer, and an audio alarm device. Additionally there is an external communication means from the central station to a Lake Pontchartrain safety watch, for bridge vehicle traffic monitoring. Central station would have two complete sets of equipment, one to serve as a backup.

In conjunction with the Loran-C system it was recommended that the 24 hour safety partol on the expressway, rather than a sensor activated Slabout Warning System be used to control vehicle traffic in the event of an emergency. The functions of the bridge monitor are shown in Figure 15. Since the safety zone was designated to give a minimum of 15 minutes warning of a potential collision, the central station operator would alert the safety patrol to proceed to the exact point to monitor both the tugboat and the vehicle traffic. A sensor activated Slabout Monitoring System provides after-the-fact information, whereas a Loran-C

Tugboat

EQUIPMENT

- *VHF Transceiver*
- *Loran-C Receiver*
- *Converter*
- *Klaxon, Speakers*

- **SYSTEM AUTOMATICALLY**
  - *Presents Loran TD's*
  - *Transmits ID and Loran TD's*
  - *Permits Continuous Tracking*
  - *Provides Klaxon, Verbal Warning*

- **OPERATOR/PILOT**
  - *Call In, Loran Working*
  - *Respond to Emergency Signals*

Figure 13. Tugboat Equipment and Functions

Central Station

EQUIPMENT

- *VHF Transceiver*
- *Loran Receiver*
- *Converter*
- *Control Unit*
- *Computer*
- *Displays*
- *Printer*
- *Antenna*
- *Audio Alarm*

- AUTOMATICALLY
  - *Calibrates Loran Signal Accuracy*
  - *Interrogates Tugs*
  - *Tracks Tug Location*
  - *Generates Alarm*
  - *Provides Emergency Instructions*
- OPERATOR
  - *Monitors Entry*
  - *Communicates with Tug Pilot*
  - *Executes Emergency Procedures*

Figure 14. Central Station Equipments and Functions

Bridge Monitor

- RECEIVES EMERGENCY WARNING
- PROCEEDS TO POTENTIAL IMPACT POINT
- MONITORS TUGBOAT
- STOPS TRAFFIC IF REQUIRED

Figure 15. Functions of the Lake Pontchartrain Bridge Monitor

system could provide fifteen minute before the fact information.

Figure 16 is a schematic of the Lake Pontchartrain area, including the expressway, the warning zone around the expressway and the Loran coverage from the east coast chain.

Upon entering the lake, the tugboat captain would advise the central station by radio that he was initiating operations on the lake. Upon verifications from the central station that his Loran receiver was operating satisfactorily, he would proceed on his way. No further communications to the central station would be required from the tugboat.

The Loran positional data from the tug together with the tugboat ID number would be periodically transmitted back to the central station. This positional data would be compared with Loran map-coordinate data through the central station computer and, simultaneously, the tugboat's position compared with the warning zone coordinates. This process is accomplished entirely within the computer nearly instantly upon receipt of the data.

Since tugboats travel at approximately 5 knots, their positions need not be updated very often. It is proposed that the central station computer interrogate each tugboat on the lake once every three minutes until an emergency situation developed. Then the offending tug would be interrogated and his position updated every 10 seconds.

A predetermined warning barrier surrounding the expressway would be established and set in the central station computer. This warning zone, if set one-and-a-half miles on each side of the expressway, would provide approximately 15 minutes of warning time.

In the example depicted in Figure 16, tugboat number 21 has just entered the lake from the east entrance and tugboat 9 is about to cross under the north passage of the expressway. Tugboat 37 appears to be off course and is about to intrude into the warning area. The central station display is shown in Figure 17, with normal operation shown on the left and a hypothetical alerting condition shown on the right.

In emergency alerting conditions an audio altering device sounds in the central station until the person on duty responds and acknowledges that he is performing the emergency action instructions displayed. It should be noted that the person on duty need not monitor the normal display and needs to respond only to the emergency alert condition.

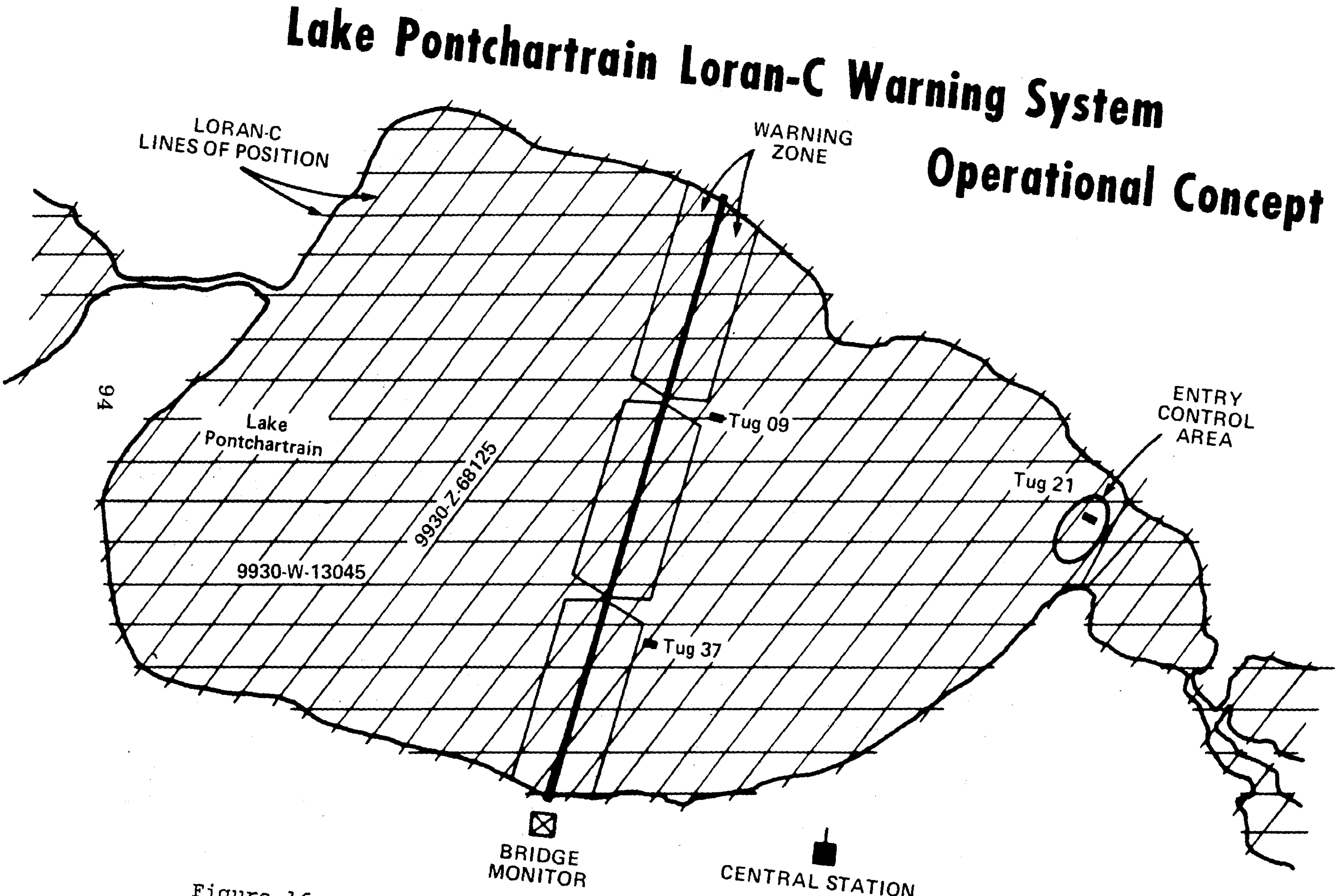
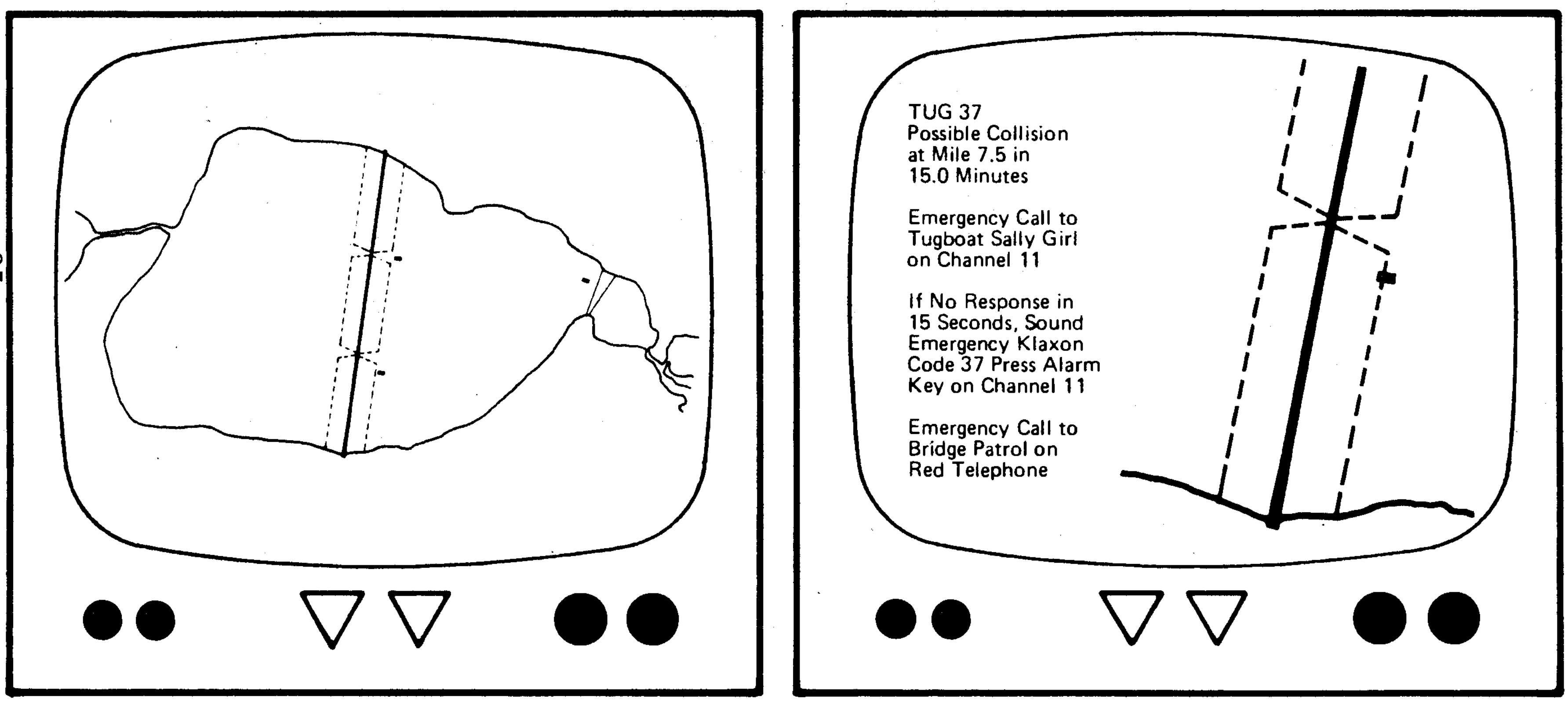


Figure 16. Lake Pontchartrain Loran-C Warning System Operational Concept

Central Station Display



NORMAL OPERATION

EMERGENCY ALERTING CONDITION

Figure 17. Central Station Display

Should a tugboat intrude the warning zone, such as illustrated by Tugboat No. 37, the duty person's first action is to attempt communication with the tugboat by VHF radio. If he does not obtain an immediate response, he then activates a remotely controlled klaxon alarm on the tugboat and at the same time alerts the traffic controller of the possibility of a collision so that a vehicle could be immediately dispatched to the location of the possible collision site. A bridge safety officer in the vehicle, upon arrival at the designated site, would be prepared to stop expressway vehicular traffic before a potential bridge-tugboat/barge collision could occur.

If the tugboat pilot, or another crew member, responds to the klaxon call and alters the tugboat course away from a possible collision, the duty person can cancel the emergency condition.

The central station equipment would include a hard-copy printer to make a record or log of important events. The log would contain time/date, tugboat identity and location where it first entered the lake, and could record each time it crossed under the expressway. In an emergency, a record would be made of all the events and actions performed by the operator and tugboat positions would be updated and recorded every ten seconds.

A complete block diagram of the system is shown here in Figure 18. The equipment to the left is that which is installed in a tugboat while the equipment to the right is the equipment installed in the central station. The dotted block titled "converter" is the digital communication interface unit. The unit stores the digitized Loran TD's in the data buffer and, when commanded by a message from the central station, formats the data in frequency shift tones for transmission over the voice channel of the VHF transceiver. The rate of transmission is controlled and synchronized by the local clock. In similar manner, the unit receives, demodulates and sorts out received transmissions and acts upon command messages directed to its particular code number.

Figure 19 lists the important findings of the detailed concept investigation. The results of the Coast Guard calibration tests of Loran-C coverage of Lake Pontchartrain proved conclusively that the accuracy and signal coverage is more than adequate for this system operation. Discussions with equipment manufacturers and government and private laboratory technical personnel including US Coast Guard engineers concurred that there was no technical problem with such a concept.

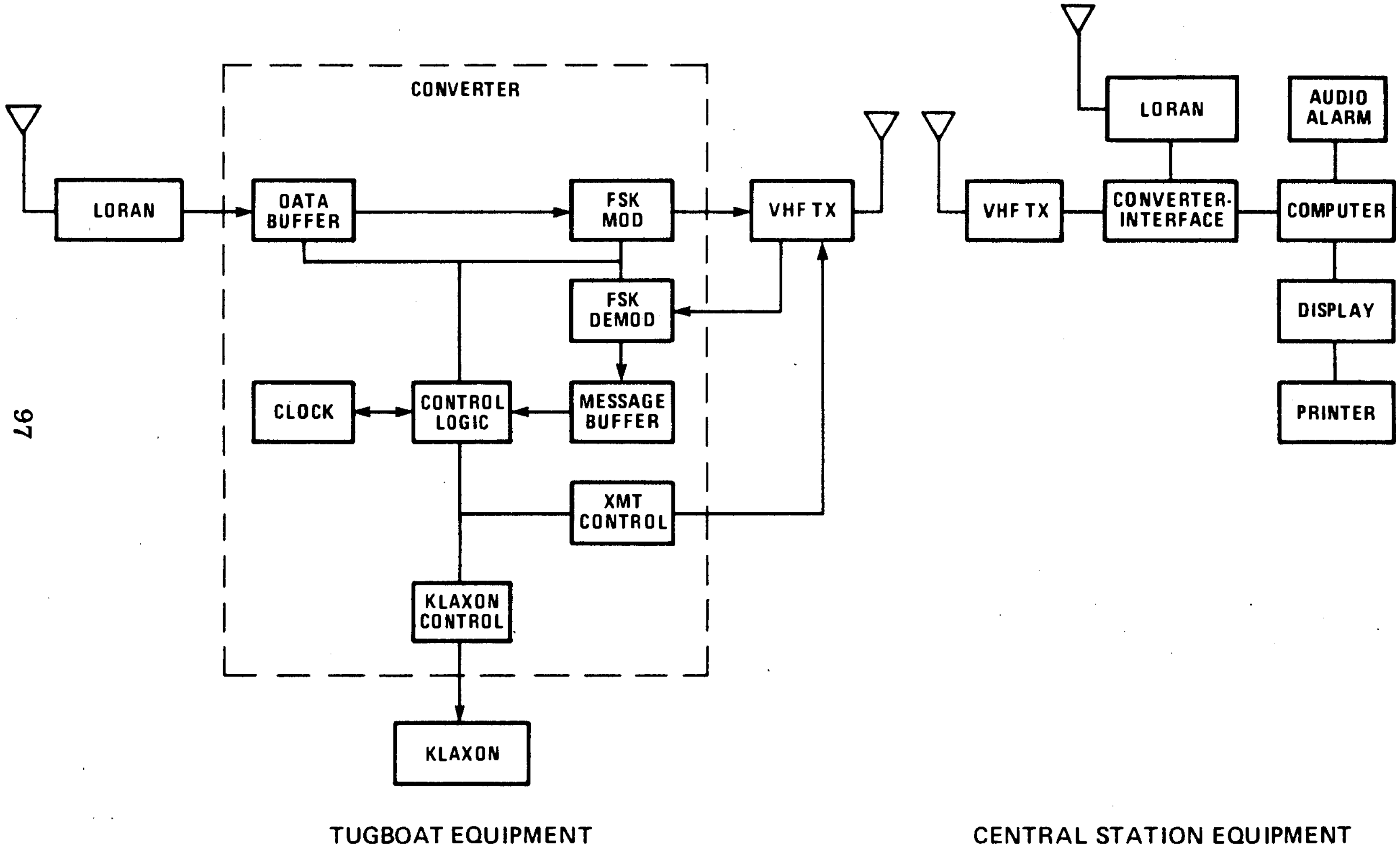


Figure 18. System Block Diagram

Study Findings

- LORAN-C SYSTEM IS FEASIBLE
- ESTABLISHMENT OF A LORAN-C WARNING SYSTEM WOULD GREATLY REDUCE THE PROBABILITY OF TUG/BRIDGE COLLISIONS
- LORAN-C SUPPLEMENTED WITH PERSONNEL MONITORING WOULD REDUCE PROBABILITY OF "VEHICLE-OFF" ACCIDENTS TO NEAR ZERO
- U.S. COAST GUARD IS LOGICAL AGENCY TO IMPLEMENT AND OPERATE
- LORAN-C EQUIPPED TUGBOATS COULD BE MORE READILY ASSISTED OR USED IN AN EMERGENCY IN NEW ORLEANS VTS AREA

Figure 19. Final Study Findings

Our own analysis shows that the probability of future tug/bridge collisions would be reduced drastically if such a warning system were to be installed and the operating procedures were strictly enforced.

Because the US Coast Guard has authority over water hazard monitors and safety enforcement, they are the logical governmental agency to implement and operate the system. Additionally, the Coast Guard operates at least three 24 hour manned centers in the New Orleans area where the system could be installed.

Finally, implementation of such a tugboat positional system could be advantageous for response in an emergency either to help a tugboat in distress or aid another vessel in distress anywhere on the Lake or in the New Orleans VTS area.

The Loran-C Collision Avoidance system which we designed, has been accepted by the Greater New Orleans Expressway Commission. The system design and operational concept have been turned over to the US Coast Guard through the Senators and Congressmen from the state of Louisiana. The US Coast Guard has been requested to implement the system and Congress has approved the line item with an initial budget of $100,000 in the FY78 budget for this system implementation.

THE U.S. LORAN-A COMMUNITY AND ITS PLANS FOR LORAN-C

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From 1 July 1976 - 30 June 1977 Oregon State University conducted a research project entitled "Termination of Loran-A: An Evaluation of Alternative Policies" through the Sea Grant Program with funds provided by the U. S. Coast Guard. The project analyzed problems associated with termination of Loran-A service and expansion of Loran-C service in U. S. coastal waters.

A major task of the project was to collect data on who uses Loran-A, where they are located, the economic and safety value of Loran-A to their marine operations, their plans with respect to Loran-C, and the problems and needs with which the navigational change will confront them. Information on Loran-A users was not previously known and was difficult to compile. Three factors in particular contributed to this lack of information: (1) Loran sets are not licensed, (2) a wide assortment of U. S., foreign, and World War II surplus sets are in use, and (3) the life expectancy of Loran receivers is highly variable. This paper summarizes the results of the various user surveys that we conducted.

Methodology

For the purposes of the study, civilian marine Loran-A users in the United States were split into the following groups: commercial fishing, commercial sportfishing, merchant marine, tug and towboat industry, offshore petroleum service vessel industry, and marine recreation. A Loran-A user is defined here as a vessel which is equipped with one or more Loran-A receivers.

Different sampling techniques were selected to collect data from the major user groups according to composition, size, and accessibility of the group. In the case of commercial fishing, field interviews with knowledgeable industry members and observers provided the basic data. For marine commercial sportfishing, a telephone questionnaire was used. The merchant marine, tug and towboat, and offshore petroleum service vessel industries were sampled with a mailed questionnaire followed by telephone interviews with a random sample of non-respondents. Indirect sources provided some of the data on marine recreation, but most data were collected by a mailed questionnaire sent to a sample of recreational boaters who were known to have purchased Loran-A receivers. Just under 2100 Loran-A users were sampled from the six groups.

The project investigators recognized the hazard of double-counting and did their best to avoid it. That is, an ocean-going tug may also operate in the offshore petroleum service industry, a recreational vessel may charter or fish commercially on occasion, and a commercial fishing boat may participate in several different fisheries in different geographic regions in the course of a year.

To the best of our abilities, we assigned a Loran-A user to that group which represented his major marine activity and the user was counted only once.

Results

Number of Loran-A Users

Table 1 presents the estimated number of U. S. civilian marine Loran-A users. By far the largest group of Loran-A users is marine recreation. Another very large group is commercial fishing. Even though the number of Loran-A users in the other groups is smaller, the economic size of many of the individual vessels in these groups is considerable.

Table 1. Estimated Number of U. S. Civilian

Marine Loran-A Users

User group	Estimated no. of Loran-A users (rounded to nearest hundred)
Commercial fishing	15,000
Marine commercial sportfishing	1,800
Merchant marine	500
Tug and towboat industry	300
Offshore petroleum service vessel industry	600
Marine recreation	32,000
Other Loran-A users	500
Total	50,700

Location of Loran-A Users

In the commercial fishing group, the distribution of Loran-A users is approximately as follows: 6000 West coast, 4700 East coast, 3500 Gulf coast, and 1200 Alaska. By contrast, in the commercial sportfishing group the largest number, 970, occurs on the East coast, and there are 570 Loran-A users on the West coast, 310 on the Gulf coast, and virtually none in Alaska.

In commercial transportation--merchant marine, tug and towboat, and offshore petroleum service industry--the vessels are highly mobile, and many operate overseas at least part of the time. For instance, less than one-third of U. S. flag merchant marine vessels operate exclusively in domestic trade. Still there are some trends within this category: there are more Loran-A equipped tugboats operating along the East and Gulf coasts (193) than along the West coast (51), and over half of the offshore petroleum service fleet operates in the Gulf of Mexico.

Little is known quantitatively about the geographic distribution of Loran-A users in marine recreation. There are very few in Alaska, but substantial numbers occur on the West, Gulf, and East coasts.

Plans for Loran-C

For the remainder of this paper commercial fishing and commercial sportfishing are combined into a category called "commercial fishing", and merchant marine, tug and towboat, and offshore petroleum service industry are combined into a category called "commercial transportation".

Table 2 shows whether Loran-A users plan to switch to Loran-C. Most users find Loran-A very valuable and intend to switch.

Table 2. Users Who Intend to Switch to Loran-C

User Category	%		
	Yes	No	Don't Know
Commercial Fishing	94	1	5
Commercial Transportation	72	22	6
Marine Recreation	53	15	32

Essentially all commercial fishermen plan to switch to Loran-C. Most commercial transportation users intend to switch; some of those who are not switching expect to dispose of the vessel or switch to satellite or Omega navigation. Loran is less essential to recreational users. Only half are sure that they will switch and many others are uncertain.

The largest number of Loran-A users who are going to switch plan to do so within six months of Loran-A termination (see Table 3). Commercial fishermen plan to switch earlier than other users; half plan to switch more than six months before Loran-A termination. By contrast, recreational boaters expect to switch later. It is noteworthy that over one-fifth of both commercial transportation and recreational users are still uncertain of their plans.

Table 3. When Users Intend to Switch

User Category	%			
	Early	Near Termination ($\pm$ 6 mo.)	Late	Don't Know
Commercial Fishing	50	37	9	4
Commercial Transportation	24	55	0	21
Marine Recreation	11	56	10	23

Loran-A users intend to use a wide variety of Loran-C sets (see Table 4). Most expect either to buy a fully automatic set or to use a reciever which is already owned, by switching an A/C combination set to the C mode or by sending a Loran-A set to the factory for conversion.

Table 4. Kind of Loran-C Sets Users Intend to Buy

User Category	%				
	Fully Automatic	A/C Combination	Manual C	A/C or Convert A Set (Presently Owned)	Don't Know
Commercial Fishing	35	15	15	38	2
Commercial Transportation	49	7	2	38	4
Marine Recreation	38	2	5	32	23

Commercial transportation users will buy fully automatic receivers. A large number already have A/C combination sets which they plan to gradually replace with fully automatic sets as their A/C sets wear out, unless government regulation forces an earlier switch. Among commercial fishing and recreational users, as many intend to use presently owned A/C combination sets or convert Loran-A sets as there are that intend to buy fully automatic receivers.

Problems Expected

The major concern of Loran-A users is the cost of buying a new receiver and of retiring an old set before the end of its useful life. Other major concerns, which vary to some extent among user groups, include availability of receivers and charts, conversion of Loran-A coordinates to Loran-C, and training of personnel.

Less commonly mentioned problems are:
--selection of proper Loran-C receiver,

--correct installation of Loran-C receiver,

--availability of competent repair and maintenance service,

--uncertainty as to tax and financial treatment pertinent to the Loran conversion, and

--general and widespread misinformation and lack of information on all aspects of Loran-C implementation.

Some Apparent Anomalies

1. Loran-A is old, yet to a user in the western Gulf of Mexico, where service started in 1968, Loran-A is relatively new.

2. Loran-A is less accurate than Loran-C, yet many Loran-A users can and regularly do obtain navigational accuracies far in excess of those advertised for the system. Loran-C has been advertised as a superior system. Users expect Loran-C to be superior to Loran-A results they actually obtain rather than just superior to advertised values.

3. To many users, Loran-A is known whereas Loran-C is unknown. Loran-A is familiar and functional. Conversion to Loran-C represents a profound change similar to conversion from the English to metric system of measurement or to switching from driving on the right-hand side of the road to driving on the left-hand side.

4. Loran-C will provide greatly expanded coverage, but some areas which are presently covered by Loran-A, like the Caribbean, will lose coverage.

5. Even though it is now well over three years since the Secretary of Transportation announced that Loran-C had been selected as the government-provided radionavigation system for U. S. coastal waters, the Loran-A community has continued to grow, a trend which is continuing even in the current year.

Summary

The community of U. S. Loran-A users is large and it is diversified in its marine activities. Loran-A users are also generally satisfied with the quality of navigational service they have been receiving.

Most Loran-A users are resigned to the change to Loran-C. Some are enthusiastic, a few are opposed. Nonetheless, Loran-A users have high expectations for Loran-C.

Users value Loran service highly, and therefore 77-98% of Loran-A users in the various groups who have made a decision plan to switch to Loran-C. Many users, however, plan to delay their switch until near the time of Loran-A termination, and the types of Loran-C receivers they plan to use are inconsistent with the navigational results they expect.

If the burdens of conversion can be reduced, the transition to Loran-C will be smoother and more constructive, and the Loran-C system can come to serve U. S. mariners well.

Acknowledgments

I wish to acknowledge the contributions of my colleagues to the project from which this paper is derived. My co-investigators were Rebecca S. Roberts and R. Charles Vars, Jr. Ms. Roberts conducted the surveys for the merchant marine, tug and towboat, and offshore petroleum service vessel industries. In addition, I wish to acknowledge Michael B. Fraser, James A. Henderson, and John F. McManus, graduate students in the Marine Resource Management program of the School of Oceanography at Oregon State University, who conducted the commercial sportfishing survey. The project was conducted through the Oregon State University Sea Grant College Program under the support of NOAA Office of Sea Grant, U. S. Department of Commerce, Grant Number 04-6-158-44094, with funds provided by the U. S. Coast Guard.

LORAN-C CHAIN IMPROVEMENTS

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ABSTRACT

In 1973 the Coast Guard commenced an ambitious program to improve the hardware and operational capabilities of existing Loran-C transmitting and control monitor stations. These improvements included programs entitled: LRE, CALOC, ICR, CGLC comms, and others.

The East Coast Loran-C Chain has been directly involved in all of these programs while performing operational test and evaluation (O. T. & E.) of the hardware/software packages. All of these improvements will eventually be applied to existing and new Loran-C Chains.

The hardware/software improvements have resulted in corresponding improvements to operational parameters, i.e., reduced unusable service time and better signal stability. With the new equipments and improved training for Loran-C station personnel, a relizable goal of 99.9% usable service time has arrived. Addition of improved electrical power sources and intra-chain communication systems should reduce unscheduled unusable service time on any baseline to less than 60 minutes/year, or more simply stated, Loran-C of the 1980's will be a 99.99% available system.

INTRODUCTION

In 1973 the Coast Guard began an ambitious program to improve the operational performance of the Loran-C system while simultaneously reducing manning levels and equipment operating costs.[1] These improvements were in direct response to the Department of Transportation's[2] selection of the Loran-C system of navigation to serve the coastal confluence zone (CCZ). When the official decision to use Loran-C as the prime radio navigation aid in the CCZ was announced in May, 1974, the East Coast Loran-C Chain (ECLC) was already being retrofitted with new Coast Guard designed, and commercial (off-the-shelf) equipment. The West Coast, Gulf of Alaska, Gulf of Mexico and existing overseas Loran-C chains were all scheduled to receive the new improved timing and control equipment, as stations were built, or equipment became available for retrofits. In addition, the West Coat and Gulf of Alaska chains were outfitted with improved versions of the AN/FPN-44 Loran transmitter. The Gulf of Mexico Chain, or the Southeast U. S. (SEUS) Chain as it is now designated, will utilize solid state Loran transmitters (SSX). Existing tube type (hollow state) transmitters throughout the world are undergoing various modifications to improve their reliability and reduce maintenance. Let us take a look at the system operational improvements to the existing East Coast Loran-C Chain, which, if not already installed, will be added to all Loran-C chains in the near future:

EQUIPMENT IMPROVEMENTS

(1) LORAN REPLACEMENT EQUIPMENT (LRE)

The LRE Program was well reported[1] by Messrs. Goodman and Oswitt during during the ION national marine meeting in October, 1975, so I will only try to convey what this equipment has meant to the Loran-C user and loran station operation. In a later section of this paper, statistics will be provided in an effort to show the improvement from a "user's viewpoint".

LRE provided loran stations with the following improvements:

a. PHASE MICROSTEPPER - This device provides a degree of control a magnitude greater than the specified stability of the output frequency of cesium oscillators, which are in fact the base or heart of the Loran-C system. Cesium oscillators were introduced to Loran-C in the late 1960's and have settability to parts in 10^{12} ($\approx$200 ns/day) frequency offset with respect to another cesium (HP-5061A), NBS or NAVOBS. The phase microstepper allows us to control the long term frequency offset to parts in 10^{13} ($\approx$20 ns/day).

b. TIMING EQUIPMENT Coast Guard designed AN/FPN-54 timer sets introduced solid state (TTL) timing equipment which is highly reliable and is capable of accepting various control commands from a remote site. The timers are completly digital, and are modular in design (board level replacement at Loran Stations) to permit rapid repair with a minimum requirement for test equipment or technical expertise on the part of Loran Station personnel.

c. PULSE GENERATORS - TRANSMITTER CONTROL - Once again, this is Coast Guard designed solid state equipment, modular, with board level replacement. The pulse generators provide excellent control for building a driving waveform to any of the existing hard tube "hollow state", transmitters. The transmitter control set together with modifications to the transmitters (amplifiers), provides automatic and/or remote switching of the transmitters.

d. ELECTRICAL PULSE ANALYZER (EPA) - The EPA provides "BITE" for control of the radiated pulse shape, power output level and Envelope to Cycle Difference (ECD) measurement. This section of LRE is most responsible for all Loran-C stations throughout the world being able to radiate the standard $t^2e^{-2t/65}$ (tee squared) pulse shape. Operational requirements are; stations to maintain a RMS error from 0-65 us (leading edge) of the radiated pulse to less than 2% rms when compared to a "tee squared" pulse. We find this requirement fairly easy to maintain without a significant increase in transmitter maintenance. For the users this translates to identical (or nearly so) pulse shapes when using different stations or chains, something that was not insured prior to LRE. In addition, accurate measurement of ECD provides a means whereby this parameter can be maintained constant. With ECD closely controlled (and minimized throughout the service area), receiver "cycle slip" or 10 us jumps have been greatly reduced. A manufacturer can align his receivers in the factory with much more confidence that they will not have to be individually "tweeked" upon installation in the field.

e. REMOTE CONTROL INTERFACE - STATUS ALARM UNIT - These two units do not directly improve service to the user, however, they do reduce manning levels on stations through automation/remote control. In turn, this provides an improvement to users as personnel errors are reduced, resulting in improved service time. Personnel errors will be covered in detail later in this paper.

(2) CALCULATOR ASSISTED LORAN CONTROLLER (CALOC)

The Calculator Assisted Loran Controller (CALOC) is a computer program which, together with a desk top calculator and various hardware peripherals, can be installed at a Loran-C time difference control station.[3]

This system has been in use for control of three baselines of the ECLC for the last two years, and is presently being installed in the WCLC.

CALOC was designed to relieve the control station operator of many tedious, routine tasks, and to perform several mathematically-based operations, which a computer can generally perform better than a human being.

CALOC performs three major tasks: time difference (TD) control, abnormality detection and recordkeeping.

a. TD CONTROL - The precise phase TD of the Loran-C signal fluctuates due to oscillator activity, transmitting station variations and propagation effects. Under normal conditions, the received signal at the TD control station is masked by received noise, and the controller must evaluate correctly all the information available prior to inserting timing adjustments in a baseline. It is, however, difficult for a human being to properly, and consistently, weight all the various competing factors that must be considered when deciding upon a timing adjustment. Therefore, the most important function of CALOC is to quantify the process of observing the received TD behavior and choosing an optimum timing correction when necessary, to keep the baseline as close as possible to the desired control number.

The operator can choose to implement or ignore CALOC's recommendations depending upon any other information which may be available to him. It is important to note that this TD control task operates on the past record of the TD, and hence a large abnormality, presumably caused by an equipment malfunction in the system, could contaminate CALOC's internal data. Thus, the control task must be inhibited from monitoring the signal, and recommending timing adjustments, during periods of signal abnormality; after an abnormality is corrected, CALOC must purge its data files before it can resume control.

b. Abnormality Detection - An equipment casualty at either the master or the secondary transmitting station can cause a sudden excursion, or abnormal behavior, in the received phase TD. Since CALOC cannot possibly anticipate the symptoms of, and corrections for, all possible system casualities, it simply inhibits control task operation on a baseline when it finds that baseline abnormal. At the same time, CALOC notifies the human operator of the abnormal condition, and then relies upon him to correct it. When the operator is satisfied that the baseline is again normal, he returns control to CALOC.

To determine if a baseline is abnormal, CALOC uses a sophisticated, adaptive, statistical algorithm. The CALOC system, in the face of ever changing received noise power, continually evaluates the two hypotheses - baseline abnormal or baseline normal - while attempting to satisfy the conflicting goals of minimizing the time to detect and the probability of making an error. In this manner, CALOC relieves the human operator of the need for constant attention to his receiver displays and strip charts.

c. Record Keeping In the prosecution of its other two major tasks, CALOC generates many numerical values which are needed by the Coordinator of Chain Operations (COCO) for his management of the Loran-C system. Since these values can assist the TD control station personnel in the preparation of their operational messages, CALOC writes them onto a printer tape and drives a plotter to show exactly how the baselines under its control performed. By using the printer tape as the major portion of his log and the plotter output, which CALOC annotates with the day's major events, the operator is relieved of much of his record keeping burden. There is certain information to which the watchstander has access while CALOC has not; this data (e.g., start and stop blink on a baseline, a particular station on or off air) can be entered into the CALOC system by the operator. Using CALOC's calculator keyboard the operator informs CALOC of these conditions; CALOC then annotates its plot, makes a log (printer tape) entry, and tabulates the entry. At the close of the day's operation, 0000Z time, CALOC prints out a daily operation summary and updates certain monthly data files it maintains on a digital cassette tape.

(3) INVERSE REMOTE CONTROL INTERFACE (ICR)[4]

The ICR is a microprocessor based system designed to supplement the CALOC system and further relieve a watchstander of many routine and tedious tasks. The ICR does not completely remove all watchstanders from the control station, instead it aids the watchstander and allows him to focus on more important tasks.

ICR performs three major functions: automatic code conversion between the CALOC system and transmitting stations RCI's, transmission of the converted codes with error checking on the retransmission of the code from the RCI, and a collection of all CALOC and RCI system controls on one centrally located control panel.

As previously stated, CALOC provides recommendations to a watchstander whenever a Local Phase Adjustment (LPA) is required. ICR provides a data transfer interface between CALOC and RCI which can be operated in three modes: manual, semi-automatic and automatic. The manual mode is operator-initiated and a command is entered and executed from the front panel of the ICR. In this mode the operator is relieved of typing the RCI control message on the teletype and he simply pushes two or three buttons to initiate the RCI control message. In the semi-automatic and automatic modes, the recommendations from CALOC initiate the sequence. With the ICR placed in semi-automatic the CALOC recommendations are displayed on the front panel of the ICR. The watchstander is summoned and he makes a "GO-NO-GO" decision (executes or cancels the recommendation). The automatic mode allows CALOC's recommendation to be executed automatically without watchstander intervention.

In all three cases, the activated RCI will retransmit the code on the teletype after a valid message is received. This is done so that the message can be checked for errors before execution. The ICR then verifies the transmitted and received codes agree and finally sends the execution character. After this sequence is completed, ICR sends a message to CALOC in order that CALOC may maintain its records.

ICR was installed at Loran Monitor Station Bermuda, UK during May, 1977 and has been continually operated in the automatic mode since installation. There have been two hardware failures resulting in loss of the automatic mode for short periods while awaiting parts (approx. six days). Since installation at LMS Bermuda, ICR has been interfaced with CALOC on the M-W, M-X and M-Y baselines of the ECLC, and has initiated in excess of 5000 error free commands.

Additionally, LMS Bermuda has cut their watchstanding level from two to one man per watch. As an comparison, the error rate for manually inserted commands in the ECLC has been one per 60 control messages, with one per 800 actually being entered into RCI requiring an additional command to remove the erroneous command. Erroneous commands have resulted in over 200 minutes of unusable time during the last three years of ECLC operation, while ICR has been error free.

(4) COMMUNICATIONS IMPROVEMENTS

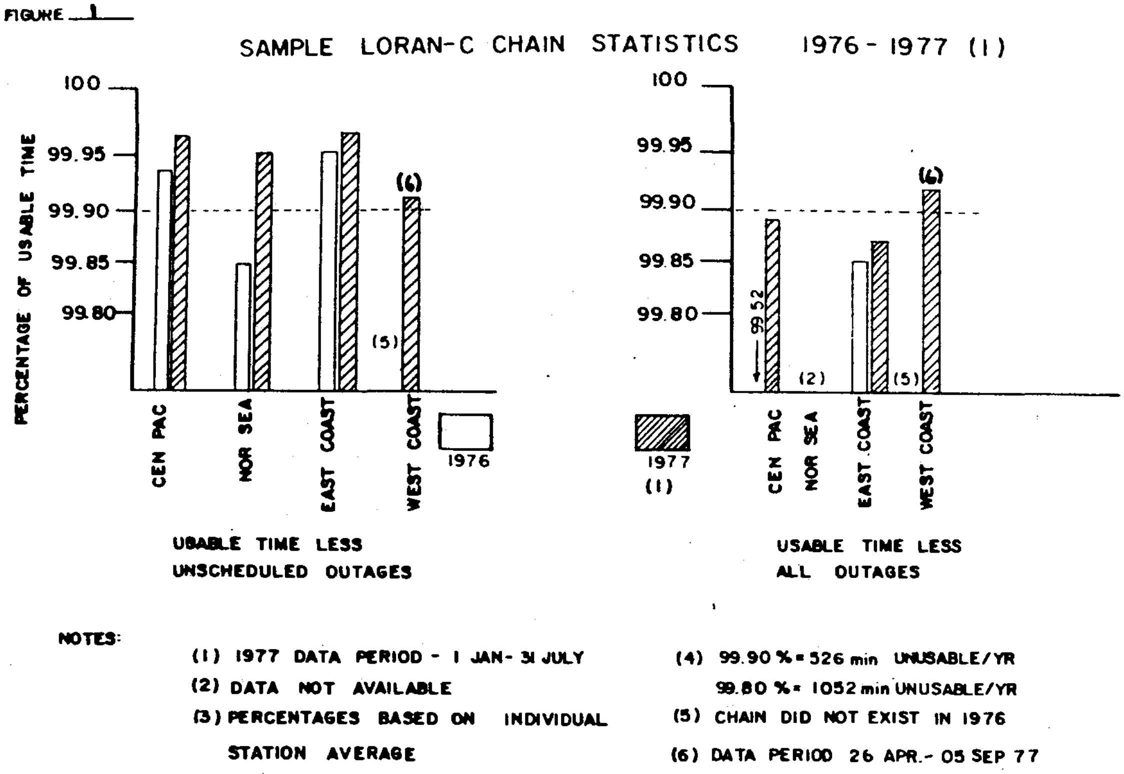
Reliable communications has been, and always will be, the heart of a Loran-C system. Keeping this in mind, the Coast Guard has made several improvements to existing communication systems in addition to developing a new Loran-C Comms system.

The Coast Guard two pulse Loran-C Communications System (CGLC)[5] provides a low data rate intra-chain communication system through pulse position modulation (PPM) of the Loran-C pulses. CGLC Comms can be used as the primary comms system for control message transfer, or as a back-up to teletype networks. The greatest advantage of CGLC comms over commercial teletype systems is that the entire CGLC system is self-contained on the Loran-C stations and does not require outside assistance from Western Union when circuit outages occur between stations, which is a common occurrence with most commercial TTY circuits. In addition to CGLC, Loran-C Chains are being outfitted with teletype hubbing repeaters and "stunt boxes" which provide remote switching or primary/alternate communications networks to insure a positive control link exists between transmitting and control stations at all times. These devices have been interfaced with CGLC/teletype in the WCLC and with SSB-RATT/teletype in the ECLC. Not only do these systems provide enhanced communications, it lessens the requirement for a watchstander to come on duty (at a transmitting station) everytime the primary control comms link is inoperative.

SYSTEM IMPROVEMENTS

(1) UNUSABLE TIME - The most dramatic improvement in Loran-C Operations which is most obvious to the Loran-C user, is reduced unusable service time. Figure one depicts recent percentages of usable time for four Loran-C chains: Central Pacific, Norweigen Sea, East Coat and West Coast USA.

FIGURE 1



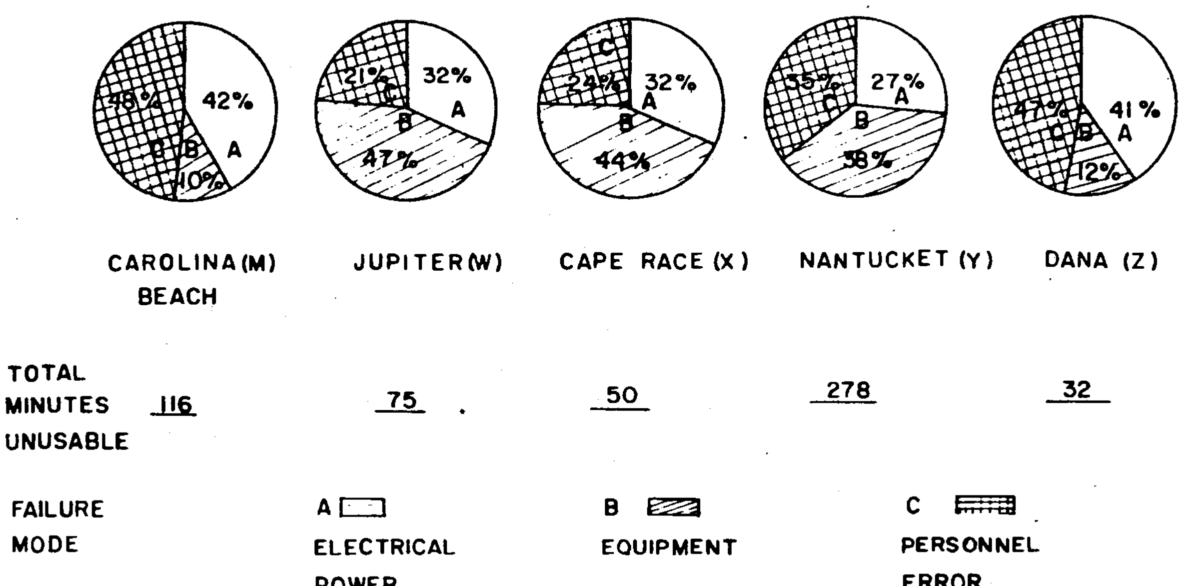
As can be seen in figure one, these chains which represent two, three and four secondary stations operation, are all exceeding 99.9% operation based upon individual station performance (less scheduled down time for maintenance). Considering the scheduled maintenance time, the figure is approaching 99.9% and will most probably exceed that figure for calendar year 1977. These are very impressive figures, however, they become even more impressive when one considers prior to 1974 (before LRE), the average availability of individual stations ranged from a low of 98.2% to 99.8%. A station exceeding 99.7% usable time during a year was considered to be performing in an outstanding manner. We now consider 99.9% (or greater) an acceptable figure. Not evident in these figures is the reduction in occurrences of unusable time or Mean Time Between Failure (MFBF). One paper[6] recently circulated in the Loran-C community reported MTBF's ranging from 3.5 to 79.7 days during 1974 and 1975. I personally take issue with these figures due to method of reporting outage times upon which they were based, and submit the actual MTBF figures were closer to 1.5 - 12 days[7,8]. Presently, the sample Loran-C chains shown in Figure One are operating with a MTBF of 10.5 days when considering all unusable time, and 16.7 days if authorized unusable (scheduled outages) time is removed from the totals. The Mean Time to Repair (MTTR) shown in the aforementioned paper of 68-134 minutes, is also questioned. Using the ECLC as a sample, the 1975-76 figures indicate a MTTR of 35 minutes including authorized unusable time, and a very acceptable 9.9 minutes if authorized unusable time is discounted. The ECLC had a two-year total of 348 events of unusable time which exceeded one minute during 1975-76. With a five station chain, this is 2.9 events per station, per month, included scheduled outages.

Why do Loran-C Chains incur unusable time? Figure two is a breakdown of the ECLC's unauthorized unusable time for the period 1 July 76 - 30 June 77 and is felt to be representative of most Loran-C chains present operation.

FIGURE 2

EAST COAST LORAN-C CHAIN UNUSABLE TIME BY FAILURE MODE

PERIOD JULY '76 - JUNE '77



As one can readily observe, the two dominant factors for unusable time are; failure of electrical power, and personnel (ET failure) errors. Electrical power failures are self-explanatory whereas "ET Failure" runs the gamut from the control station entering improper commands to transmitting stations "pulling the wrong cable". However, we have real hope for the system as figure three is a breakdown by failure mode and totals, over a two year period which indicates our power problems are becoming a "bigger slice of the pie", as are personnel failures. At the same time, equipment failures are becoming less and less a problem and, more importantly, the total unusable time is being greatly reduced. The figures might mislead one to think our training programs are not adequate. Not true! Although the percentage of failure due to "ET Failure" has risen, the total time attributed to personnel error and equipment failure has decreased markedly. Power failure remain fairly constant at 50 to 75 minutes per year, and has ranged up to 300 minutes per year. The power failure outage times can be reduced through No-Break (Jupiter) or auto-start systems such as are installed at Cape Race and Dana.

FIGURE 3

EAST COAST LORAN-C CHAIN UNUSABLE TIME BY FAILURE MODE IN % OF TOTAL

STATION	CAROLINA BEACH (M)		JUPITER (W)		CAPE RACE (X)		NANTUCKET (Y)		DANA (Z)	
FAILURE MODE	1975	1976-77	1975	1976-77	1975	1976-77	1975	1976-77	1975	1976-77
POWER	20	42	24	32	30	32	31	27	21	41
EQUIPMENT	34	10	40	47	56	44	55	38	55	12
PERSONNEL	46	48	36	21	14	24	14	35	24	47
1975 TOTAL MINUTES UNUSABLE (LESS AUTH)	621		329		817		403		194	
1976-77 TOTAL MINUTES UNUSABLE (LESS AUTH)	116		75		50		278		32	

(2) PULSE SHAPE - LRE provided all Loran-C stations with a common reference for pulse shape control, namely, the Electrical Pulse Analyzer (EPA). Using a calibrated reference waveform, all stations are equipped to match their output pulse shape against a "tee squared" pulse. Even with the EPA, the start of the pulse was left to subjective evaluation by the data taker, or the "guy operating the scope". We now have a statistical

device[9] called Loran Operation Information System (LOIS), developed by Coast Guard Activities, Europe. Using a curve fit routine comparing measured data against a "tee squared" pulse in a programmable calculator, stations can determine the percentage of RMS error of the leading edge of any pulse, and includes amount of error associated with each 1/2 cycle as compared to the reference pulse. LOIS provides a measure of ECD, which can be checked against a station's built-in ECD meter for comparison and/or verification. As previously stated, the maximum allowed RMS error is 2% on the leading edge of the pulse, with nominal values presently reported in various chains as: AN/FPN-44, 1%; AN/FPN-42 1.5%; AN/FPN-39, 1.8%. In addition to pulse shape, LOIS together with the EPA have "fine tuned" our envelope control eliminating Envelope Timing Adjustments (ETA's) by controlling stations. The combination of pulse shape and envelope timing improvements, result in reduced "cycle slip" for most receivers, and the ability to operate chain to chain without recalibration of a receiver due to pulse shape differences.

(3) SIGNAL STABILITY - An equally important parameter of Loran operation from the user's standpoint, as compared to loss of signal, is signal stability or repeatability. Figure four is a comparison of the predicted geometric fix errors at LMS Bermuda (ECLC) based upon standard information, i. e., crossing angles and standard deviation (one sigma) of 100 ns, versus two other "real world" methods utilized in the control monitor program.

PROBABLE GEOMETRIC FIX ERRORS EAST COAST LORAN-C CHAIN
AT LORAN MONITOR STATION BERMUDA, UK

PAIR	CROSSING ANGLES	2DRMS SIGMA= 100 ns	2DRMS SIGMA= DAILY SAMPLE	2DRMS SIGMA = SHORT TERM (T=370 MIN)
MW MX	68.2°	416.6 FT	12.2 FT	75.5 FT
MW MY	42.5°	629.8 FT	18.4 FT	85.9 FT
MX MY	25.7°	575.3 FT	17.4 FT	77.8 FT
		ADVERTISED STANDARD DEVIATION	ONE HOUR DAILY SAMPLE (LONG TERM OR ANNUAL STAT.)	AVERAGE DAILY NOISE TEST AN/FPN-46 TIMERS IN BW3

FIGURE 4

The 2drms (95%) values given in the second and third columns are indicative of what we are controlling to in the real world through the use of cesium oscillators, CALOC, LOIS, LRE and ICR. Stated simply, at LMS Bermuda the ECLC is repeatable to less than 90 feet. Although I do not have figures available, this is a reasonable figure for all Loran chains with comparable equipment (i.e., WCLC) at the monitor stations. Using the ECLC, various Coast Guard units and commercial users report repeatable accuracy of ±100 ns at locations ranging from Newfoundland to Cape Kennedy, and slightly higher (±150 ns) in the northeast Gulf of Mexico. CALOC provided a quantum reduction in the standard deviation of LMS Bermuda's received Loran signals as shown in figure five (long term averages).

FIGURE 5

EAST COAST LORAN-C CHAIN
SIGNAL STABILITY (CONTROL) ANALYSIS

	JUPITER (W)		CAPE RACE (X)		NANTUCKET (Y)	
	MEAN	SIGMA	MEAN	SIGMA	MEAN	SIGMA
BEFORE CALOC CONTROL- 1974	-7.0	56.0	+4.0	32.0	+3.0	30.0
AFTER CALOC CONTROL-1976-77	+1.4	3.2	+0.7	3.2	+0.5	3.1

(1) ALL FIGURES IN NANO SECONDS.
(2) MEAN IS BIAS (OFFSET) FROM CONTROLLING STANDARD TIME DELAY (CSTD) AT SYSTEM AREA MONITOR (CONTROL) STATION, DAILY AVERAGES.

We have in fact, reached the instrumental accuracy of present day monitor receivers. A statistical study conducted on the Mediterranean Sea Chain revealed the System Area Monitor (SAM), or Control Station, to be holding the baselines to $\leq |20|$ ns instrumental error with a 95% limit on TD sample of $<$ 35 ns. Throughout the Mediterranean Sea service area, the error was $<$40 ns rms (after removing SAM bias from CSTD) and was determined to be propagation variations[10]. The conclusion of the study was: "Loran-C equipment and operation have improved the synchronization and hence accuracy limits of the system to the point where they are largely bounded by physical constrains of propagation"...

(4) OSCILLATOR CONTROL - For the Rho-Rho user we have some interesting data in figure six. The frequency offset of secondary stations with respect to the master oscillator has been significantly reduced through addition of phase microsteppers, and, through statistical analysis of cesium behavior by the LOIS programs for oscillator control. For the hyperbolic user, the increase in the number of LPA's entered, (adjustments to maintain a

constant TD at a monitor station), from approximately 2-3 per day at 100 ns each under the old system of control, to the several per day with CALOC and LOIS can be transposed to an unadvertised tolerance of ± 20 ns. Because the magnitude of most LPA's are now 20 ns, very few Loran receivers can detect these small changes.

FIGURE 6 SECONDARY STATION OSCILLATOR CONTROL
EAST COAST-WEST COAST LORAN-C CHAINS
MAY-AUGUST 1977

STATION	WHISKEY		X-RAY		YANKEE	
CHAIN	ECLC	WCLC	ECLC	WCLC	ECLC	WCLC
AVERAGE NUMBER OF LPA'S/DAY	13	9	14	9	6	6
AVERAGE OFFSET/DAY (ns)	22	41	25	15	16	39

STATION WITH LEAST FREQ OFFSET
WCLC (X) 15ns/DAY = 1.7 X 10^{-13}

STATION WITH GREATEST FREQ OFFSET
WCLC (W) 41ns/DAY = 4.7 X 10^{-13}

TYPICAL CONTROL
26ns/DAY = 3 X 10^{-13}

SUMMARY

Through the use of new equipment and operational procedures, Loran-C chains have essentially reached their limit of repeatability. Some progress can be made in pulse shape stability and reduction of pulse to pulse phase modulation through transmitter modifications. However, the greatest benefit to the user would be further reduction in unusable time by: making improvements to electrical power sources (No-Break Systems?); continued emphasis on personnel training; and full automatic control of transmitting stations through use of a microprocessor based system which would include power, and control communications switching.

The views expressed are those of the author and do not necessarily represent those of the U. S. Coast Guard.

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OFF-SHORE CALIBRATION OF CANADIAN WEST COAST LORAN-C CHAIN

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R.M. Eaton
D.H. Gray

Canadian Hydrographic Service

ABSTRACT

The Canadian Hydrographic Service performed a calibration of the Canadian West Coast Loran-C chain from 1 to 350 km from shore, during the period March to June 1977 using Satnav and Trisponder for control to confirm Time of Arrivals to verify latticing of nautical charts. Chain performance was monitored by cycle selection tests on commercial hyperbolic receivers in addition to data from a USCG modified Austron 5000 receiver.

INTRODUCTION

The Canadian Hydrographic Service has the responsibility of making available the charts of navigable Canadian waters and of the approaches thereto. In certain instances and localities shipping is required by Canadian Law to have, maintain and use Canadian charts. Therefore, when it became apparent that the United States Coast Guard, with co-operation from the Canadian Ministry of Transport, were about to install a Loran C Chain to provide coverage for the Canadian West Coast, the Canadian Hydrographic Service took immediate interest. We had representatives reconnoitering the suitability of the Williams Lake area as early as the Spring of 1974. We provided technical advice to Transport Canada based on our experience with Loran-C. We also considered how we were going to calibrate the chain so we could accurately depict the latticing on the nautical charts.

The three West Coast chains (Gulf of Alaska, Canadian West Coast, and California) are a new breed of Loran-C chain in that some or all of the transmitters have been deliberately established inland to provide better geometry, better overall coverage and fewer transmitters. But this has been done at the expense of shorter ground wave range and greater uncertainty of line of position because of the phase errors caused by the intervening land segments around the transmitters.

To provide Loran-C latticed charts of the West Coast, we had to have knowledge of the "phase" of the transmissions, as opposed to the signal strength. The phase of the transmission is akin to the travel time of that transmission. It is known that the atmosphere slows the speed of radio waves by about three parts in a thousand and the ground (or sea water) over which the ground wave passes slows the transmission even more and in a non-linear fashion (Johler).

Differing electrical properties of that ground delay the transmission by significantly different amounts. Combinations of land and sea cause a delay greater than for an all sea-water path. This additional delay is known as Additional Secondary Factor (ASF) which can be as large as 8 micro seconds (See Fig. 1).

The calibration designed by the Canadian Hydrographic Service was to answer the following questions about the phase of Loran-C transmissions:

1) What electrical properties (conductivity and permittivity) can be assigned to the land segments?

2) What effect do the intervening mountains have, and how far from the coast does it extend?

3) Can Millington's Method (Bigelow) be used for the determination of Additional Secondary Factor (ASF) over composite land-sea paths or is a more complicated computation method required?

4) Can corrections be determined well enough so that the latticing be drawn to the shore or should it be cut off some distance off the shore?

5) Are there any localities where the latticing will have to be warped to fit predicted and/or observed local anomalies in hyperbolic readings?

6) Is there any variability due to seasonal conditions?

And the following question about the signal quality:

7) Are there areas where the correct cycle cannot be reliably determined by commercial hyperbolic receivers?

METHOD OF CALIBRATION

The method used to calibrate the Loran-C Chain was to observe the Time of Arrivals (TOA) of each of the three transmissions at a known surveyed location. The reason for going to the extra trouble to measure the TOA of each signal was to be able to analyze each transmission as a separate entity. When a Time Difference (TD) observation is anomalous, it may be impossible to say which leg (master or secondary transmission) is the trouble maker. Also, the Time Difference observation would only provide the difference in Additional Secondary Factor (ASF) caused by the land path segments to each transmitter; whereas the TOA observation would give absolute ASF for each signal.

In the offshore areas, our surveyed locations were to be determined by doppler satellite fixes, sometimes called satnav or navsat. In the in-shore work, trisponder or sextant resection angles were used for positioning.

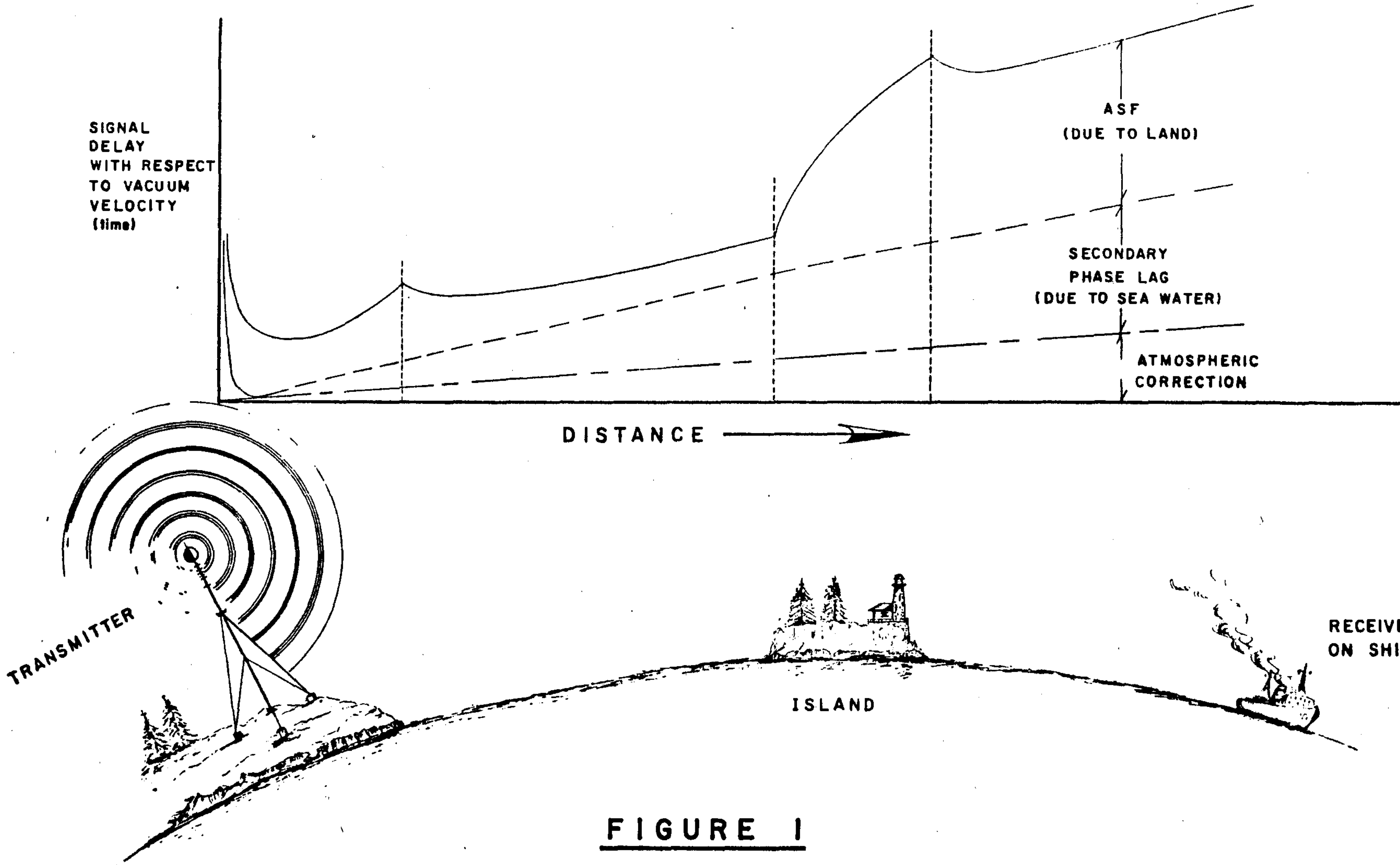
SIGNAL
DELAY
WITH RESPECT
TO VACUUM
VELOCITY
(time)
ASF
(DUE TO LAND)
SECONDARY
PHASE LAG
(DUE TO SEA WATER)
ATMOSPHERIC
CORRECTION
DISTANCE
TRANSMITTER
ISLAND
RECEIVER
ON SHIP

FIGURE I

The Loran-C receiver, to be used in a Time of Arrival mode, has to be synchronized with the instant of transmissions from the master and secondary stations. We are literally measuring the time it takes for the radio wave to travel the distance from transmitter to the ship. Knowing the velocity of the radio wave (approximately 300,000 km/sec) we can compute the distance. Therefore, for 30 metre accuracy in the distance, the time of the instant of transmission must be known to 0.1 microseconds. The transmissions are controlled by a cesium beam frequency standard that has a very stable frequency. These frequency standards are often called atomic clocks. If the receiver also has a cesium clock, then the instant of transmission can be determined from it once it has been synchronized at a known distance from the transmitter. However, the frequencies of the cesium standards at the transmitter and receiver are usually slightly different, and that difference has to be determined by observing the change in TOA at a stationary location over several days. Any uniform change in TOA is caused by the frequency difference, commonly called a 'clock rate'. It is usually a fraction of a microsecond per day. This clock rate must be applied to all observed TOA's. The clock rate has to be checked frequently to maintain the necessary TOA measurement accuracy since our experience has shown occasional changes in the clock rate between two cesium clocks.

The receiver's clock has to be synchronized with the chain. The receiver and clock have to be taken to a point where the TOA is known or can be accurately computed. And then the TOA's are observed until a stable reading is obtained. The difference between the observed TOA and known TOA is the clock synchronization and must be applied to all readings since there is no method of setting a cesium clock to a specified value. For this chain, we had to take the clock and receiver to Williams Lake (near the Master) and to Moses Lake (near Y secondary) by truck and helicopter and to Masset on Queen Charlotte Islands (near X Secondary) on the ship to synchronize the receiver with each transmitter. By getting close to the transmitters, the effect of not knowing the precise electrical characteristics of the ground is minimized but it is undesirable to get too close to the transmitter since the local induction field of the antennae extends for several kilometres.

The following equation is used to obtain the ASF for each transmitter at each calibration point:

ASF= TOA - CLOCK - SYNCH - ATMOS - SEC - toa

where: ASF= Additional Secondary Factor
TOA= Observed Time of Arrival
CLOCK= Clock rate correction, which is a linear function of time,
SYNCH= Clock synchronization, which is a constant,
ATMOS= Atmospheric correction, which is a linear function of distance to the transmitter,
SEC= Secondary phase lag over an all sea-water path, which is a non-linear function of frequency, conductivity, permittivity and distance (Johler).
toa= Distance X vacuum velocity (299,750 km/sec)

PREPARATION FOR CALIBRATION

It was initially anticipated that the Canadian West Coast Loran-C chain would be operating in January 1977. Allowing for the inevitable delays and the stabilizing of operations, our field operations were not scheduled to start until March 1977. Time was made available for the calibration using our survey ships during March and April before the height of the hydrographic field season. The chain was late coming on air but we suffered only slightly by that delay.

To start with, we loaded a U.S. Coast Guard modified Austron 5000 receiver and a cesium beam atomic clock into a Canadian Coast Guard Bell 212 Helicopter and went on a circuit from Victoria, B.C. to Williams Lake and back and Victoria to Moses Lake and back. At Williams Lake we compared the frequency of the cesium clock that was controlling the Master transmission and of the cesium clock that controlled our receiver. At both Williams Lake and Moses Lake we observed TOA's at nearby geodetic stations where the 'true' TOA could be calculated; thereby synchronizing our system with the chain. Then, with the knowledge of the clock rate, it would be possible to establish the TOA's in Victoria. I said "would be" because we found that our long lead-in wire appeared to act as an auxiliary antenna, introducing large enough out-of-phase signals to make our readings unreliable.

This interference meant we had no synchronization before our calibration. However, we had planned repeating the operation at the end of the calibration and any difference would possibly have been attributed to the seasonal variation. Now we had to plan a new way of synchronizing the system, to be done at the end of the calibration. This was done in May with a properly insulated and shielded van and was quite satisfactory until the inside the van got too hot for the cesium clock to maintain a steady clock rate.

OFF-SHORE CALIBRATION

The equipment was then loaded on board CSS Parizeau, a 65 m multipurpose survey ship. The equipment included:

- USCG modified Austron 5000 receiver with extra notch filters, cesium clock and PDP 8 computer (on loan from USCG) for monitoring TOA's;
- Austron 5000 receiver with cesium clock with PDP 8 computer (on loan from Bedford Insitute of Oceanography) for speed and course input for;
- Magnavox doppler satellite receiver and associated Hewlett Packard 2100 computer (on loan from Central Region of CHS at Burlington, Ont.) for position determination;

- Four commercial hypberbolic receivers (one was purchased, the others were on loan from dealers);
- Hewlett Packard 9825A computer.

Clock rates of the two cesium clocks with respect to the chain were determined 5 times: at Patricia Bay, the new home of the Institute of Ocean Sciences near Victoria, B.C., before and after the calibration, twice at Winter Harbour (near the north end of Vancouver Islands) and once at Masset (at the north end of Queen Charlotte Islands). Also the two clocks were intercompared daily. Long term clock rates were available because the ship returned to the same spot both at Winter Harbour and at Patricia Bay so the change in TOA's could be proportioned over the elapsed time. For 16 days, the Parizeau cruised up and down the west side on Vancouver and Queen Charlotte Islands both eight and twenty miles from shore, steamed a zig-zag pattern in Hecate Strait, made several passes in Dixon Entrance and steered along two radials from the Master almost as far as the 200 nautical mile limit for a total distance of 3200 nautical miles (see Fig. 2). During that time, more than 350 good doppler satellite position fixes were determined that have a positional accuracy of 150 metres (one standard deviation). From these data, we are analyzing the results for the most likely value of conductivity and permittivity of the land.

CYCLE SELECTION TESTS

During the cruise, we were constantly testing for correct cycle acquisition on the commercial receivers. These acquisitions have been analyzed with respect to Time Difference (TD), receiver, notch filters and time taken to acquire the signals. It was found that in the Strait of Juan de Fuca and as far west as Tofino it was almost impossible to lock on to the correct Time Difference involving the Shoal Cove secondary. Similarly, it was difficult for the receivers to acquire the correct Time Difference for the George secondary throughout the Dixon Entrance area. These two facts are already noted in Cautions on the three Loran-C charts of the west coast of Canada published by the Canadian Hydrographic Service.

IN-SHORE CALIBRATION

The calibration with Parizeau ended at the Easter weekend and the USCG modified Austron 5000 receiver with cesium clock was transferred to the CSS Vector, a 40 m research ship. Also, the ship was equipped with a Trisponder (2 range) positioning system which has an accuracy of a few metres. The ship calibrated the Loran-C chain across the mouth of the Strait of Juan de Fuca and also in the Gulf Islands and Strait of Georgia (see Fig. 3). Her job was to investigate the suitability of Millington's Method close to shore where, theoretically, there is a "phase recovery" as the groundwave comes from land onto the sea water. We also wanted to check on the signal stability close to shore. Both factors are important when considering how close lattices should be drawn to shore. Also, off Cape Flattery, there should be rapid change in ASF in the signals from

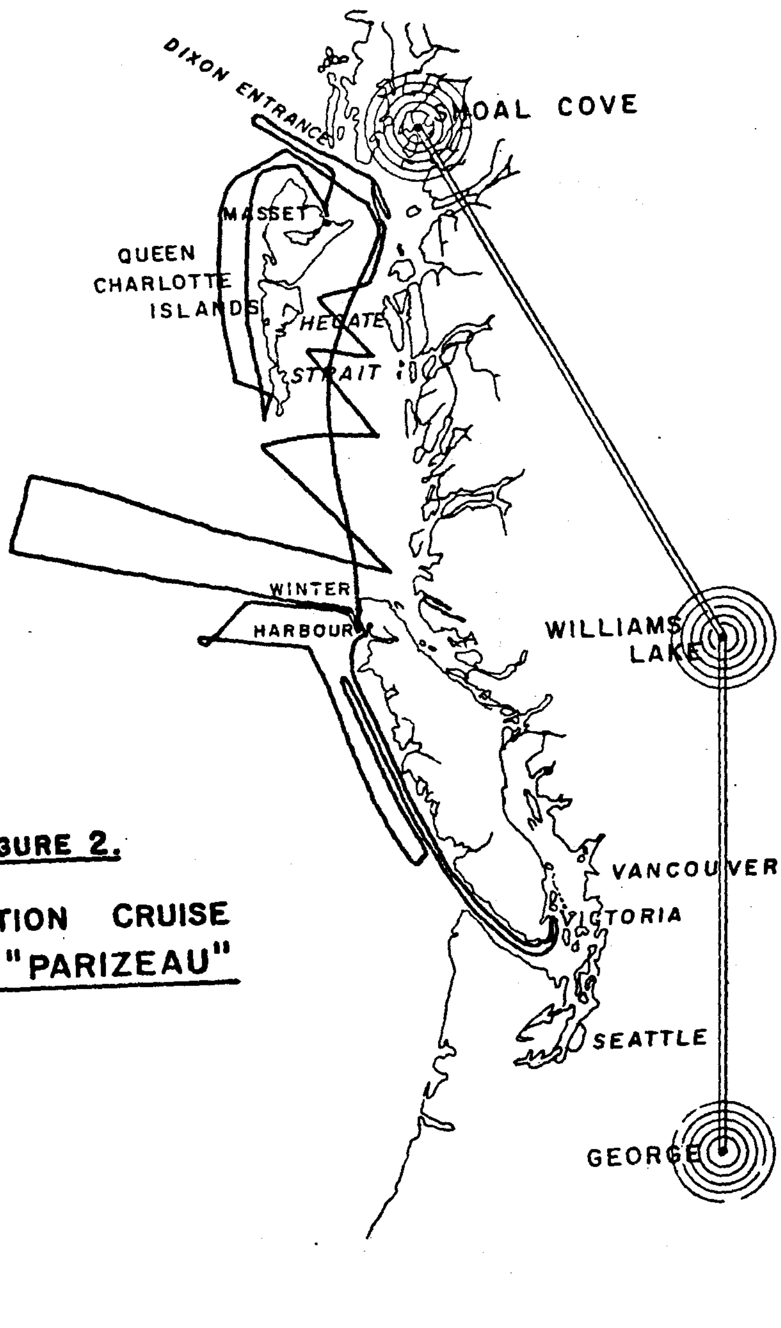

FIGURE 2.

CALIBRATION CRUISE OF CSS "PARIZEAU"

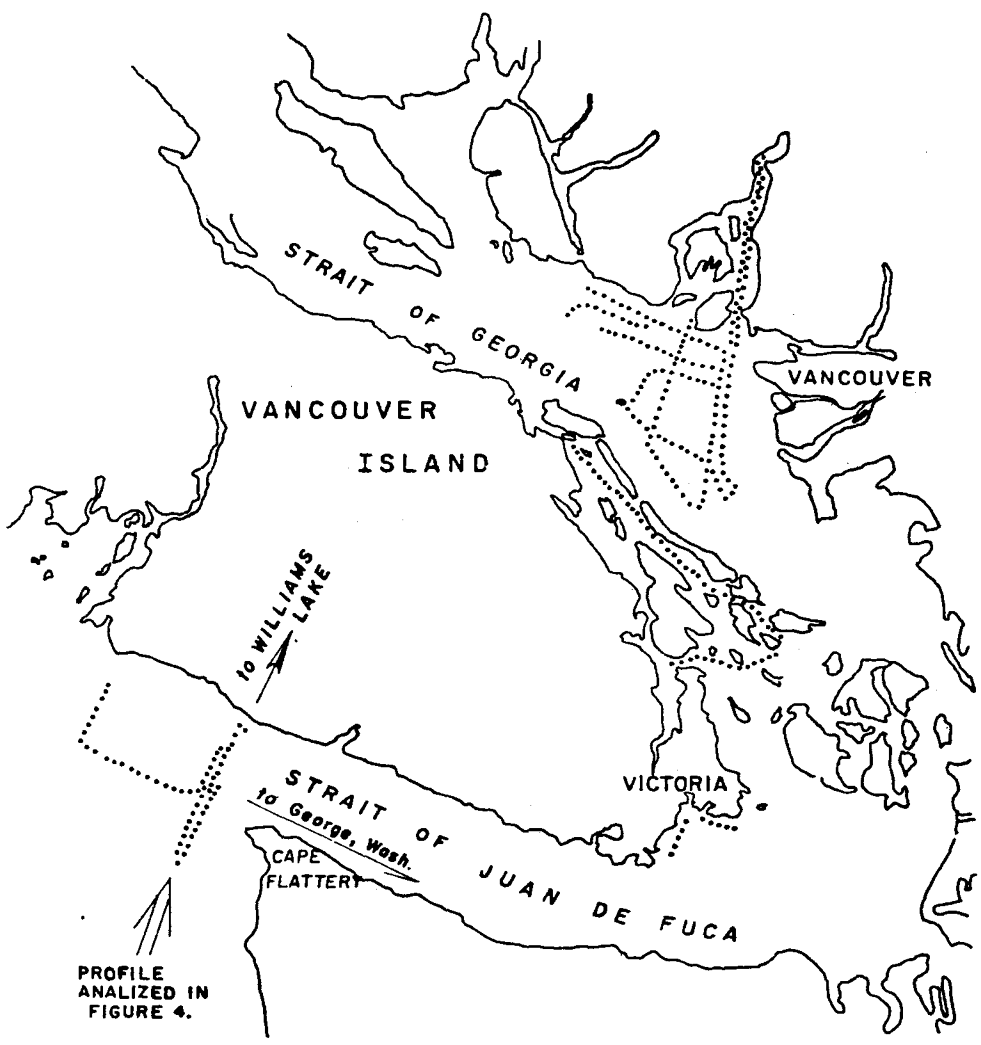

FIG 3. CALIBRATION CRUISE OF CSS "VECTOR"

George, depending on whether the signal comes down the length of the Strait of Juan de Fuca or comes across the land as far as Cape Flattery (see Fig. 4). This would cause an observable warping in the lattice at some chart scales. The work in the Gulf Islands was to see if, generally, it would be possible to lattice the charts of this area without sizeable errors in the lattice. Throughout this cruise, even the Auctron 5000 receiver, which is designed for signal to noise ratio of 1:10, could not acquire the Shoal Cove transmissions except on rare occasions. TOA's from the Williams Lake and the George transmitters were observed at more than 650 positions throughout the two week calibration with CSS Vector.

SUMMARY

It appears that this calibration will be able to answer most of the seven questions we had asked ourselves. This Convention is at a very opportune time to discuss how beneficial these Loran-C chains are. But to be able to report on the results of a calibration of one of these chains is difficult. It is presently two months after the calibration as we write this paper and we are only part-way through the analysis. So some of the other questions will have to wait. Tentative answers to the questions are:

1) Yes, we do think we will be able to assign conductivity and permittivity values to the land.
2) The mountains do have an effect on the signals. They make the land appear to have a lower conductivity and they shorten the maximum range of the ground wave.
3) Millington's Method does seem to provide a suitable approximation to the Additional Secondary Factor (ASF).
4) The feasibility of accurately latticing to shore is still to be analyzed.
5) There are areas where the latticing will have to be warped to fit observed anomalies in hyperbolic readings. This is a problem for the computer programmers of our Automated Cartography Section to solve. You might not be aware but for several years all borders, graticules, lattices and other mathematically related functions normally shown on Canadian charts, have been drawn on an automatic plotter controlled by a PDP-11 computer. We are in the process of automating many of the other drafting functions of chart construction including contouring and selection of soundings.
6) Unfortunately, we lost the chance in this calibration to see if there is any seasonal variation. The evidence would not have been very conclusive anyway because the calibration loops would have been only six weeks apart.

And finally about the signal quality:

7) Most definitely there are areas important to safe navigation in Canadian waters that lack reliable reception of Loran-C signals. These are the Strait of Juan de Fuca and westward as far as Cape Beale or Tofino, and to a lesser extent, Dixon Entrance.

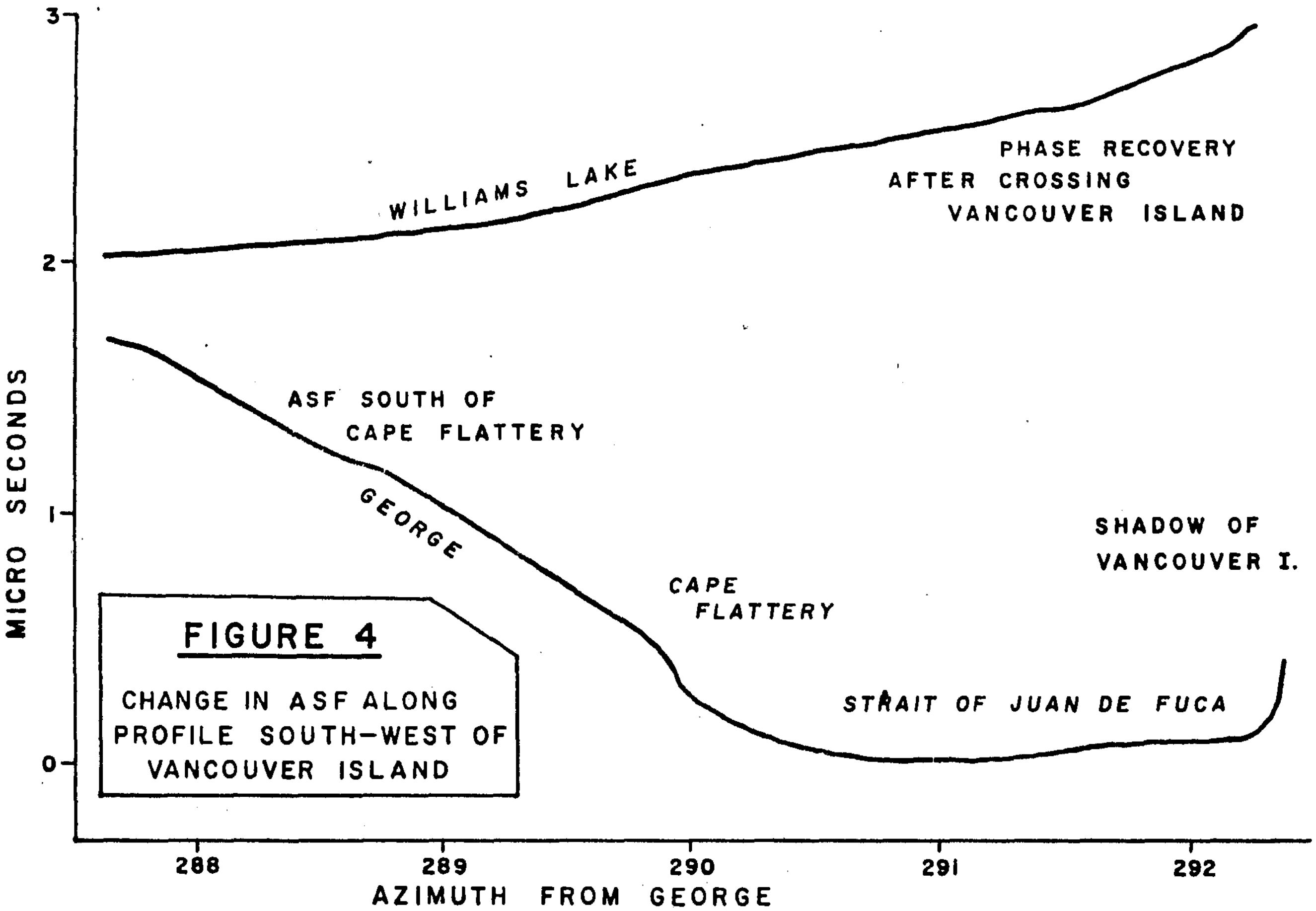

FIGURE 4

CHANGE IN ASF ALONG PROFILE SOUTH-WEST OF VANCOUVER ISLAND

To be able to answer most questions that we set out to do, the calibration can be termed a success. I am sorry that I can't yet provide all the answers of the analysis, but you will see them in the charts produced by the Canadian Hydrographic Service.

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A Systematic Method of Loran-C Accuracy Contour Estimation

D. Amos*

D. Feldman*

Abstract

The determination of fix-accuracy contours for Loran-C navigation systems has traditionally involved automatic computation of a simplified geometric error expression for each triad, followed by manual combination of these coverages with propagation effects, noise, and transmitted power. A complete error expression which includes all these major parameters is described and integrated into a computation algorithm. This yields azimuthal equidistant plots of accuracy contours for chains of arbitrary complexity, with all major parameters included. Paths with different conductivities can be approximated and loss-of-navigation due to weak signals shown. This algorithm can be implemented in a desk-top calculator, and an application example for European and U.S. West Coast Loran-C coverage is given.

Introduction

The subject of Loran-C accuracy contours dates from the development of loran itself in World War II. Within Loran-C, the formulation given in the Jansky and Bailey report of 1958 has formed the basis for the layout of subsequent chains and the determination of accuracy contours (and hence "coverage diagrams", that area lying within or covered by a given contour). The procedure uses a simple expression which maps a triad's (master and two secondarys) Line-of-Position (LOP) geometry into cartesian position fix variation, determining contours from this result. The additional parameters such as transmitted signal power levels, atmospheric noise, propagation attenuation etc. are then specified as the minimum necessary to achieve the desired contours. Chains which utilize more than two secondary stations are analyzed by repetitive application of this triad analysis.

*The authors are both assigned to the staff of Commander, Coast Guard Activities, Europe who provides technical and operational direction to the 7930, 7970 and 7990 Loran-C chains in Europe. The opinions expressed are those of the authors and do not represent the official policy of the U.S. Coast Guard.

Our purpose is to derive a complete mathematical expression for cartesian position error in terms of all system parameters, and then imbed this in a computation structure for computing accuracy contours for chains of any complexity. The computation will also include azimuthal equidistant plotting of the specified accuracy contour, offset to any geodetic location. The results can then be used for initial chain design of arbitrary numbers of secondarys, analysis of existing chains and possible modifications thereof, and to analyze the composite coverage of multiple or linked chains via the offset plotting feature.

The Problem

Loran-C, like any radio navigation system, has two types of accuracy, a geodetic and a repeatable. The former denotes an observer's ability to determine his position on the earth from observations of the received radio signals and assumptions on their propagation to him, while the latter refers to his ability to return to a position where he has previously made these observations. Neglecting receiving equipment, operator and signal transmission errors, the repeatable accuracy of the system is set by the geometry of the LOPs and the radio noise induced variations of the observed time-differences (TDs). Loran-C accuracy contours and coverage diagrams are wholly concerned with modeling and predicting these latter two factors to describe the resulting uncertainty of position.

The three transmitted signals, master and two secondaries, are received additively combined with radio noise. The latter may be natural or man-made in origin. Two TDs are estimated by the receiver, master to each secondary, and these TDs have noise-induced random variations which are related (correlated) since the master is common to each TD. These random variations in the TDs are mapped into random position variations by the LOP geometry at the observer's location. The position variation is a two dimension random variable which describes a region of uncertainty which can vary from a circle, to an ellipse, to (in the limit) a straight line. Conventional navigation methodology uses a single statistic (drms) to describe this uncertainty and accuracy contours are plotted which indicate a constant value of this statistic. The navigation observer located within a given contour may then presume (recalling the assumptions) that a major percentage of his fixes lie within a drms-factor range of his true (repeatable) position. We might say that the generation of accuracy contours is an exercise in reducing a complex multi-dimensional problem to a diagram that a two-dimensional human mind can grasp and use for decision making.

Our approach to this problem is as follows:

a. Develop an expression for the received strength of a Loran-C signal, given the range to the transmitter and the transmitter's power.

b. Develop an expression for the TD variance and covariance given received signal strength, received noise level, signal recurrence rate and receiver processing time constant.

c. Develop an expression for the statistic of position error, drms, from the TD variances and covariance, and the location of the observer relative to the stations.

d. Develop a computational structure and plotting algorithm to use the drms expression in generating accuracy contours by computer.

Received Signal Strength

The solution to the groundwave propagation equation on a sphere of finite conductivity is a difficult computation and given the many unknown conductivities in actual propagation need not be determined exactly. Loran-C coverage diagrams have generally used tabulated curves for various conductivities taken from TM 11-499 (a U.S. Army publication). We shall develop a simple functional approximation to these curves for a few conductivities which can be used in a calculator computation of error contours. These curves reveal that the difference between inverse distance attenuation and actual attenuation appears to have an exponential shape on the logarithmic plot, or

$$\text{Difference Function} \propto -A\exp\left((-B-\ln D)/C\right)_{dB}$$

which is

$$\text{Difference Function} \propto -[k_1 D]^{k_2}{}_{dB}$$

We selected values of k_1 & k_2 to minimize the squared error between the tabulated curves and this expression for various conductivities with the results given in table I. We see that this function gives an excellent "correction" to simple inverse distance for most conductivities. We can then write the complete expression for any transmitted power:

$$E_{\mu V rms} = 124 - 20 \text{ LOG } D + 10 \text{ LOG } P/400 - [k_1 D]^{k_2}$$
dB above 1 V/m

$$E_{\mu V/m\ rms\ ssp} = \sqrt{\frac{P}{400}} \cdot \frac{10^{6.2-[k_1]^{k_2}}}{D} \qquad (1)$$

Where P is peak pulse power, kW
D is distance, nautical miles
$E_{\mu V/m}$ @ Standard Sampling Point, 1/2 peak rms signal

and

Conductivity Type	k_1	k_2
Seawater	$1.06\cdot10^{-3}$	1
Freshwater/Farmland	$1.6\cdot10^{-3}$	1
Rocky Soil	$2.45\cdot10^{-3}$	1
Snow covered volcanic mtn	$3.7\cdot10^{-3}$	1
Extremely poor , cities	$6.55\cdot10^{-3}$	1

Equation (1) provides the necessary field strength estimate at any distance from a Loran-C station.

Table I

Approximation Error for Field Strength vs Distance [illegible]

D (distance, n miles) Seawater	Error dB	D (distance, n miles) Snow Covered Volcanic Mtn	Error dB
100	-1	15	+1
200	-2.35	25	+1.25
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	-.[illegible]	[illegible]	+[illegible]
[illegible]	-1.87	[illegible]	+1.[illegible]
[illegible]	+.3	200	+2
[illegible]	+1.25	350	+.1
1700	+1.5	600	-2

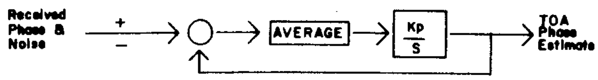
Freshwater/Cultivated Soil	Error dB	Extremely Poor (Cities)	Error dB
50	-1.1	5	+1.3
100	-.2	10	+3.7
200	-.1	20	+6.7
400	+.2	35	+7.4
700	-.9	66	+8.8
1000	-1	120	+8.3
1200	+.6	250	+3.2
1400	+.2	500	-5

Poor Soil	
40	0
80	+.3
160	+.16
300	+.3
450	-1
600	-.4
850	-.15
1150	+1.6

Receiver TD Variations

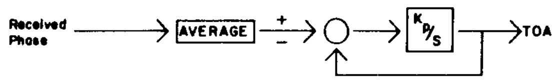
The phase tracking function of a Loran-C receiver is usually modeled as a linear servo mechanism, either Type I or II, which is an excellent model for the small variations in its output (1 to 3% of the carrier period). In choosing model details one must select either an entirely digital receiver or some hybrid digital/analog form. The difference for our purposes is that changing the Loran-C Group Repetition Interval (GRI) changes the apparent bandwidth of the digital receiver's servo, maintaining constant noise output, while the analog receiver maintains constant signal bandwidth with output noise varying in response to GRI changes. We shall model the latter type of receiver although the difference is not critical for our purposes.

The receiver model is shown in Figure 2-A, with an equivalent in 2-B. The averaging device usually has a time constant of 1-2 seconds, serving to smooth the sampled phase error plus noise prior to integration. In Figure 2-B we have moved the averaging through the summing junction and deleted it in the feedback path because the output is slowly varying.



HYBRID LORAN-C Phase tracking loop

FIG. 2—A



EQUIVALANT

FIG. 2-B

The received signal level is computed from (1) whilst the rms noise level can be estimated from the CCIR noise curves, or estimated from field measurements. We believe the latter is more appropriate in most cases because the received noise is usually dominated by a sum of man-made communication signals near the Loran-C frequency band. From this we have a received noise-signal ratio, N/S, or its inverse as is more common, SNR. The linear approximation for the phase tracking loop requires that we evaluate the signal derivative at the operating point, the zero crossing, whence

$$\text{Tracking signal} = \left.\frac{d}{dt}(1.414S \sin 2\pi 10^5 t)\right|_{t=0} = 0.89S \text{ V/us}$$

For a standard rms signal amplitude of unity, required to maintain a constant tracking time constant, we have an rms noise level in equivalent s of

$$\sigma_{NOISE} = (1.12 N/S)\mu s \text{ rms}$$

This noise if first averaged by an RC filter of 2 seconds time constant, equivalent to a 1 second moving-average filter. This reduces noise level to

$$\sigma_{NOISE} = \frac{(1.12\ N/S)}{8/GRI}$$

We are now implicitly modeling the noise process as a sequence of independent (white) noise samples, hence we apply the conventional expression for the standard deviation at the output of a filter to obtain

$$\sigma^2_{OUT} = \sigma^2_{IN} \int_0^\infty h^2(t)dt$$

$$\sigma^2_{TOA} = \frac{1.12\ N/S}{\sqrt{2\ \tau\ 8/GRI}} \qquad (2)$$

Equation (2) can be used to estimate N from observed timing receiver fluctuations at the transmitting stations, given the path and remote signal power and the receiver's time constant.

An actual time-difference receiver is usually constructed with three tracking loops, with the master channel much wider in bandwidth than the secondary. Effectively the master-secondary time difference is filtered by the secondary tracking loop and because the noise is independent in each time interval we can root-sum-square their effects as

$$\sigma^2_{TD} = \frac{(1.12N/S_M)^2 + (1.12N/S_S)^2}{(2\tau_S\ 8/GRI)} \qquad (3)$$

Finally, because the master noise samples are common to both TDs we can determine the TD covariance. Using superposition and the knowledge that secondary noise samples are independent, one can show directly that

$$CoV(TD_A TD_B) = \sigma^2_{AB} = \frac{(1.12N/S_M)^2}{2\tau_S \cdot 8/GRI} \qquad (4)$$

Equations (3) and (4) provide us the necessary tools to deal with the statistical fluctions at a navigation receiver's TD output, given its location and ambient noise level, while (2) and (3) allow us to estimate this noise at existing Loran-C stations.

Conversion of TD Error to Geometric Error

As the first step in conversion of TD error (noise induced variations) to geometric position errors, let us define a polar co-ordinate system as shown in Figure 3. We state the following definitions and facts:

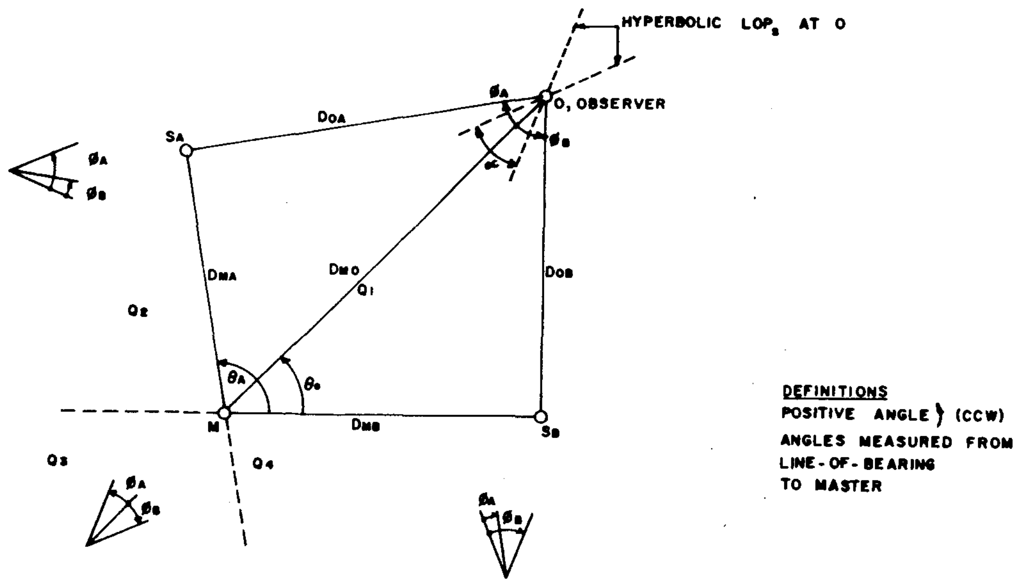
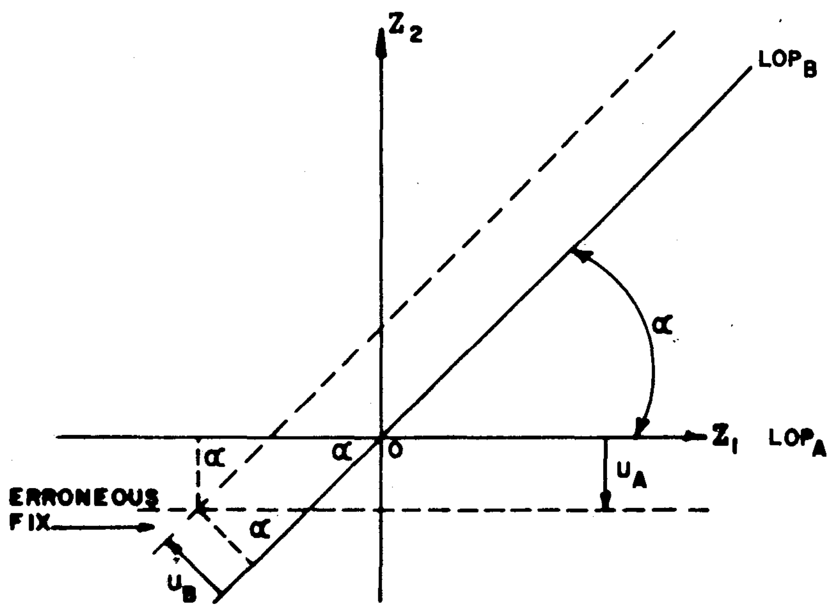


FIGURE 3. CO-ORDINATE DEFINITIONS.



U_A and U_B directions shown for a decrease in TD in section Q_1

Figure 4 cartesian transformation.

a. The given parameters are:

D_{MB}, D_{MA}, θ_A, θ_0 and D_0

b. These quantities are computed by plane or spherical trigonometry

D_{OA}, D_{OB}, ϕ_A, ϕ_B

c. Crossing Angle of LOP @ 0

$$\alpha = \left|\frac{\phi_A}{2} - \frac{\phi_B}{2}\right|$$

d. The four sectors are labeled Q_1, 2, 3 & 4, entirely specified by the signs of ϕ_A and ϕ_B. A sector sgn function, Q, is given by:

"Quadrant"	Q	
1	-1	
2	+1	$Q = \mathrm{sgn}\,\phi_A \cdot \mathrm{sgn}\,\phi_B$
3	-1	
4	+1	

Let us turn now to examine the effect of TD variation at an observer's location, O. In Figure 4 we show a cartesian co-ordinate system ($Z_{1,2}$) aligned with the Z_1 axis coincident with one LOP (the LOP coordinate system is $U_{A,B}$). By geometry the Z co-ordinates of the erroneous fix are:

$$Z_2 = \mathrm{sgn}\phi_A \; U_A$$

$$Z_1 = -\frac{\mathrm{sgn}\phi_B \; U_B}{\sin\alpha} + \frac{\mathrm{sgn}\phi_A \; U_A}{\tan\alpha}$$

The value of U in nautical miles is the product of the TD variation and the TD/distance gradient and can be shown to be:

$$Z_2 = \frac{0.082 \; \mathrm{sgn}\phi_A \; TD_A}{\sin\phi_A/2} \text{ N miles}$$

$$Z_1 = -\frac{0.082 \; \mathrm{sgn}\;\phi_A \; TDB}{\sin\;\phi_B/2 \; \sin\alpha} + \frac{\mathrm{sgn}\;\phi_A \; TD_A}{\sin\;\phi_A/2 \; \tan\alpha} \quad \text{N miles}$$

TD_A and TD_B are assumed to be normal random variables of zero mean and variance/covariance given by equations (3) and (4). The new variables, Z_1 and Z_2, being linear transformations of these form a bivariate normal distribution with correlated variates. The three possibilities for the distribution $P(Z_1,Z_2)$ are shown in Figure 5.

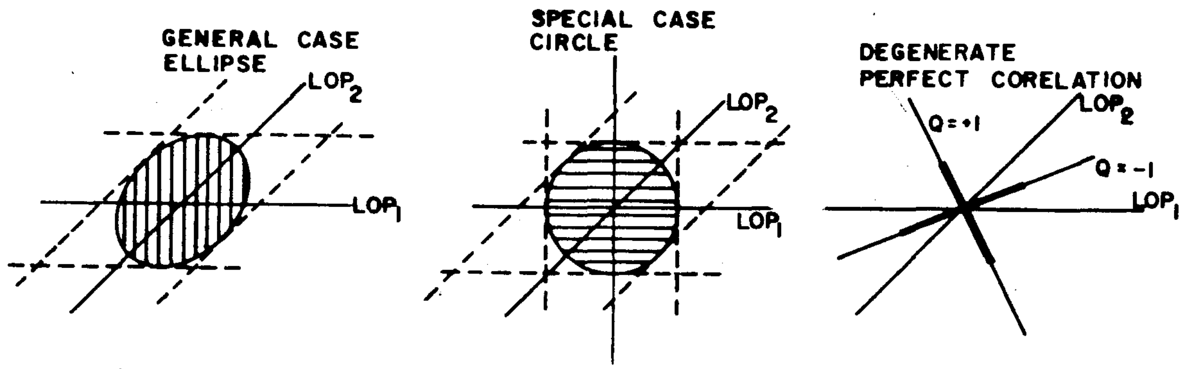


Figure 5 Possible distribution of: $P(Z_1, Z_2)$

There are two statistics of $P(Z_1, Z_2)$ that are conventionally used to represent its dispersion; Circular Error of Position (CEP) and the square root of average squared radial error, drms. CEP is a more exact metric in that it maintains a constant probability, but drms is conventionally used in navigation systems as it is more conservative and mathematically more tractable. Computing the average squared radial error

$$d^2rms = \overline{Z_1^2 + Z_2^2}$$

and substituting Z as a function of TD we have

$$d^2rms = \frac{(0.082)^2}{\sin^2}\left(\frac{\sigma^2 TDA}{\sin^2 \phi_A/2} + \frac{\sigma^2 TDB}{\sin^2 \phi_B/2} - \frac{2Q\,\sigma^2 AB \cos\alpha}{\sin \phi_A/2 \sin \phi_B/2}\right) \quad (5)$$

To examine in detail the probability lying within a drms-factor radius we must further transform the Z_1 Z_2 variates so that they are uncorrelated. Specifically

$$Z_1 = X \cos\gamma - y \sin\gamma$$

$$Z_2 = x \sin\gamma + y \cos\gamma$$

where γ is given by $\cot 2\gamma = \dfrac{\dfrac{\sigma_B^2}{\sin^2\phi_B/2} + \cos 2\alpha \dfrac{\sigma_A^2}{\sin^2\phi_A/2} - Q\dfrac{2\sigma_{AB}^2 \cos\alpha}{\sin\phi_A/2 \;\sin\phi_B/2}}{2\sin\alpha\left[\dfrac{\sigma_A^2}{\sin^2\phi_A/2}\cos\alpha - Q\dfrac{\sigma_{AB}^2}{\sin\phi_A/2 \;\sin\phi_B/2}\right]}$

This value of γ forces σ_{xy} to be zero, i.e. x and y are statistically independent. From this, one can evaluate σx and σy, knowing that $\sigma_{xy}=0$, and then enter bivariate tables. Burt et. al. (AD 629 609) provide a comparison of CEP and drms and discuss details of the fix probability enclosed by drms. Loran-C accuracy contours are plotted for a 2drms radius, which always includes at least 95% of the fix probability.

Comments on drms

Equation (5) for drms reduces to

$$d^2rms = \frac{\sigma^2(0.082)}{\sin^2\alpha}\left[\frac{1}{\sin^2\phi_A/2} + \frac{1}{\sin^2\phi_B/2}\right]$$

when we ignore TD correlation and assume equal TD variance. This is the classic form utilized in coverage diagram or accuracy contour analysis. Unfortunately, when the TD variances are equal we usually find ourselves at the outer limits of the prime service area (the Q_1 sector) and master variations dominate both TD variations, hence

$$\sigma^2 TD_A = \sigma^2 TD_B = \sigma^2 TD_{A \cdot B}$$

Dividing equation (5) by (7) with these approximations and setting $\phi_A=\phi_B$ (i.e. 0 is in Q_1 on the bisector of Θ_A) we have

$$\frac{d^2 \text{ rms-actual}}{d^2 \text{ rms-approximate}} = \frac{3 \cos \kappa}{2}$$

or 3/2 for small crossing angles. The actual drms error metric is 50% greater than the usual approximation reveals. From equation (1) we see that to compensate for this actual increase we must increase power by about 50%. Geometrically what has happened is represented by Figure 5 - "Ellipse" and "Degenerate". The ellipse is the distribution $P(Z_1,Z_2)$ for equal variances and zero correlation. The degenerate case is for perfect correlation (i.e. master noise dominates both TDs) and the distribution line extends to the dotted corners of the ellipse plot and bisects the crossing angle, .

When the observer moves to sectors Q_2 or Q_4, the Q function reverses sign and the correlation actually reduces 2drms.

Then two Q values are seen in Figure 5 (recall that Q reflect the movement of U_1 and U_2 for a change in TD). Unfortunately the master is never the weakest signal in these sectors and hence tends to zero and the usual approximation (eq (7)) is quite valid here (it is actually conservative because TD_A TD_B or visa versa).

The complete 2drms Expression

Let us now put all three factors, signal strength, receiver filtering and geometric transformation together to form a complete error expression in meters:

$$2drms = \frac{1.682\,N}{10^{3.2}\,\sin\alpha} \cdot \sqrt{\frac{GRI}{\tau_s}} \left[\frac{\dfrac{D_{MO}^2\, 10^{2KD_{MO}}}{P_M} + \dfrac{D_{OA}^2\, 10^{2KD_{OA}}}{P_{SA}}}{\sin^2 \phi_A/2} + \frac{\dfrac{D_{MO}^2\, 10^{2KD_{MO}}}{P_M} + \dfrac{D_{OB}^2\, 10^{2KD_{OB}}}{P_{SB}}}{\sin^2 \phi_B/2} - \frac{2Q\, D_{MO}^2\, \dfrac{10^{2KD_{MO}}}{P_M}\cos\alpha}{\sin\phi_A/2 \quad \sin\phi_B/2} \right]^{1/2} \text{meters} \tag{8}$$

where we have

N, rms noise field strength, V/M

α, LOP crossing angle, $|\phi_A/2 - \phi_B/2|$

ϕ_A, ϕ_B, (see Figure 3, NOTE ϕ is a signed quantity)

GRI, Group Repetition Interval, seconds

τ_s, Secondary phase tracking channel time constant, seconds

D_O, D_{OA}, D_{OB} distances in nautical miles, see Figure 3

k_1 propagation curve fit coefficient

P_M, P_{SA}, P_{SB}, Transmitted rms Pulse Peak Power, kW

Equations (3) and (4) can be used to estimate noise (N) from field observations. Since these equations are used in (8), if N is estimated in this way and the same power levels used in (8) the contour results will be calibrated to the field observations and independent of the absolute values of N and P. A different use of the field observations can be made if one assumes that N can be estimated reliably from one signal with a known conductivity path. Then the effective conductivity on a different path to a different station can be estimated by solving for S in (3).

Non-Homogeneous Effects

Equation (8) can be used in a computational structure to determine the 2drms error for signals propagating over a homogeneous surface and perturbed by a spatially constant received radio noise field. This situation is an adequate model for many locations, but most Loran-C chains include non-homogeneous signal paths which can have a major effect on signal strength and hence 2drms error. Our 2drms expression requires the computation of range and bearing from each station to the observer's location where the error is being computed, and advantage can be taken of this to approximate the effects of major non-homogeneities to almost any degree of accuracy desired. This is accomplished by varying signal power and path conductivity during execution of the contour program.

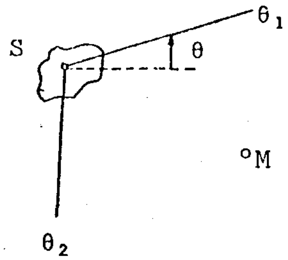
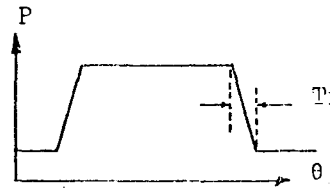
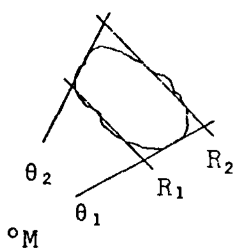
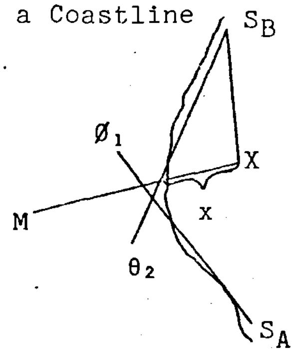
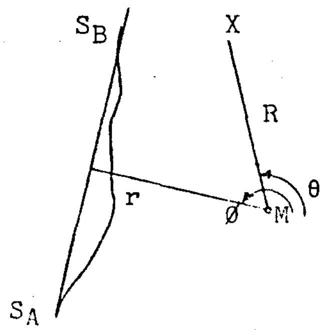
We term this dynamic modification of parameter inputs to (8), "GEOMOD". The first step is to describe or bound each geographic variation to be modeled with a combination of ranges and bearings from one or more stations in the Loran-C chain. Then, depending upon the type of anamoly being described, prepare an expression which modifies transmitted power and/or conductivity of the stations concerned when the observer's location falls within the bounding ranges and bearings describing the anomaly. The procedure is one of judgement with the anticipated impact of the anomaly on coverage the criterion for "GEOMOD" complexity. The end result is that transmitted power or intervening conductivity varies coarsely as the observer moves through the service area.

Table 2 gives four usefull types of modifications to treat islands and coastlines, and man-made interference which originates onshore and decays over the service area of the chain. The first two examples illustrate the judgement factor. In the first, we are not interested in system performance over/on the shielding island, only its impact elsewhere in the service area. We simply reduce power transmitted to these shielded areas. In the second case we are interested in both and hence use a power modification that varies with distance over the island. The modifying expression is usually simple and by proper choice of the bounding condition, and execution on the exceptional, the overhead of the GEOMODs on the total program (described below) is minimal, but the effects on the coverage diagram can often be dramatic.

TABLE 2

Geographic Modification Techniques

(For efficiency, always test for and modify during the exceptional conditions)

Situation	Method
Shielding Land Mass 	Set S power to an effective value to account for land mass attenuation. When $\theta_1<\theta<\theta_2$ increase to full power 
Shielding Land Mass 	Set Mpower to the normal value. When $\theta_1<\theta<\theta_2$ AND $R_1<R<R_2$ derate M power by a variable factor to account for different attenuation, such as $P = P_o/(1+(R-R_1)/k)$ [k estimated from TM-curves] When $\theta_1<\theta<\theta_2$ AND $R_2<R$ derate M power by a constant
Propagation Over a Coastline 	When $\theta_1<\theta$ and when $\emptyset<\emptyset_1$ change propagation constant (k(i)) for S_B and S_A respectively (a transition region can be used). Greater accuracy can be obtained by also computing x from M and S_B bearing and ranges and derating M_7 power as above.
Variable Noise Field 	When noise fields are dominated by man-made land-based sources, these decay off shore. When $R\cos(\emptyset-\theta)<r$, derate noise by $N/(1+(r-R\cos(\emptyset-\theta))/k)$ K is the range to the -6dB point. Otherwise, N is constant.

Accuracy Contour Computer Program

The 2drms error expression, equation (8), coupled with the "GEOMOD" concept results in a computational expression for the error surface which is non-linear and discontinuous. The only practical method for generating the iso-error lines, or accuracy contours, is to compute 2drms at a large number of points throughout the chain service area and then interpolate the desired contour between these discrete points. Since (8) is based upon ranges and bearings from all stations including the master in the center, a logical sampling technique is to evaluate (8) along great circle arcs passing through the master, i.e. nest a range iteration along the great circle within a great circle bearing iteration.

Figure 6 is a flow chart for this structure, and we see that after the two observer location loops, we perform the GEOMODs, and finally compute the 2drms error, using (8), for all possible TDs and store the least as the minimum error obtainable at that location. The only additional equations necessary to implement Figure 6 are conventional spherical trigonometric expressions, the oblique triangle law of cosines and the co-polar triangle for Lat/Long conversion to great circle arc and bearing. In constructing the program one must take care to preserve angle signs, to insure not only position accuracy but also correct evaluation of (8).

Figure 6 lists an action "flag low SNRs" which we use to introduce another important element to the final diagram; whether or not boths TDs are even measurable at the location. This question, whether we are considering signal acquisition, or tracking by the receiver, is generally not addressed in coverage diagrams based as they are on assumed TD fluctuations. Since (8) requires the computation of SNRs for all signals, it is an easy matter to test these for some minimum value and then indicate on the plot if the test failed. Our coverage diagrams use an SNR minimum of -18 dB; below this most receivers will soon fail to track the signal.

The use of great circle geographic coordinates in the algorithm provide a wide choice of plotting transformations. Lambert conformal is available, although we have used azimuthal equidisant which plots great circle bearing and range directly, preserving these dimensions about the master station when this coincides with plot center. An offset plot center is another usefull feature so that coverage diagrams from multiple chains can be concatenated.

The program of Figure 6 requires 130 lines of Basic code and requires about one hour to plot a five station chain, executing in an HP-9825 calculator.

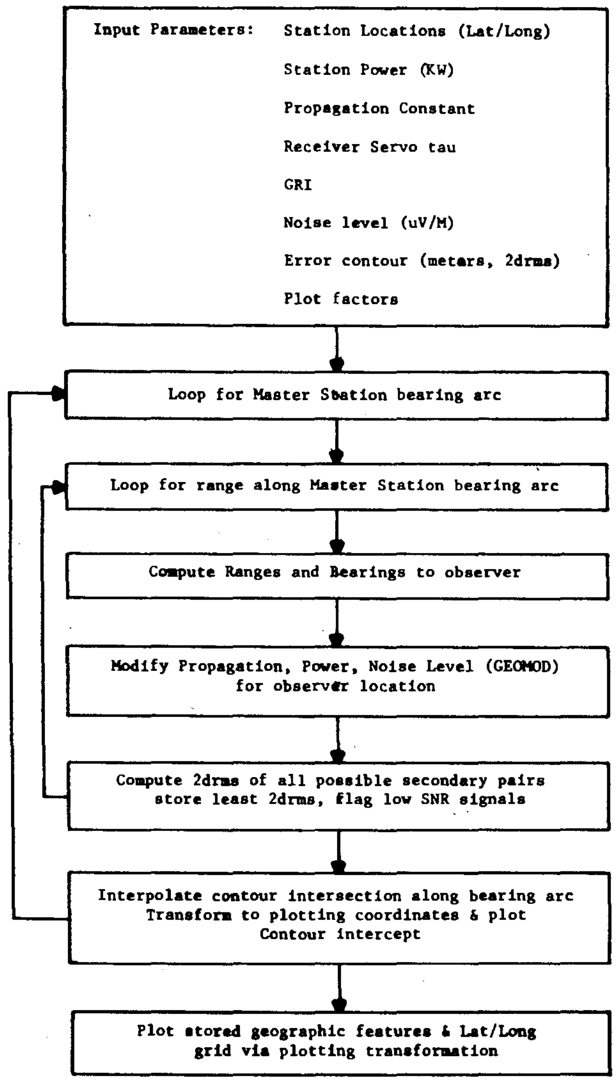


Figure 6 Computation Flow Chart

Example

Figure 7 shows the coverage of the 7970 Norwegian Sea chain computed by this program. The shielding action of Iceland, England and the Norwegian coast is modeled, as well as the man-made noise originating in Europe. Loss-of-signal is indicated by replacing the plotting symbol with the number of the station failing the SNR test. This coverage, while less than that usually predicted, agrees with experience, particularly in the North Sea and along the Norwegian coast.

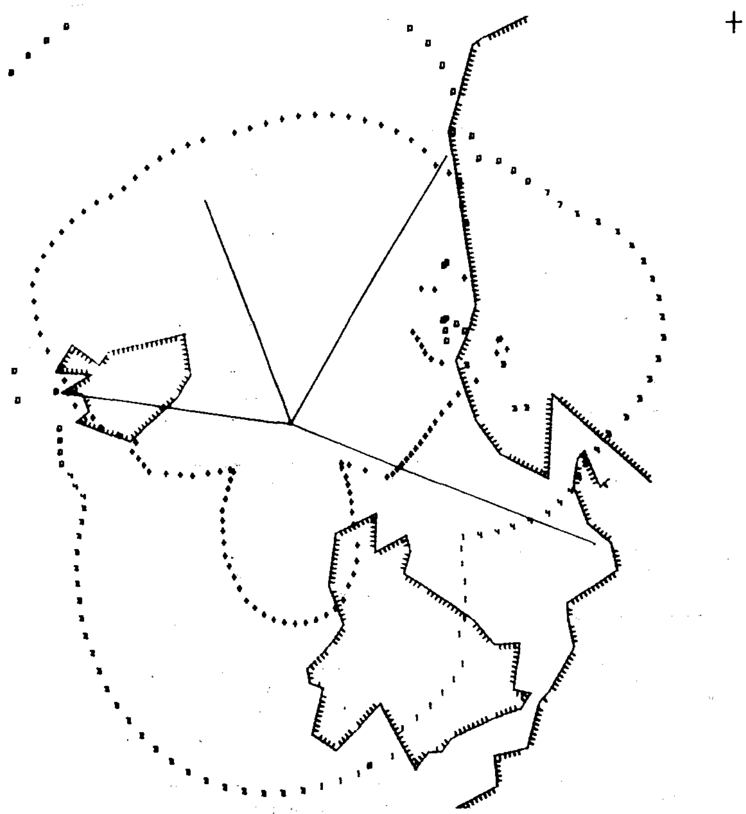


FIGURE 7 NORWEGIAN SEA COMPUTED COVERAGE, 75 AND 500 METER 2DRMS
"GEOMODS" FOR ICELAND/ENGLAND AND NORWAY/AND VARIABLE
(DECAYING) NOISE FIELD FROM EUROPE
15 SEC RCVR TAU, -18 DB SNR LOSS-OF-TRACK INDICATION

In Figure 8 and 9 the computed coverage of the new western US and Canadian chains is shown. This is based on models for the coastal shielding of the Middletown, Fallon, George, Willams Lake, Shoal Cove and Tok stations, and uses observed daytime and nighttime noise levels of 200 and 600 V/M @ 35 kHz bandwidth. In addition, the nighttime plot uses an SNR threshold of -10dB, representing an acquisition limit rather than a tracking limit. Thus Figure 8 is an estimated best case, and Figure 9 a worst case.

The 2drms error expression, used within a computer program, offers a significant increase in the ease of coverage diagram preparation, and their accuracy. Perhaps most important, it facilitates sensitivity analysis, that is how critical are the assumptions on parameters such as noise level, transmitted power, and station location.

Program documentation may be obtained from the authors.

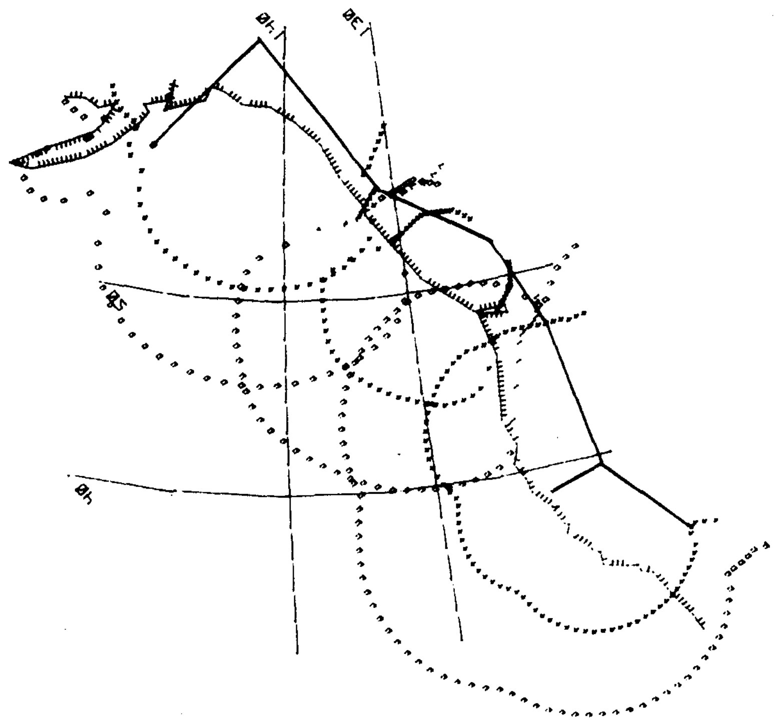


FIGURE 8 WEST COAST COMPUTED DAYTIME COVERAGE/75 AND 500 METER 2DRMS CONTOURS. "GEOMODS" FOR COASTLINE EFFECTS
200 UV/M RMS NOISE, 15 SEC RCVR TAU, -10 DB LOSS-OF-TRACK INDICATION

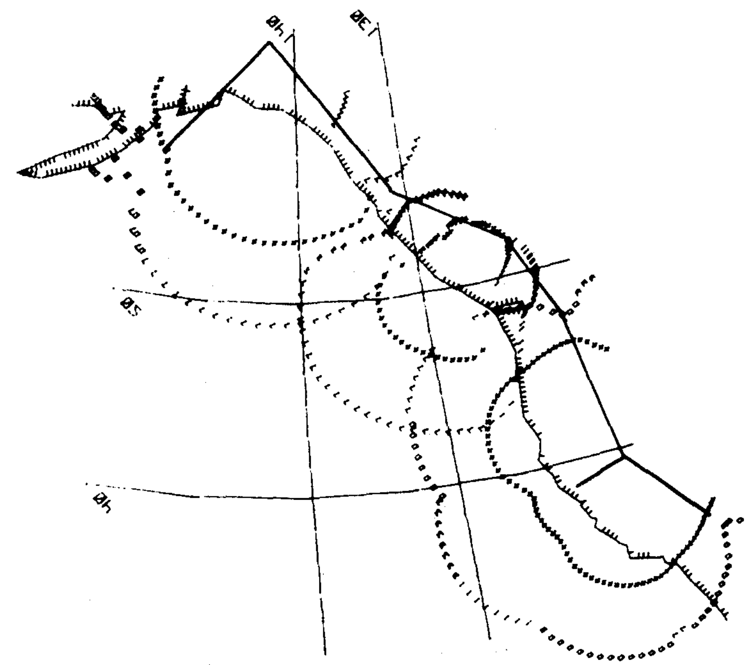


FIGURE 9 WEST COAST COMPUTED NIGHTIME COVERAGE, 75 AND 500 METER 2DRMS CONTOURS.
600 UV/M RMS NOISE, 15 SEC RCVR TAU, -10 DB ACQUISITION FAILURE INDICATION

Successive-Cycle Phase-Distortion Effect on Loran C/D Accuracy

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Abstract

In real Loran pulses, cycles deviate in length from the ideal 10 microseconds for various reasons which must be considered when highest accuracy (better than 0.1 microseconds) is desired. A simple coherent treatment of the subject is given which correlates calculations and measurements from a number of sources in graphical form and shows good agreement. The ways in which the phenomena does and does not affect accuracy in various modes and types of Loran operation are analyzed. It is shown that the present practice of adjusting the transmitter antenna current for minimum phase distortion balances radiation and propagation effects in a way which is near optimum for usual Loran operations, but suggestions for further improvement are given.

Introduction

The ideal Loran C and Loran D pulse is usually considered to have a 100 Khz carrier amplitude modulated by a specified pulse envelope shape. In such a pulse, the zero crossings of the r-f signal would be separated by exactly five microseconds, and the whole cycles would be exactly ten microseconds long. For the usual user of Loran, and for the normal use of Loran to precisions of about 0.1 microsecond, such a view is satisfactory and the pulse has been so specified (1, 2, 3). The equipment and system designer can concern himself, usually, with larger problems, such as the effects of overland propagation on the travel time of the Loran signal carrier (secondary phase factor), the possible effect of propagation velocity changes (weather effects), and the effect of changes between cycle timing and pulse envelope timing (envelope-cycle difference).

However, for the most precise present and future use of Loran, it should be appreciated that the above description of the Loran pulse is an approximation, and that small departures in the length of the Loran C r-f cycle from the ideal value may be present.

The term 'phase modulation' has commonly been applied in the past to this phenomena. However, many things have also been so-called, including: phase coding, pulse tail change for communication, and phase 'dither' or 'jitter', both intentional and inadvertent. Therefore, I have selected the term 'successive-cycle phase distortion' to describe deviations in successive cycle lengths from the ideal value, but will also use here 'phase distortion' in the same restricted sense.

Successive-cycle phase distortion is not a new problem in the Loran field, but it has been a specialized worry. Now, the interest in recent years in obtaining the maximum possible accuracy from Loran for both civilian and military uses has emphasized the need for an easily understood treatment which analyzes and correlates scattered information often provided incidentally while considering other aspects of the system.

We will consider here first the basic causes of successive cycle phase distortion, and get an appreciation of the magnitude of the phenomena. Then the effect on various types of Loran system operation is analyzed and recommendations for optimizing operation are provided. Analytical and historical details are included as appendices.

A fundamental principle, and the one behind much of the discussion here is that the transmission of any radio-frequency pulse, such as the Loran pulse, requires a band of frequencies, and that maintenance of pure amplitude modulation requires that side band frequencies above and below the (100Khz) carrier be treated equally. If there is any difference in attenuation (or phase shift) of the upper and lower side band frequencies, elementary communication theory teaches that phase modulation is introduced and cycle lengths change. Most Loran pulse energy lies between 90 and 110 Khz.

Pulse Radiation Effects

Presuming that the Loran transmitter has generated an ideal current pulse, the first distorting element is the transmitting antenna itself. The radiation field for a given current in the antenna is proportional to frequency, so the upper sidebands produce a greater field intensity than the lower sidebands, with consequent phase distortion.

The effect can be calculated as described in appendix A, and results in the cycles in the pulse leading edge being shorter than 10,000 nanoseconds by a delta amount as shown in figure 1. This incremental method of showing data has an advantage over showing cumulative cycle zero crossing error from pulse beginning or pulse peak; it can be used later in the paper to also show field test data where the pulse beginning is obscured by noise and the pulse peak is contaminated by skywave.

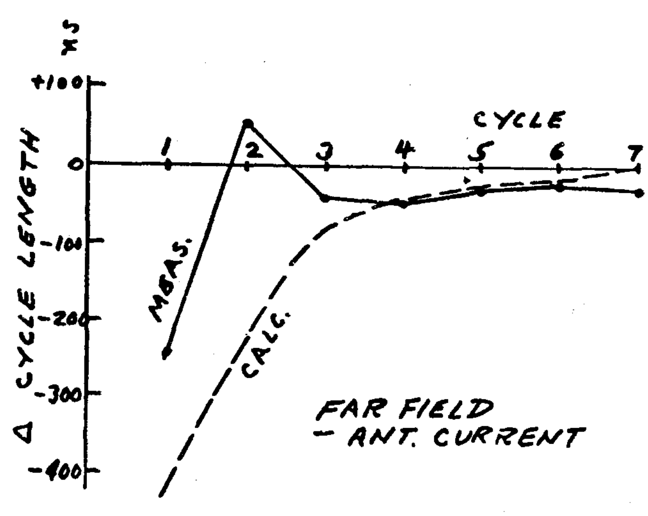


Figure 1. Successive-cycle phase distortion in radiation far field near transmitter.

Measurements of the difference between antenna current and radiation field (4) at a distance of eight miles are also plotted in figure 1. There is a general confirmation of the calculations.

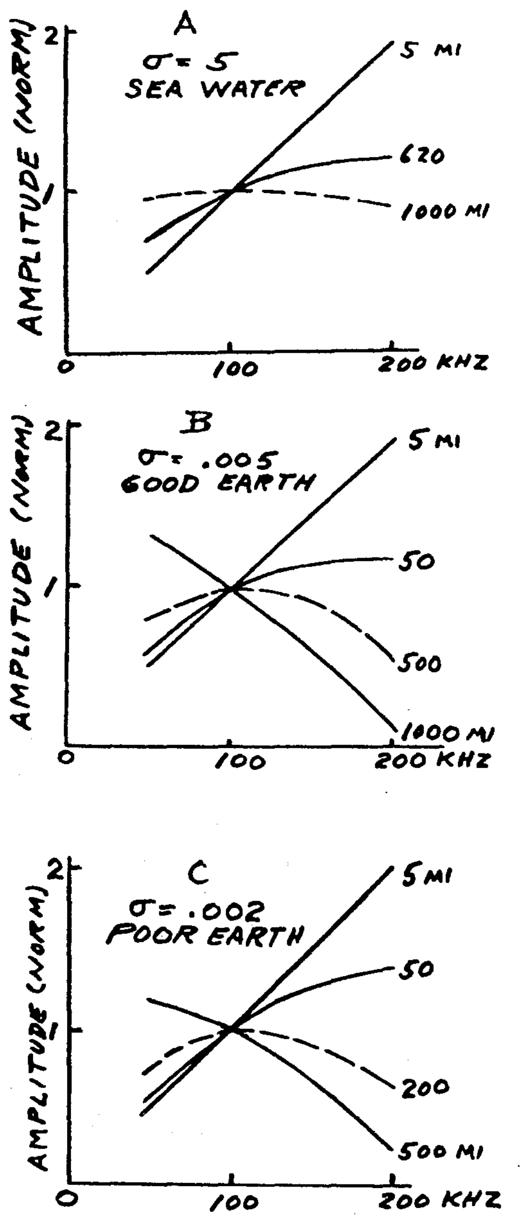
The phase distortion produced by antenna radiation has led in the past to many debates over where the phase distortion should be minimized: in the antenna current or in the radiation far field (beyond the induction field) 5 to 10 miles or more from the transmitter. However, as we shall now see, the problem is not that simple, since propagation itself over the real finitely conducting earth also affects the phase distortion. Thus, even attempts to specify successive cycle phase distortion in the far field (5) does not solve the problem, for there is not a single 'far field' applicable to all users, when tolerances under 100 nanoseconds are specified!

Propagation Phenomena

Ground-wave propagation in contrast to transmitter antenna radiation, has less loss for lower frequencies (6) and counteracts the transmitting antenna effect. The combined effect, for three different ground conductivities and a number of distances have been normalized to unity at 100 Khz, and plotted in Figure 2. At distances of about 1000 st. mi over sea water, 600 st. mi. over good earth, and 200 miles over poor earth, the two effects balance, and a minimum net phase distortion would be expected.

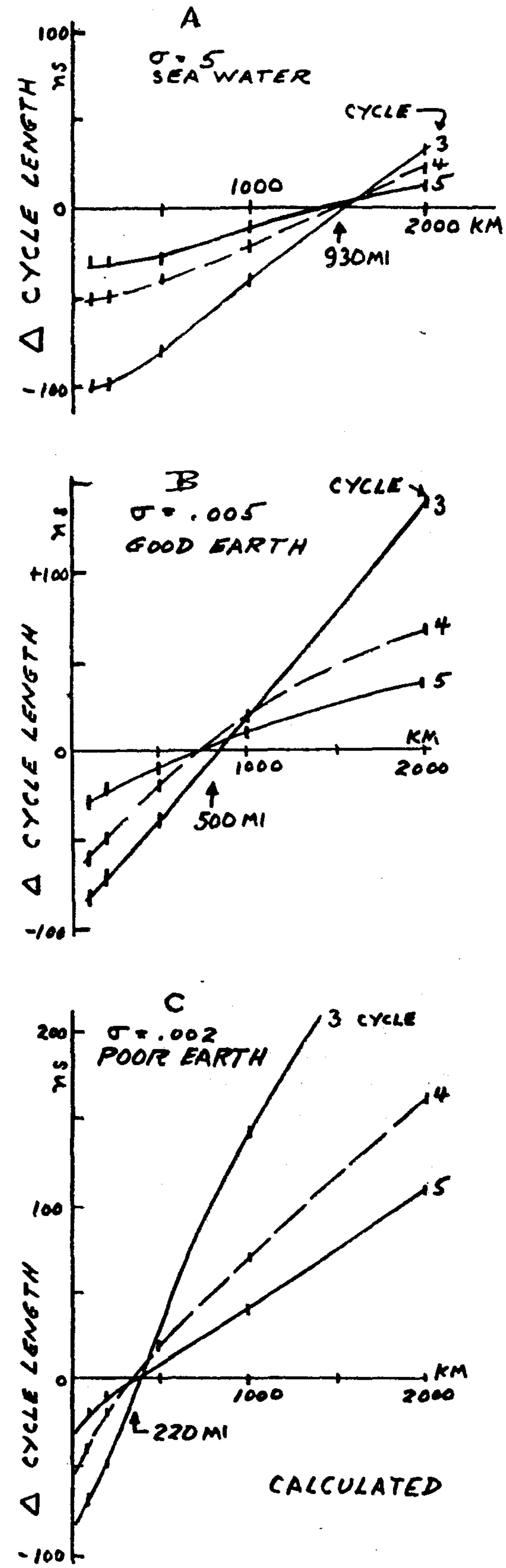
The requisite detailed calculations on the radiation and propagation of Loran C pulses have recently been published, incidental to investigating envelope-cycle difference (7) and supplementing more limited earlier calculations (8,9). Tabulations are provided in the form of total secondary phase factor, i.e., the delay relative to a continuous wave signal traveling at the speed of light. The successive-cycle phase distortion component, the delta length by which individual full cycles differ from 10,000 nonoseconds have been calculated by subtractions between tabulated values. These are plotted in Figure 3 for the three cycles between 20 and 50 microseconds from the pulse start for the same ground conductivities as in Figure 2. The distances at which there is a minimum of phase distortion (delta length) agree quite closely with the values deduced above from symmetry.

Some calculations are also available on the effect of very rough inhomogeneous terrain, (10). The particular area modeled is 200 to 300 km from a transmitter on an east-west path going over the edge down into Death Valley, California. The average surface impedance corresponds to a conductivity of .005. The delta cycle lengths derived from calculations are about twice those for smooth homogeneous terrain at the worst points, and comparable to smooth homogeneous terrain at many points.



(Above)
Figure 2. Combined transmitter antenna and ground-wave propagation frequency response, for three ground conductivities.

(Right)
Figure 3. Combined effect of transmitter antenna radiation and ground-wave propagation on successive-cycle phase distortion, for same ground conductivities.



Recently, field measurements of successive-cycle phase distortion have been made by Applied Physics Laboratory, incidental to investigating envelope-cycle difference and secondary phase factor (11). The measurements were made on paths from three Loran stations, as shown in Figure 4, which all passed through the Naval Observatory, Washington, D.C. so that one-way propagation times could be measured relative to the observatory. That is not important for our discussion here; what is of interest is the tabulation of a number of measurements of cycle zero crossing times for simultaneous sets of measurements made with carefully matched receivers at a fixed reference site, (the Naval Observatory) and in succession at the 10 other sites.

A detailed description of the method of abstracting the desired information from the test measurement is given in Appendix B. The results of the analysis are presented in Figure 5. Since neither the transmitters or receivers had negligible effect on the individual measurements, it is not possible to obtain an absolute measure of delta cycle length, as calculated and shown in Figure 3, but it is possible to abstract precise measures of the relative length of each specific cycle at the various points along each propagation path. In Figure 5, the shape of each curve is certain, but each individual curve contains an uncertain vertical shift.

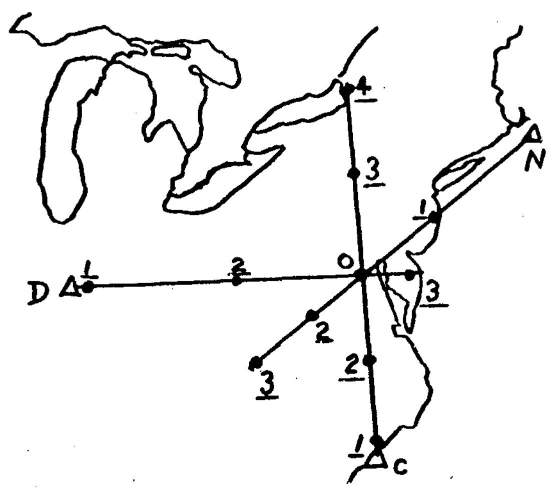
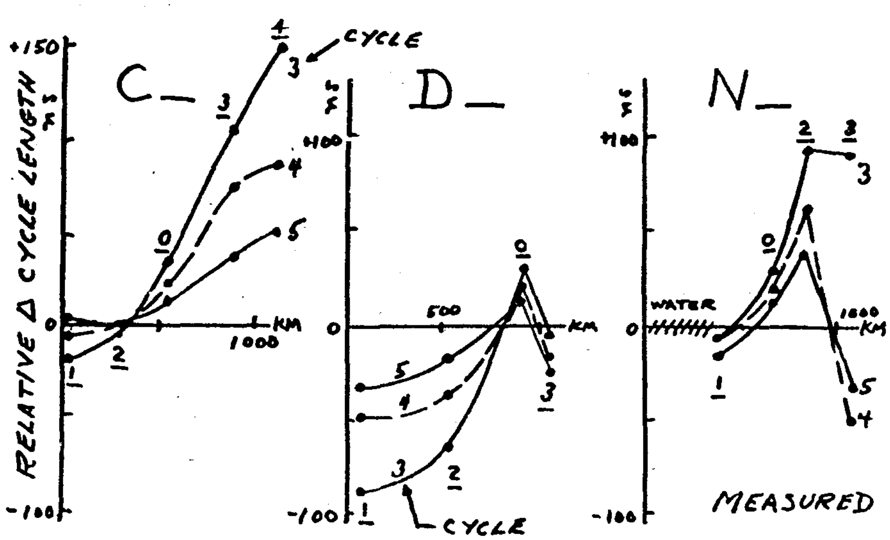


Figure 4.
APL propagation research measurement sites. C is loran station Carolina Beach. D is loran station Dana. N is loran station Nantucket. O is Naval Observatory, Washington.

Figure 5. (Below)
Successive-cycle phase distortion deduced from APL propagation measurements, for sites on each of three propagation paths.



The curves of Figure 5 have shapes similar to those of Figure 3 with the exception of the data for two of the most distant points: N-3 and D-3. A strenuous but futile attempt was made to improve the published data for these two sites. The data for these sites was peculiar in other ways also, and was recognized by APL as non-conforming to the original purposes of the measurements. Obvious possibilities such as skywave interference do not appear reasonable -- measurements were made during summer days, when the skywaves were observed to be very small.

The curves based on measurements match most closely the calculated curves for .002 conductivity, with perhaps an indication of slightly higher conductivity. This is quite consistent with signal attenuation data and secondary phase factor data in the APL Report, in Figures F-16 and F-14 of Vol. D, as well as other published conductivity values for the area.

It should be mentioned that an older set of phase distortion measurements made over a 20 Km square in a mountainous region near Asheville, N.C., (12) showed much larger variations in cycle length than even the anomalous sites above. In some cases, the length of the 3rd cycle measured in error by over one microsecond. The published paper gives few details by which the precision or confidence of the measurements can be assessed. Some additional information was found (13) indicating that the measurements were obtained with a Loran timing receiver by scanning the pulse with a sampling gate at rates up to one microsecond per second, with a slow recorder chart speed, limiting scaling resolution to 0.3 microseconds. There is no data on the deviation of the measurements due to noise, but it was noted that the region was characterized by large changes in signal amplitude between measurement sites, as well as relatively large changes in secondary phase factor between sites, suggesting reflections from the mountains. Further attempts to obtain additional information or references was unsuccessful. It can be readily seen that the confidence of the Asheville measurements is nowhere as good as the APL measurements, where each point represents the average of one hour of data.

Transmitter Pulse Generation

Presently operational Loran C vacuum tube transmitters (AN/FPN-42, 44, 44A, 45) and Loran D transistor transmitter AN/TRN-21A have the output pulse shape and successive cycle phase determined at least partially by the antenna coupler tuning and antenna tuning. Present standard practice is to minimize the phase distortion by fine-tuning of the antenna and coupling network when the station is initially commissioned. West Coast stations are understood to have had antenna current except the first two cycles initially adjusted to within 50 nanoseconds absolute (14) well within the informal system characterization (1). The recently installed Loran Replacement Equipment (15) provides precise measurement and control of pulse shape and envelope cycle difference but does not control successive-cycle phase distortion. Of course the effect of any change in 30 microsecond zero crossing timing is controlled.

Some measure of the phase distortion tolerances of older Loran stations can also be obtained from the APL data; as analyzed in Appendix B, the maximum difference between Carolina Beach, Nantucket and Dana transmitter corresponding 3rd, 4th or 5th cycle lengths was about 75 nanoseconds (in 1975).

Newer solid state SCR transmitters have various closed-loop controls of cycle zero timing to minimize successive-cycle phase distortion. The Megapulse SCR transmitter built for the USCG and the Sperry AN/TRN-38 Loran D transmitter built for the USAF are of this type. Antenna current successive-cycle phase distortion is understood to be under 50 and 10 nanoseconds, respectively, over most of the leading edge (17A, 17B).

The Megapulse Accufix/Pulse-8 low power transmitter utilizes automatic antenna tuning to maintain low phase distortion (16). The tuning is adjusted to hold phase difference between 3rd cycle zero crossing and a later cycle zero crossing to under 10 nanoseconds. Distortion in the interval between these points is also minimized by initial adjustment of antenna coupling network.

By far the easiest and most reliable parameter to monitor and control at the transmitter station is antenna current. Should it be considered desirable to make the cycles of antenna current non-uniform several options are available. The transmitter control design may include the capability of generating non-uniform cycle length, as in the AN/TRN-38 Loran D transmitter. An analog circuit can be inserted in the current monitor path to provide the desired transform to the current at the control point (4), but also affects envelope-cycle difference.

Many signal simulators imitate transmitters in using tuned circuits to shape the pulses. A newer technique, which seems to have originated independently in several organizations, utilizes a digital-to-analog converter to directly form the shaped RF pulse envelope and cycles without the use of tuned circuits. Such methods should practically eliminate phase distortion in simulators. Even fairly large distortion should not cause trouble when testing, provided it is equal on all signals, insofar as time difference error is concerned, but may have a secondary effect on cycle selection and other receiver performance.

System and Receiver Considerations

If the receiver does not equally attenuate upper and lower sidebands, successive-cycle phase distortion of individual transmitters will occur. In time-difference receivers, the effect will tend to cancel; this, of course, is why Loran C works as well as it does and why successive-cycle phase distortion has not been a worry for most types of users. If the signals from master and secondary have different successive-cycle phase distortion, but the timing is monitored by a monitor receiver having a similar bandwidth as the user receiver, then there still will be no time difference error, if both monitor and user sample at the same point on the pulse. Otherwise there may be some small secondary order effects which, unfortunately, I do not have information on to elaborate at this time. In any event, if there is no change to any differences between master and secondary signals, there will be no error in time difference repeatability.

It is desirable to have the signals to have similar phase distortion to reduce the possible error if sampling occurs at a non-standard point on the pulse; this may occur accidentally due to misadjustment of a receiver, or deliberately if the user wants to obtain a better signal to noise ratio. This may be done in Loran D or other short range uses where longer skywave delays and lesser skywave amplitudes so permit (18).

It may be desirable to reduce phase distortion to improve operation of other receiver functions, such as cycle selection. Distortion is minimized when receiver response to upper and lower sidebands is approximately equalized. Band pass filters designed by transforming a low-pass filter design to 100 Khz will result in a filter having geometric rather than arithmetic symmetry about 100 Khz, and will emphasize the upper sideband. This effect can be counteracted by a slight detuning of the filter toward lower frequencies, and/or by adding low pass filtering.

Notch filters used to reject narrow-band interfering frequencies will also introduce a phase shift into the Loran signal, which is a function of both notch frequency and sample point (19), i.e., successive-cycle phase distortion.

For time of arrival measurements compensation for the distortion is required if notch filter frequency or sample point is changed. This compensation can be accomplished either by open loop predetermined correction (19) or by the use of pilot pulses (20).

Recommendations For System Optimization

In view of the counteracting effects of antenna radiation and groundwave propagation, I recommend as standards that antenna current be controlled as at present to minimize successive-cycle phase distortion in the transmitter antenna current, and that receivers be tested with simulators having minimum successive-cycle phase distortion. This seems to be the simplest and best overall compromise for normal receiver and system operation.

The distances at which propagation distortion balances radiation distortion and produces minimum net effect, as shown in Figure 3, are within the usual user distances. Particularly over land, the zero error region is in the central portion of the service area. By having a point of minimum error in the central portion, errors are negative at shorter ranges and positive at longer ranges; if the transmitter antenna current is adjusted to produce zero error in the radiation far field but near to the transmitter, the error will be positive at all user ranges and the maximum magnitude will be larger than when the error is balanced.

Modifications to the above, to minimize distortion in geographical areas of particular interest should be considered the subject for further study which could also consider second order effects of transmitter and receiver tolerances on overall system performance.

Appendix A -- Mathematics of Antenna to Far Field Transform

The familiar Loran C and Loran D pulse has been widely defined in the form: $f(t)=(t/65)^2 \exp(2-2t/65)\sin(\pi t/5)$, t is in microseconds. Phase code and envelope-cycle difference (ECD) terms are not shown. Where the antenna current is in the form above, the far field has been stated to be in the form of the derivative: $f'(t)=(t/65)^2\exp(2-2t/65)[\cos(\pi t/5)+(1/6.5\pi)(65/t-1)\sin(\pi t/5]$. The second term in the brackets is a rapidly decaying quadrature component which produces the successive-cycle phase distortion, as shown in Figure 1. The equation for f'(t) is a rearrangement of that in reference 4, in accord with reference 21. The change of primary term from sin to cos also produces a 2.5 microsecond change in ECD.

Appendix B -- Analysis of APL Test Data

In the APL Report (Reference 11) Tables F1 and F2 of Vol D list zero crossing times for various cycles in the Loran pulses deduced from measurements, with one zero-crossing normalized at 30.000 microseconds, the usual Loran C sampling point. Three data samples of 20 minutes each are listed for each site*. The three data segments for each site were averaged, and then the actual measured lengths of 3rd, 4th and 5th r-f cycles between nominal "20", "30", "40" and "50" microsecond zero crossings were obtained by differencing these zero crossings. On days 154 and 188 both receivers were at the NAVOBSY -- the one normally there whenever measurements were made at a field site, and also the one used at the various field sites. Thus the consistency of measurements between the two receivers can be evaluated. The two receivers agree within 5, 1, and 4 nanoseconds for the 3rd, 4th and 5th microsecond cycles, respectively, even though the actual lengths of the cycles changed as much as 95 nanoseconds between the two measurement days, and the cycles themselves measure shorter than 10 microseconds by as much as 285 nanoseconds. Therefore we have high confidence in differencing the two receivers on other days to obtain the changes in cycle lengths produced by propagation, and in assuming that the difference in measurements on D and N signals at NAVOBSY would be the same as the difference in the measurement on C. This difference is plotted as the site CO, DO and NO data in Figure 5.

Note neither the actual phase distortion present in the individual transmitter antenna currents or the phase distortion produced by the non-symmetry of the receiver r-f pass band are individually known. Nevertheless the differences between the phase distortion of the individual transmitters can be approximated by assuming (reasonably) that the receiver has not changed, and additionally making a minor correction (from Figure 3A) for the overwater path between transmitter N and site N1. The maximum differences between average length of corresponding cycles of the various transmitters (in summer 1975) was 75 nanoseconds.

An indication of the effect of changing transmitters at C (in summer 1975) can be obtained by comparing CO day 228, when a different transmitter was used, data with other CO data. The only significant change is an increase of the 3rd cycle from 170 nanoseconds average to 228 nanoseconds -- a change of 58 nanoseconds.

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*To compensate for an exception in the sampling time, as noted in APL Vol D page 185, the middle data segment for Day 188 in Table F1 was shifted 5 microseconds left; another exception for Day 161 data appears to have been already compensated.

Appendix B - cont'd.

All cycle lengths measure short compared to 10.000 microseconds. This is consistent with the receiver pass bands, shown in APL Vol C Figure 6, which are definitely asymmetrical about 100 Khz, with less attenuation for higher frequencies.

Appendix C -- Historical Note

In "Cytac" and early Loran C. the processes of phase detection and sampling were separated because of then existing limitations of equipment complexity and frequency response. The output of the phase detector was a "phase envelope" which was sampled and then zeroed at the sample point by a servo-loop. The point of sampling was controlled by the envelope servo. Any phase distortion was readily apparent at the phase detector output -- the phase envelope did not go to zero simultaneously along the pulse leading edge! Since the envelope servo could have a few microseconds error in locating the sample point, the differential phase modulation represented a potential cycle phase error. Direct r-f sampling as presently used eliminates that source of error.

The desirability of tuning the transmitting antenna and matching network accurately to minimize phase distortion was well recognized during Cytac work. the differential phase distortion between master and secondaries was routinely measured in the field, but the only measurement of the effect of propagation on phase distortion (page 246, Fig. 196 of ref. 22) was made with a single receiver first at a distance of 37Km from a transmitter and at least a week later at a distance of 1098Km. The measurements correlate in magnitude but not in detail with Figures 3 and 5 of this paper.

A brief general caution on Loran C operating phase distortion limitations and propagation effects was published previously (23).

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PRODUCT OBSOLESCENCE

John M. Beukers
President, Wild Goose Association

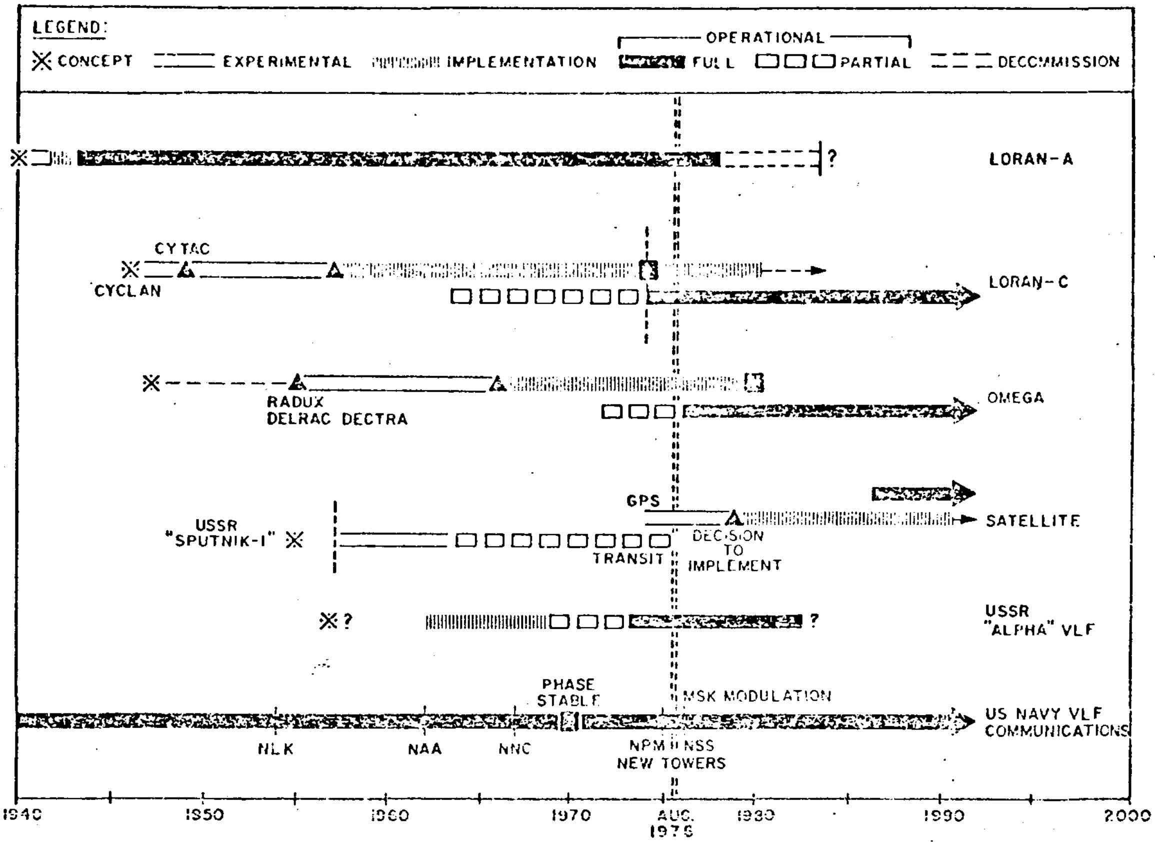
As a way of introduction to Loran-C I would like to discuss with you this morning a matter unique to the American way of life that effects all of us and our pocketbooks - Product Obsolescence.

With radio navigation product obsolescence can occur in three ways, first the system of navigation can be changed, secondly the product used for navigation, the receiver can be obsoleted by new improved equipment having better performance and capability. Thirdly, changes can be made to existing navigation systems that require modifications to our new receiving equipment. The latter can be largely overcome by timely publication and control of system specifications so that changes can be made only through regulatory procedures with public hearings. Obsolescence from new improved equipment is healthy since it is generated by user demand encourages competition and does not necessarily force the user into involuntary expenditure. This leaves navigation system obsolescence which I will address this morning.

You may recall that in 1974 the Secretary of Transportation made the decision that Loran-C would become the precision navigational aid within the U.S. Coastal Confluence zone. With this decision a plan for the curtailment and eventual phasing out of the Loran-A services was announced. We are not sure exactly how many users this decision has affected, but certainly many of you here today have a financial and operating interest in the changeover.

Originally it was thought that as soon as Loran-C came on the air, Loran-A in that area could be phased out. Talk of a two year transition phase was common in government and industry circles. As time has passed I believe we in the radio navigation community have come to recognize that the change in radio navigation systems just isn't that simple. When people's livelihoods rest upon using a system they have worked with for years and in which they have a financial stake the problem of change becomes very real and has a different ring to it. Technological improvements and government funding considerations get modulated with public demand for answers to why, when and how much?

Let me pose this question - How long is Loran-C going to be around before a new and better system is foisted upon us? I am interested in the answer to this question and would like to share with you some thoughts as to the longevity of the Loran-C system.



Long Range Radio Navigation Implementation - Operation Schedule

Let us review the history of radio navigation by going back to 1940. As World War II progressed the exceedingly rapid pace of technological progress made the development a reliable radio navaid imperative. Towards the end of the war Loran-A came into being within a surprisingly and impressively short time scale. As we know Loran-A is with us today and some stations will probably still be on the air well into the 1980's. A 40 to 45 year life. The transition phase for Loran-A to Loran-C started in a small way in the early 1970's, received the official stamp in 1974, will reach a peak between now and 1980 and will decline during the early 1980's, to be completed by about 1985. A transition period we observe to be in excess of ten years.

The Loran-C implementation program is now well under way in this country and overseas and will be essentially completed by 1985. By this time the majority of users will have converted or purchased Loran-C or Omega radio navigation sets depending upon their individual requirements. We could say that the clock starts running for Loran-C around 1980, more than 20 years after the first experimental transmissions took place. Loran-C will be with us now until a new and better system becomes available, so let's take a look at what's on the drawing boards. An expensive and technically sophisticated system of navigation is currently being developed. Taxpayers money amounting to hundreds of millions of dollars has already been appropriated much of which has been spent. A total expenditure in excess of 1 billion is anticipated. The system is known as the Global Positioning System (called GPS or NAVSTAR), it will use 24 satellites together with tracking ground stations to provide three dimensional positioning anywhere on the globe. Some of you may have heard or even used Transit, a forerunner to the Global Positioning System. It provides precision positioning information and is now almost universally used to establish datum around the world. Unfortunately because of the infrequency of satellite passes the Transit system can be used only for position fixing. However experience with Transit leads us to believe that the Global Positioning System will be the ultimate navigation system and will provide precision navigation in three dimensions throughout the world to be used by <u>all</u>, so we are told.

But when? At what cost and who pays? There are those in government who tell us that GPS will be with us by 1985 and allowing a two year transition we can start to phase out Omega and Loran-C in the late 1980's. I challenge these statements and offer my own schedule based upon realism and history. In the first place it is highly unlikely that a system as technically sophisticated can be brought into service in ten years during peace time. Secondly, it will take two or three generations of user equipment to develop operationally acceptable user equipment to sell at a price competitive with current and future generations of Loran-C and Omega equipment.

Assuming no break in GPS system development and implementation funding and no serious technical problems it would seem reasonable to predict that by 1990 the system would be ready to be used by the people such as yourselves. Perhaps in 1990 the Secretary of the Department of Transportation will announce that GPS is to become the precision Navaid for land, sea and air. We can compare this point in time with 1974 which started a ten year transition period. If this reasoning appears logical then Loran-C will be with us until the turn of the century. But there is more to it than that. By 1990 the number of world wide users of Loran-C and Omega will probably be ten times that of Loran-A users today so that if anything a year 2000 phase out of Loran-C is too near. Remember Loran-A will have been with us for more than 40 years - I predict Loran-C will have a similar life span.

My message to you, the loran user, this morning may be summarized as follows:

(a) Based upon the history of navigation system development and implementation, and a realistic assessment of user sentiment in my opinion Loran-C will be with us for at least 25 years;

(b) In providing navigation services such as Loran the government has a responsibility to state what the life of a system is to be;

(c) Congress must become informed as to the serious and involved process of transition from one navigation system to another. If the Global Positioning System becomes a reality there will be a 10 to 15 year transition period which must be planned carefully;

(d) The optimistic and unrealistic development and implementation schedules given by proponents in the government of the new Global Positioning System must be questioned seriously and brought into focus with facts of life in the user community. Congress must be persuaded not to short change existing navigation services by channeling funding to new system development based on the erroneous assessment that an accelerated program will save the taxpayer money;

and lastly

(e) You, the user, must be heard in this expensive game of technological leap frog and not be used as a pawn in the giant military complex. It is up to each one of us to make our navigation needs and concerns known to our congressmen.

WEST COAST LORAN-C - THE PROMISE AND THE PRODUCT

ABSTRACT

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The West Coast Loran-C system, stretching from Baja, California to the Aleutian chain of islands, has been operational for almost six months. This largest ever, strictly civil loran project, has been accompanied by a great deal of ballyhoo on the one hand and skepticism on the other. It is appropriate to review the results to date.

The initial objectives of coastal Loran-C are reviewed with emphasis on chain control, reliability, signal availability, coverage and accuracy. Actual user experiences both private and government are compared with the Coast Guard's initial objectives and differences are discussed. Future efforts to bring actual results into closer conformity with predicted results are recommended where necessary.

Editor's Note: Capt. Manning's paper was not available at the time of publication. However, it is suggested that persons interested in the paper contact the author directly.

DEVELOPMENT OF CHARTING CORRECTIONS FOR LORAN-C CHARTS IN THE COASTAL CONFLUENCE ZONE

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ABSTRACT

With the adoption of LORAN-C as the primary electronic navigational control for the Coastal Confluence Zone (CCZ) and the requirement for one-quarter nautical mile positioning within the CCZ shipping lanes, the necessity of extracting maximum accuracy from the system for the maritime industry is imminent. This paper describes the current approach used by the Defense Mapping Agency Hydrographic Center (DMAHC) in determining the most accurate corrections to be included in the electronic lines of position (LOP) printed on National Ocean Survey coastal charts. These corrections, termed Additional Secondary Factors (ASF), are theoretical and will have to be certified in the field at some future date.

As an introduction to the remainder of the paper, the report of an informal small area survey intended to verify the charted LOP lattice incorporating ASF corrections for the Upper Chesapeake Bay, is included. The survey findings demonstrate the stability, and therefore, correctability of the LORAN-C system in near shore waters. The lattice verification aspect of the survey comprises both a success and a failure, which leads into a brief explanation of a newly developed correction program by DMAHC. This is followed by a discussion of the importance user involvement will have in future correction development for the LORAN-C Navigation System.

INTRODUCTION

In July 1974, the National Plan for Navigation, which is maintained by the Department of Transportation (DoT) was amended. The amendment, as published in the Federal Register, designates LORAN-C as the government provided radio navigation system for the U.S. Maritime Coastal Confluence Zone (CCZ) and Great Lakes. The U.S. Coast Guard is proposing the addition of a stipulation which will state that vessels of 1600 gross tons and over, when transiting the CCZ, must be equipped with a LORAN-C receiving unit. The CCZ is defined as the seaward approaches to land - from 50 nautical miles (n.m.) or the 100 fathom curve, whichever is greater, to the coast or harbor entrances. The Zone is to be divided into shipping lanes varying in width from about 1 n.m. at harbor entrances to 5 n.m. at the outer extremities. An accuracy requirement for the navigational control system of 1/4 n.m. 95% of the time has also been imposed by DoT. This requirement, if met, should enable a vessel to stay within its designated shipping lane.

The National Ocean Survey (NOS) is tasked with producing navigation charts for the CCZ waters, and because of the CCZ requirements, these charts must provide a coastal navigator with LORAN-C lines-of-position (hyperbolic "lattices") which are capable of providing the required 1/4 n.m. position accuracy. In an attempt to insure this accuracy capability, the U.S. Coast Guard has requested the Defense Mapping Agency Hydrographic Center (DMAHC) to generate LORAN-C lattice corrections for NOS charts to compensate for signal retardation caused by non-homogenous overland propagation paths. Charts published by NOS prior to this request contained LORAN-C lattice corrections for an assumed all seawater signal propagation path only and did not take into account any other signal phase retardation. The seawater correction referred to is called a Secondary Phase Factor (SF), the primary phase factor is the theoretical free velocity for an electromagnetic wave. Any correction for phase retardation caused by overland conductivity, when added to the SF, is termed the Additional Secondary Phase Factor (ASF). Omission of the averaged ASF, now applied to NOS LORAN-C charts, can account for position errors on the order of 1 n.m. (See Figure 1).

To date, DMAHC has furnished NOS with ASF corrections for some 200 coastal charts. Present ASF corrected LORAN-C charting coverage for Alaska and the West Coast is shown by Figure 2.

No correction is given for charts of 1:1,500,000 scale or smaller. At these scales, the magnitude of the ASF correction is not significant and no single averaged correction could represent all of the corrections for a chart depicting such a large area.

Figure 1. A depiction of the relationship between charted Loran-C hyperbolic lines-of-position uncompensated for groundwave signals and the observed lines-of-position.

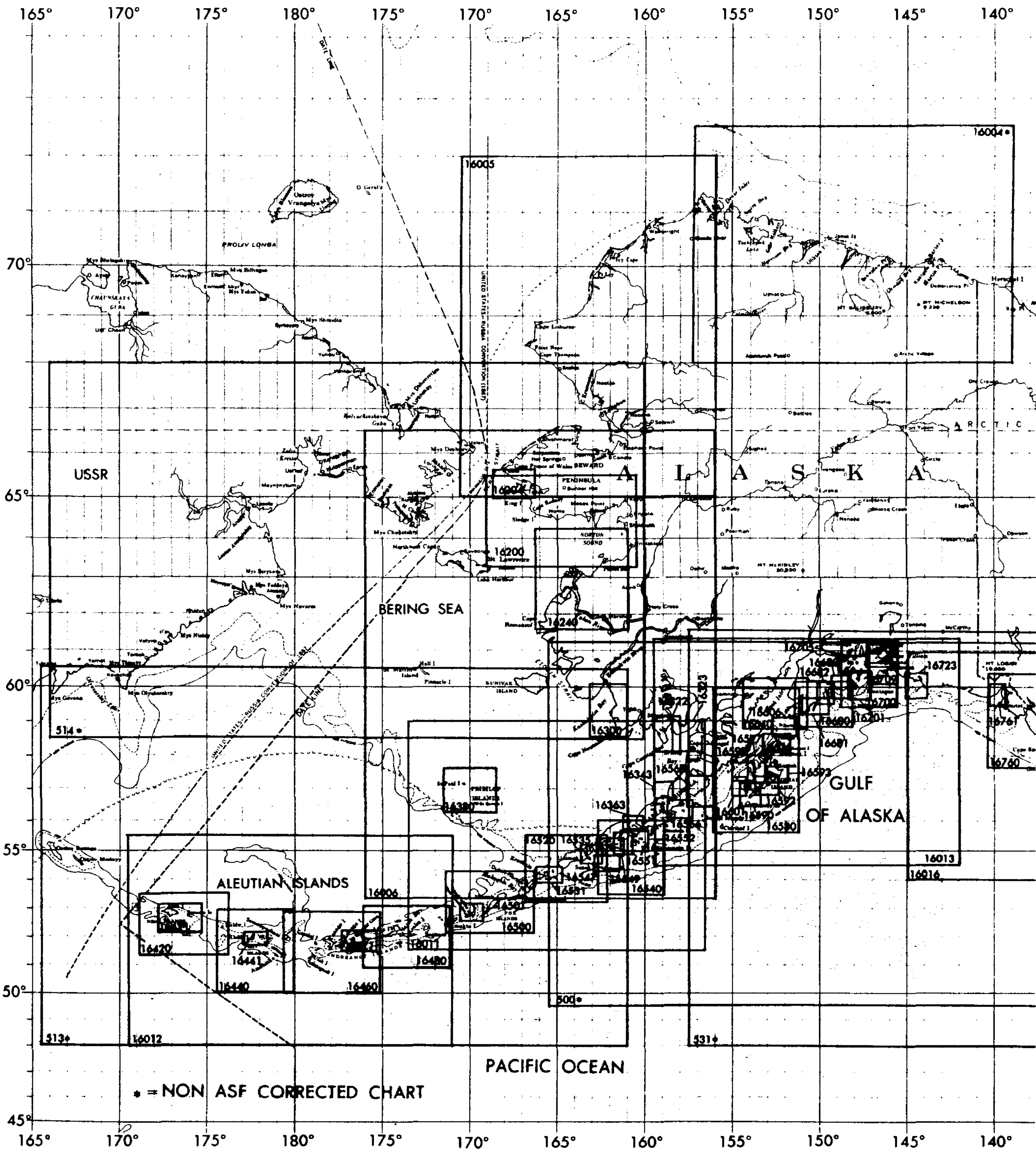

Figure 2. Loran-C charts presently on issue for Alaskan waters.

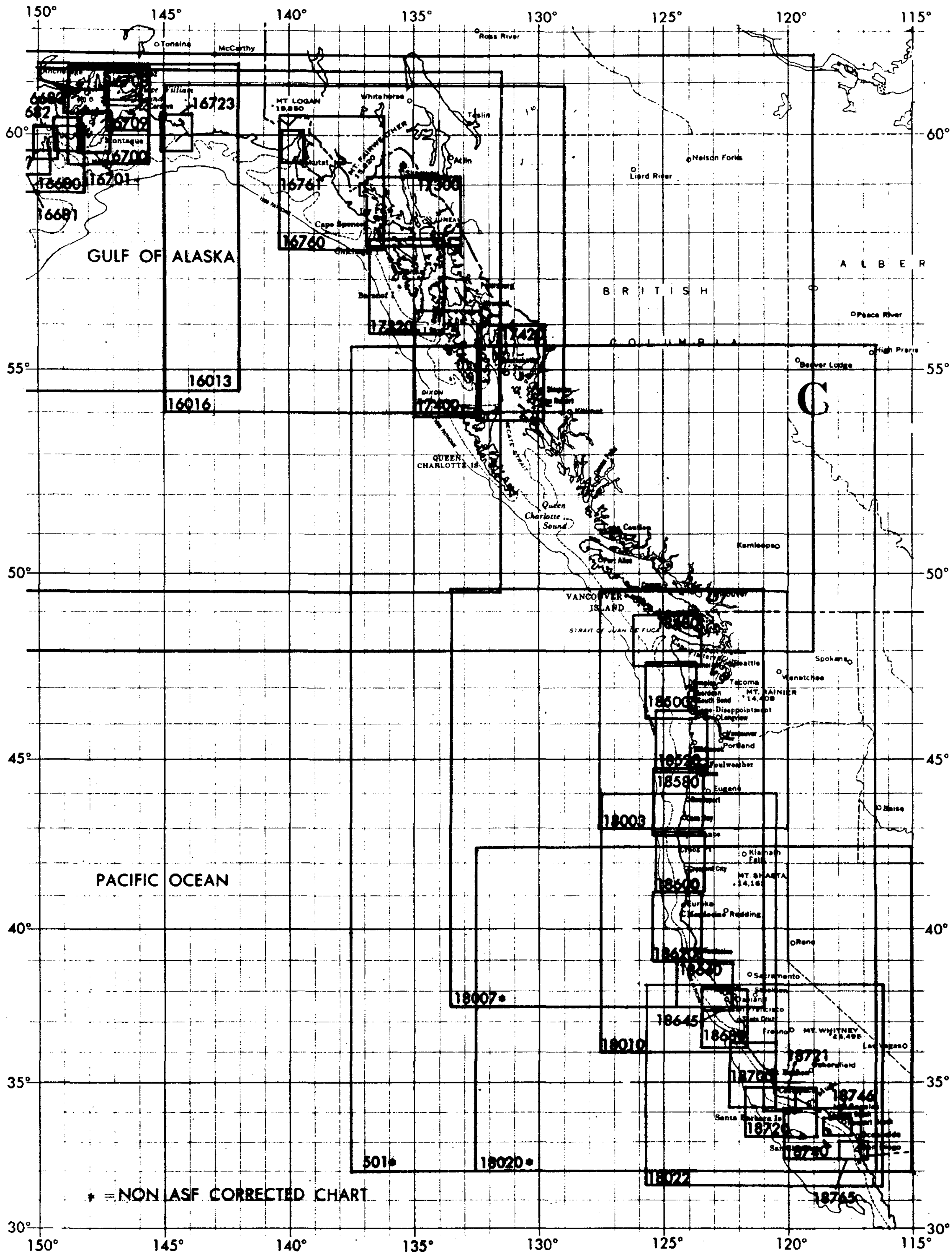

Figure 2. Loran-C charts presently on issue for West Coast waters.

ASF DETERMINING PROCESS

ASF corrections are theoretically derived corrections based upon hand measurements of mapped ground conductivity segments lying between each LORAN-C transmitter and geographic positions in the area to be charted. The LORAN-C signal retardation values for particular ground conductivity codes assigned to these segments have been established by the National Bureau of Standards (NBS) and are a function of transmitter proximity and type of terrain encountered along the transmission path. Terrain/conductivity code value correlation is determined by the U.S. Coast Guard after a study of field monitored calibration data has been made.

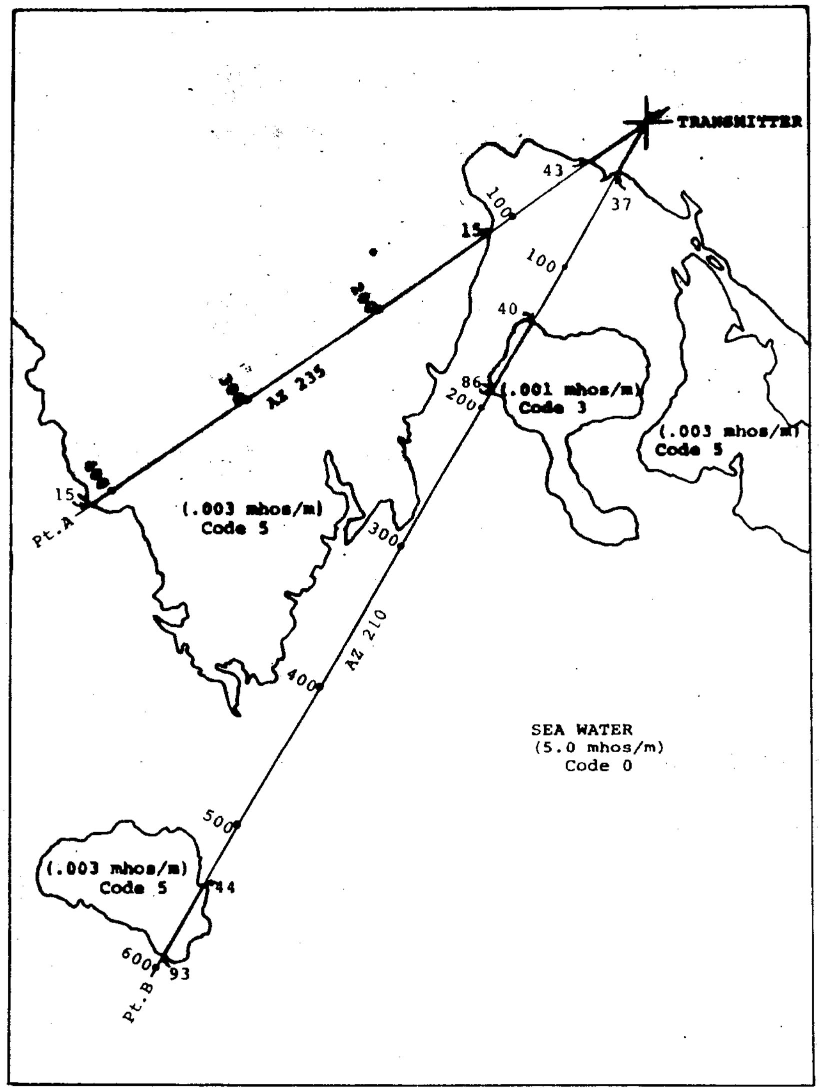

Figure 3. Source map with azimuths and measured conductivity segments.

Figure 3 illustrates the hand measuring process (scaling) by which information is taken from a source map and translated into a useable form for recording and storage. Two azimuths, 210 and 235 degrees, have been drawn on the map and their construction is representative of the computerized portion of the process. Also included in the map are the assigned ground conductivities and their numerical codes as determined by a Coast Guard calibration team. To allow for measurement of long distances accurately, azimuths are broken into 100 n.m. segments each terminating with a "control Point" code. The land or water conductivity segment lengths along the azimuths, between control points, are measured and recorded by hand on forms for subsequent ASF computations.

The conductivity segment data and azimuth values are input to Millington's Method based computer programs designed to determine the ASF correction for any selected geographic position. Millington's Method is a prediction formula which, in simple terms, states that the direction of radio wave transmission across a medium does not affect the response of the medium. Millington's Method predicts a phase delay, in terms of microseconds (Usec), by computing a correction from a transmitter to a receiver location, reversing the process and then averaging the two values. The two computed values are not identical because the conductivity segment retardation values, as determined by NBS graphs, are biased by the proximity of the transmitter.

APPLICATION

Positions chosen for computation of the ASF correction for a particular coastal chart are selected from an area lying between 10 and 50 n.m. from land. The 10 n.m. from land limitation is imposed for computer program convenience and because of the theoretical uncertainty of radio wave propagation near land/sea interfaces. It is generally believed that this area of uncertainty lies within 3 n.m. of the interface. This "area of uncertainty" is of major concern since the corrections being developed are for coastal charts. The computation points are set at a minimum interval of 10 minutes of latitude and longitude. A sufficient number of points are selected and arranged so that the resulting matrix, from which an averaged correction can be determined, truely represents the charted area.

The individual Master and Slave transmission path corrections for each point are then subtracted algebraically, yielding a single correction which can be applied as a hyperbolic line-of-position or lattice correction. These hyperbolic corrections are then averaged to get one representative lattice correction for the charted area. This correction is then compared with adjacent corrected charts to assure some measure of continuity. The calculated average ASF correction for each electronic lattice is then tested by a 1/4 Mile Accuracy Program. This program insures that the difference between the geodetic positions derived using the averaged ASF correction and the geodetic position derived using the actual ASF correction, for each selected point, is not more than 1/4 n.m. This test is run in an effort to ascertain whether or not a single averaged correction can adequately represent the ASF for a particular charted area. In the future, a program which will incorporate ASF corrections at any interval into the lattice could be employed to yield systematically corrected, rather than shifted, LORAN-C lattices.

The corrections agreed upon for each chart are then sent to NOS, where they are added algebraically to the applicable LORAN-C system coding delay which includes the assumed seawater correction (SF) previously mentioned. This algebraic addition to the coding delay, in effect, changes the baseline length between the Master and Slave transmitters, which shifts the lattice to offset the delays caused by the differing propagation paths. The ASF corrected lattices are then overlayed on their base charts for publication. An accompanying note (Figure 4) explaining the incorporated lattice shift is printed on each chart.

The Loran-C lines of position overprinted on this chart have been prepared for use with groundwave signals and are presently compensated only for theoretical propagation delays which have not yet been verified by observed data. Mariners are cautioned not to rely entirely on the lattices in inshore waters. Skywave corrections are not provided.

Figure 4. Chart Notice explaining compensating Loran-C lattice shift.

CHECK SURVEY

In June of 1976, a small area survey was conducted in the upper portion of the Chesapeake Bay to assess the validity of the theoretical ASF values forwarded to NOS for that "land/sea interface" area. The report of that survey follows:

STUDY OF LORAN-C OBSERVATIONS MADE IN THE CHESAPEAKE BAY

A. INTRODUCTION:

This report is to describe an informal LORAN-C system operational survey and to discuss some of its implications regarding the Defense Mapping Agency Hydrographic Center's LORAN-C Additional Secondary Factor Program (ASF). The impetus for the study was curiosity as to whether or not LORAN-C lattice corrections supplied by the DMAHC to the National Ocean Survey could be substantiated by empirically derived values.

B. EQUIPMENT DESCRIPTION:

1. The survey was conducted in the Chesapeake Bay during the weekend of 5 June 1976 by Messrs. R.J. Doubt, D.M. Rigor, and D.A. Stout of the DMAHC. The platform used was a 37' ketch (Figure 5); the power supply, a small gasoline motor generator set (M.G. set) was provided by the Naval Oceanographic Office; and the LORAN-C receiver, a Decca DL-91, was provided by the DMAHC. M.G. Set/DL-91 compatibility was established ashore by adjusting the DL-91 input voltage requirements prior to the start of the survey. Unfortunately, the M.G. set is an unregulated power supply and despite frequent voltage output monitoring, the DL-91 fuses were blown on one occasion, which resulted in a loss of data near the Cheaspeake Bay Bridge. No other adverse consequences were noticed while using the unregulated power supply. Time difference (TD) values were compared with those received while using regulated power before and after the survey and the differences were nil.

2. The gear was placed aboard the sailing vessel with the antenna and coupler mounted atop the mainmast (37' above the water), the M.G. set on the fore deck, and the DL-91 in the cockpit. During the survey, the antenna coupler was lowered to the deck because of rough seas, and one of the main mast stainless steel shrouds was substituted for the antenna with no impairment of signal reception. The vessel was "swung" before departure to determine additional compass deviation caused by the deck mounted M.G. set.

Figure 5. Vessel used in Loran-C signal monitor survey.

C. SURVEY AND DATA DISCUSSION:

1. One hundred miles of track line were run, primarily under sail, with several stations taken at anchor. The area covered extended from the Chesapeake Bay Bridge in the north to a point near the mouth of the Patuxent River in the South. Navigational control was dependent upon passing close to major buoys (10-20

feet) and upon anchorages alongside lighthouses, in harbors, and near daymarkers in addition to magnetic bearings (Figure 6). Navigation control quality can therefore be directly related to the charted positional accuracy of the aforementioned navigation features which should be excellent in consideration of the proximity of land.

Figure 6. On station.

2. The recorded data was examined for the characteristic LORAN-C "10 usec jumps" and then compared with theoretically derived microsecond values for the eleven selected monitor points. Each of the comparisons displayed an offset consistency in both direction and magnitude from the theoretical. This "consistency" is both a mark of data credibility and system stability. The observed system stability is of special interest, when considering the area surveyed, since an ASF value is theoretically unreliable when computed for a G.P. within 3 n.m. of land.

3. Figure 7 is a chartlet depicting the survey area and the monitor site locations. The site numbers correspond to data group numerical notations shown in Figure 8, which is a listing of the site geographic positions (G.P.'s) on North American Datum (NAD), the G.P. to TD conversion values, the monitored TD's for the sites, and additional derived correction data for each rate and fix. As a data check, two of the sites, 1 and 2, were occupied twice on different days. The second visits are listed as 11 and 7.

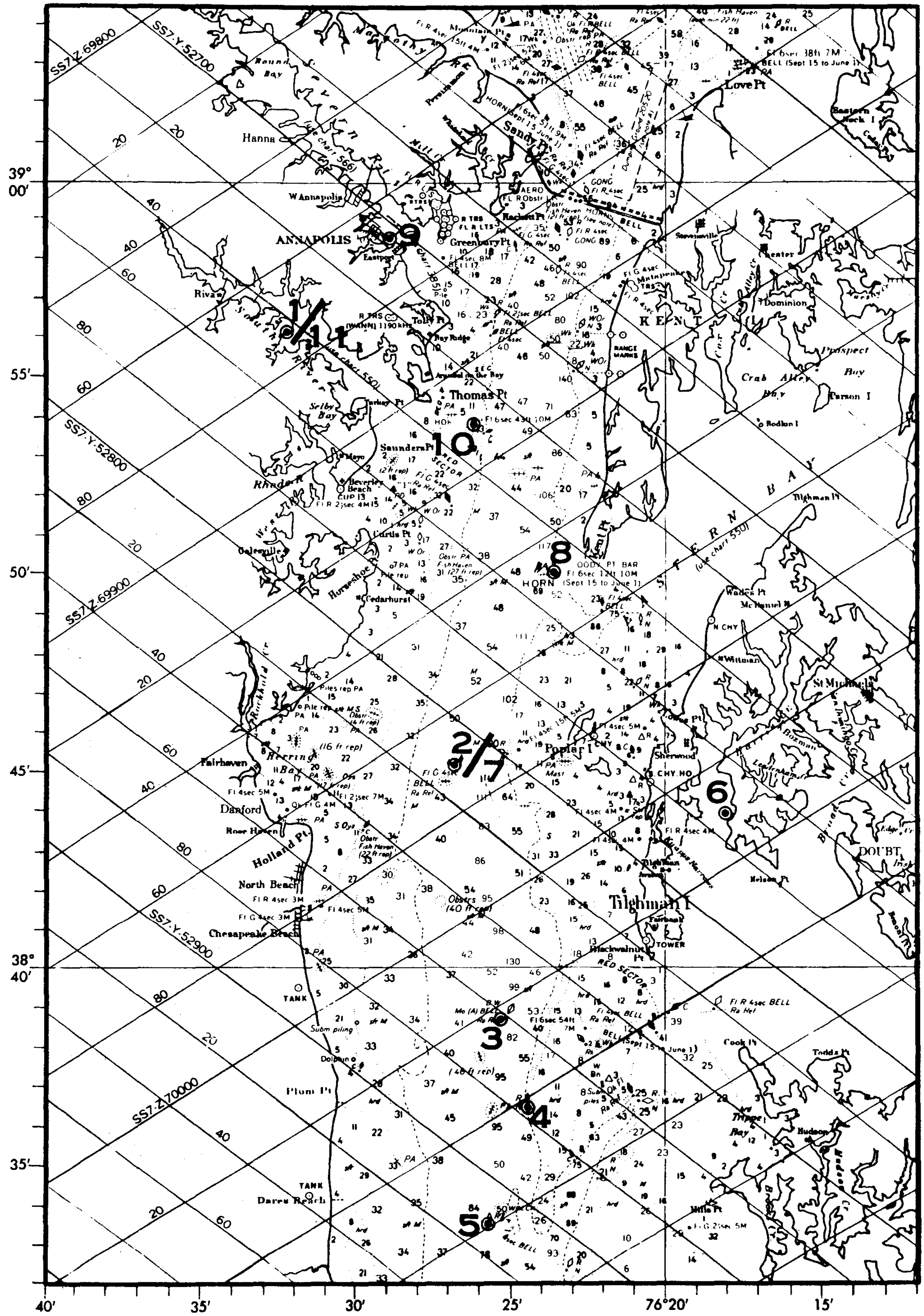

Figure 7. Survey Area.

Site No.	Site Location (NAD)	Computed TD 9930-Y & Z	Monitored TD 9930-Y & Z	Δ TD (9930-Y vs Z)	Monitored TD to G.P. Conversion (NAD)	Fix Correction (Col. 6 vs Col. 2)
1	L38°- 56.12'N	Y-52745.49	Y-52743.50	Y + 1.99	L38°- 56.20'N	AZ. 243.90°
	λ076°-32.33'W	Z-69874.39	Z-69874.60	Z - 0.21	λ076°-32.12'W	Dist. 0.18 n.m.
2	L38°- 45.12'N	Y-52812.19	Y-52810.10	Y + 2.09	L38°- 45.24'N	AZ. 235.6°
	λ076°-26.75'W	Z-69972.72	Z-69972.80	Z - 0.08	λ076°-26.44'W	Dist. 0.28 n.m.
3	L38°- 38.62'N	Y-52862.98	Y-52860.80	Y + 2.18	L38°- 38.68°N	AZ. 254.8°
	λ076°-25.25'W	Z-70024.24	Z-70024.80	Z - 0.56	λ076°-24.97'W	Dist. 0.23 n.m.
4	L38°- 36.50'N	Y-52878.00	Y-52876.50	Y + 1.50	L38°- 36.47'N	AZ. 277.3°
	λ076°-24.50'W	Z-70042.50	Z-70043.30	Z - 0.80	λ076°-24.20'W	Dist. 0.24 n.m.
5	L38°- 33.33'N	Y-52913.31	Y-52911.50	Y + 1.81	L38°- 33.36'N	AZ. 261.6°
	λ076°-25.70'W	Z-70060.80	Z-70061.50	Z - 0.70	λ076°-25.44'W	Dist. 0.21 n.m.
6	L38°- 43.78'N	Y-52777.13	Y-52776.00	Y + 1.13	L38°- 43.82'N	AZ. 250.1°
	λ076°-18.12'W	Z-70011.89	Z-70012.10	Z - 0.21	λ076°-17.98'W	Dist. 0.12 n.m.
7	L38°- 45.12'N	Y-52812.19	Y-52809.90	Y + 2.29	L38°- 45.24'N	AZ. 228.9°
	λ076°-26.75'W	Z-69972.72	Z-69972.90	Z - 0.18	λ076°-26.45'W	Dist. 0.26 n.m.
8	L38°- 50.07'N	Y-52751.24	Y-52749.00	Y + 2.24	L38°- 50.18'N	AZ. 200.9°
	λ076°-23.58'W	Z-69948.43	Z-69948.50	Z - 0.07	λ076°-23.35'W	Dist. 0.19 n.m.
9	L38°- 53.90'N	Y-52731.64	Y-52730.40	Y + 1.24	L38°- 53.93'N	AZ. 256.4°
	λ076°-26.20'W	Z-69912.13	Z-69912.50	Z - 0.37	λ076°-26.04'W	Dist. 0.13 n.m.
10	L38°- 58.47'N	Y-42706.74	Y-52704.40	Y + 2.34	L38°- 58.58'N	AZ. 238.8°
	λ076°-29.00'W	Z-69869.98	Z-69870.00	Z - 0.02	λ076°-28.77'W	Dist. 0.21 n.m.
11	L38°- 56.12'N	Y-52745.49	Y-52743.60	Y + 1.89	L38°- 56.19'N	AZ. 245.8°
	λ076°-32.33'W	Z-69874.39	Z-69874.60	Z - 0.22	λ076°-32.13'W	Dist. 0.17 n.m.

Figure 8. Survey Data Sheet.

4. A summary of the study is shown by Table 1. This table is followed by a key to the table column headings.

TABLE 1

Rate	Av. Δ by obs.	Av. Δ in n.m.	Δ by ASF Method	Obs. Δ vs. ASF Δ (Col.2 - Col.4)	Av. Corr. for Y/Z Fix
9930-Y	+1.79μs	0.18	+1.24μs	.55μs=.05n.m.(294')	Dist. 0.20n.m.
9930-Z	-0.30μs	0.04	-1.78μs	1.48μs=.18n.m.(1067')	AZ 245.0°

(a) <u>Average Bias (Δ) by Observation</u> - the average time difference displacement, in microseconds, from the theoretical or charted hyperbolic TD values for the survey monitor points.

(b) <u>Average Bias (Δ) in Nautical Miles</u> - average bias determined by observation converted to nautical miles.

(c) <u>Bias (Δ) by ASF Method</u> - the theoretical equivalent of "Average by Observation". This is the charting correction value supplied to NOS. The value represents the difference between the charted hyperbolic TD value with a seawater propagation correction applied and the corresponding TD value with both a seawater and an overland propagation correction applied which is the "Additional Secondary Factor" (ASF).

(d) <u>Observed Bias (Δ) vs. ASF Bias</u> - the difference between the empirically derived ASF value and the theoretical, expressed in nautical miles and in feet.

(e) <u>Average Correction for Y/Z Fix</u> - the average of azimuth and distance values which, if applied as a correction, would cause the plotted fixes to coincide with the actual site positions.

D. RECOMMENDATIONS:

Observations regarding the collected data concern the obvious discrepancies found when comparisons are made with the theoretical ASF values. It is recommended that an attempt be made to resolve these discrepancies and in so doing to improve the ASF product. Since the ASF derived values for the area surveyed are correct with regard to direction (+ or -), but in error with regard to magnitude, it seems a fair assumption that the ASF methods and principles are correct. The fault then probably lies in the ASF input data, i.e., the conductivity code values. It is, therefore, suggested that the code values for 9930-Y and 9930-Z be compared and if a common value is found, that it be altered until the ASF values more nearly correspond with those empirically derived. If this or some similar conductivity value manipulation yields the desired results, then a detailed examination of the altered values is warranted. Should the suggested conductivity value manipulation prove to be futile, then an attempt should be made to use the survey data in developing a workable algorithm that can withstand testing with other empirically derived values representing a variety of conductivity paths.

CHECK SURVEY DISCUSSION

The survey findings, regarding each rate/fix correction direction, and magnitude, demonstrate the stability and therefore, correctability of the LORAN-C system in this near shore "uncertainty" area. The collected data, upon examination, also demonstrates the high degree of accuracy attainable using the theoretical ASF determining process, in the case of 9930-Y. In the case of 9930-Z, however, the data demonstrates a failure in the ASF determining process to compensate for signal retardation. DMAHC plans for the resolution of this and similar failures noted in seemingly disassociated areas is the subject of the remainder of the paper.

FUTURE DEVELOPMENT OF LORAN-C CHARTING CORRECTIONS

Two DMAHC Research and Development (R & D) programs presently underway are efforts to expedite and improve the ASF determining process. The first program, developed under contract with The Analytical Sciences Corporation in 1976, is a computerized algorithm, termed LORAN-C Force Fit System, which is designed to incorporate empirically-derived data with the theoretical in a "force-fit" routine. The resulting data can then be used for error prediction in locations, including land/sea interface areas, within 130 miles of a monitor site where no information is available. In effect, proper use of the algorithm will alleviate failures such as that discovered during the Check Survey, with a compromise. The expected accuracy improvement is 15% to 50%.

The second R & D effort, named Accurate Rapid Additional Secondary Phase Factor Determination (ARAD), is in response to the rapid expansion of the LORAN-C system and the establishment of the CCZ. It is now necessary to develop a capability for rapid correction determination, for particular positions within sectors of the CCZ, commencing with transmitter sites originating propagation paths not previously scaled. This necessity stems from support considerations given to survey requirements within the CCZ and along the Continental Shelf, to possible combat demands, and to lane keeping problems that will develop when convoy style shipping is implemented within the Zone. The implementation of ARAD will, effectively, incorporate applicable portions of a recently developed world map data base into the ASF program. This innovation involves the superimposition of conductivity areas, with their values upon the map data base and the writing of associated software which will yield a correction computation capability for any position, along any azimuth, and from any transmitter site whether previously scaled or not. In addition to what will amount to a greatly improved ASF determining process, is another expected benefit that will manifest itself in terms of improved accuracy since present inherent program averaging, in computing ASF values for particular G.P.'s will be eliminated.

CONCLUSION

A marriage of the LORAN-C Force-Fit System with ARAD, through the present ASF automated processes, will nearly automate the entire ASF determining process. The resulting ASF program will have the additional flexibility necessary for experimentation, such as that mentioned in the Check Survey recommendations, and the speed necessary to comply with recent demands for increased productivity. The ultimate expectation, however, is for consistent ASF value accuracy. Fulfillment of that expectation hinges upon the availability of monitored data. This monitor data, which will serve the future ASF program input standards, can originate with any mariner equipped with LORAN-C receiving equipment. In accordance with this statement, Notice to Mariners, containing a solicitation for LORAN-C monitor information, are being issued (See Figure 9). The Defense Mapping Agency Hydrographic Center will issue these notices on a monthly basis commencing with Notice to Mariners #37 (September 1977). Your participation in this program will be appreciated.

HYDROGRAM

INFORMATION OF SPECIAL INTEREST OR IMPORTANCE TO MARINERS

Defense Mapping Agency
Hydrographic Center
Washington, D. C. 20390

SPECIAL ANNOUNCEMENTS
NEW PRODUCTS OR SERVICES
IMPORTANT CHANGES

NM 37/77 10 September 1977

NEW EDITION OF LIST OF LIGHTS

PUB 114, 6 AUGUST 1977, LIST OF LIGHTS AND FOG SIGNALS FOR BRITISH ISLES, ENGLISH CHANNEL AND NORTH SEA, IS READY FOR ISSUE.—SEE PAGES I-3.4, II-1.6, AND SECTION III.

NEW EDITION OF PUB 117B

THE 9 JULY 1977 EDITION OF PUB 117B, RADIO NAVIGATIONAL AIDS FOR THE PACIFIC AND INDIAN OCEANS AREA, IS READY FOR ISSUE—SEE PAGES I-3.4, II-2.3, AND SECTION III.

NEW CHANGE TO SAILING DIRECTIONS

CHANGE 1 TO PUB 192, SAILING DIRECTIONS (ENROUTE) FOR THE NORTH SEA, IS READY FOR ISSUE—SEE PAGES I-3.4, I-2.4 AND SECTION III.

NEW PUBLICATION

ALLOWANCE REQUIREMENT FOR NAUTICAL CHARTS AND PUBLICATIONS, FIRST EDITION 1977, IS READY FOR ISSUE—SEE SECTION III.

PUBLICATION CANCELED

PORTFOLIO CHART LIST, PUB. 1-PCL, IS CANCELED. SEE SECTION III.

DMAHC LORAN-C CHART CALIBRATION QUESTIONNAIRE

CALIBRATION INFORMATION IS BEING COLLECTED TO EVALUATE AND IMPROVE DMAHC DERIVED LORAN SIGNAL PROPAGATION CORRECTION. SEE QUESTIONNAIRE IN SECTION III.

NM 37/77 **SECTION III**

DMAHC LORAN-C CHART CALIBRATION QUESTIONNAIRE

Calibration information is being collected in an effort to evaluate and improve the accuracy of the DMAHC derived LORAN signal propagation corrections incorporated in National Ocean Survey Coastal LORAN-C charts. LORAN-C monitor data consisting of receiver readings with corresponding well defined reference positions are required. Mariners aboard vessels equipped with LORAN-C receiving units and having precise positioning capability independent of the LORAN-C system (i.e., docked locations or visual bearings, radar, navigation satellite, Raydist, etc.) are requested to provide monitor information via the questionnaire found at the back of this Notice to Mariners. Please mail this questionnaire to Defense Mapping Agency Hydrographic Center, Washington D.C. 20390. Attention Code NVE.

DMAHC LORAN-C CHART CALIBRATION QUESTIONNAIRE

VESSEL NAME ________________

LORAN-C RECEIVER MAKE AND MODEL ________________

OBSERVER ________________

GMT	DAY OF YEAR	YR.	LORAN-C TIME DELAY (TD) READINGS (XXXXX.XX Usec.) Rate Designations (xxxx)–W	(xxxx)–X	(xxxx)–Y	(xxxx)–Z	REFERENCE POSITION (Ref. Posit. must coincide with time of TD Reading) LATITUDE XX°-XX.X' N/S LONGITUDE XXX°-XX.X' E/W	REFERENCE POSITION SOURCE DESCRIPTION (i.e., Visual Bearings, Radar, Navigation satellite, Raydist, etc. or Pier location, number, & berth desig.)

Figure 9. Notice to Mariners—publicized request for Loran-C monitor information.

ACKNOWLEDGMENTS

The author wishes to acknowledge the editorial and technical assistance of DMA Hydrographic Center personnel Edith Reeves, John E. Hanna, Jr., Edwin Danford, Terry Goodspeed, and David Somerville.

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CONVERSION OF LORAN COORDINATES

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Commercial shrimping is a viable fishery in the Northwest Gulf of Mexico. Excluding productive waters off Mexico and east of the Mississippi River, Texas vessels have some 25,000 square miles of ocean floor which is shrimped rather extensively. This fishing fleet is highly mobile and fishing intensity of an area relies much on the concentration of shrimp. In the course of one trip, it is possible for a vessel to fish waters off Brownsville in South Texas, as well as northeastern areas off Louisiana. A vessel may fish an area only every few years due to localized availability of the seafood product.

Shrimp fishing employs trawls which are dragged along the Gulf seabed. Underwater obstructions are a constant threat to shrimping activities. Hangs are a potential danger to crew safety; moreover, rocks, wrecks, coral, and bottom debris have cost the shrimp industry millions of dollars in destroyed or damaged gear. As Gulf shrimp vessels pull three to five trawls simultaneously, it is possible to damage or completely lose more than one net on an obstruction. Sometimes gear can be repaired aboard the vessel at a minimum cost of materials. Other times elaborate and expensive onshore repair is necessary. In 1972, it was estimated that the average Gulf shrimp vessel annually lost some $5,000 to hangs in gear alone. Regardless of the gear damage, valuable fishing time is lost. Often the time required to recover gear from the obstruction, replace or repair the trawl array, and resume fishing activities results in a great financial loss in production to the vessel and crew.

Loran-A has been of significant benefit in reducing loss of fishing gear. In the late 1960's, Loran became an everyday word in the shrimp fishery. Its value as a navigational aid rapidly became recognized. An additional use for Loran was uniquely adapted by commercial fishermen. Loran became instrumental in positioning and avoiding obstructions to shrimping gear.

Fishermen maintained logs of obstructions that were confronted in their shrimping operations. These logs often consisted of 10 - 300 Loran fixes of obstructions which were either hit by a fisherman or by his friend on another vessel.

As the fishing areas in the Northwest Gulf are so extensive, it was impossible for independent fishermen to maintain records of the vast number of obstructions on the seabed. As a result, in 1972 our Sea Grant Program at Texas A&M University undertook the task of interviewing fishermen to obtain Loran fixes of hangs. These obstructions were catalogued and charted. Hang books and charts are now periodically updated and disseminated to the fishing industry. To date, over 3,000 l.o.p.'s of reported hangs are plotted and recorded. Needless to say, industry response has been very positive to this effort. The vast majority of the fishing vessels employ our hang books to successfully avoid costly hangs.

The impact of the approaching Loran-C transition as related to bottom obstructions remains to be seen in the Gulf. Certainly, it is believed that Loran-C is a superior navigational system which in the long run, will serve the industry in an excellent capacity. However, concern has been expressed by industry as to the immediate effects of the transition. The number of hangs in the Gulf are so numerous that a system must be available to accurately convert Loran-A coordinates to those of Loran-C. Failure to accomplish this task will undoubtedly create a hardship to our shrimp fishermen.

Several systems for making coordinate conversions have been proposed. During the two year overlap of Loran-A and -C, evaluations of various systems will be conducted. Hopefully a satisfactory method will be derived whereby coordinate conversion can be accurately achieved before Loran-A is terminated.

During the period of simultaneous Loran coverage, we hope to accomplish some of the needed conversions by cooperation from the fishing industry. Hopefully, a number of our vessels will begin to employ Loran-C at an early date. Several fishermen have pledged to support a conversion effort. This can be done by running to Loran-A coordinates of a hang and recording its Loran-C reading.

This system will probably be the most accurate for conversion purposes, but certainly it has limitations. During the proposed two year overlap of both Loran systems, it would be impractical to assume that over 3,000 locations in a 25,000 square mile area could be converted in this manner.

A system of conversion by using chart overlays is being considered as a possible conversion method. Personal past experiences in plotting latitude and longitude readings on a chart and obtaining corresponding Loran-A readings has been less than desirable. Early attempts were made to report converted Loran-A readings of capped-off oil wells and related oil field obstructions from latitude and longitude fixes. Accuracy was lost in chart positioning and conversion; as a result, estimated Loran coordinates were not usable. Inherent errors in chart construction introduces still further inaccuracies into coordinate conversion involving overlays. Attempts will be made to obtain Loran-C readings from an overlay of Loran-A coordinates. The accuracy of this system will be evaluated, although its desirability is very doubtful.

The possibility of utilizing computers for conversion of Loran l.o.p.'s has been pointed out as a very promising solution to the problem of Loran coordinate conversion. The U.S. Coast Guard has been very instrumental in early efforts to compute coordinate conversion. A program is being developed for the West Coast. Its evaluation is to be performed in the immediate future. If accuracy can be obtained utilizing relative inexpensive computers, a solution to this major problem can be effectively achieved. This concept of coordinate conversion is viewed as being far superior to others discussed. The evaluation of this system is anticipated with interest.

A primary consideration relative to any of the Loran coordinate conversion systems must be identified with the accuracy of Loran-A itself. I believe that regardless of the conversion system, accuracy will be limited. In cataloging obstructions, as many as nine different combinations of Loran-A readings on one single hang have been received from various fishermen. In contrast, numerous hangs have been reported with only a one microsecond difference - often only a .08 NM difference in some instances. Obviously, inaccuracies resulting from the operator, Loran receiver, and overall Loran system will make exact l.o.p.'s of the obstruction difficult to acquire. The shortcomings of Loran-A are recognized by the fishing industry. Cautious fishermen give a reported hang at least four microseconds berth when fishing in the vicinity of an obstruction.

When conversion of fixes are transposed to Loran-C in our cataloging program, additional berth will probably be necessary. This will allow for added inaccuracies in the conversion system. It will be quite possible that during early coordinate conversion, cataloged hangs will be reported to the fishermen as being only in a given vicinity. It will be stressed that sufficient distances be maintained in these areas. Perhaps in the initial recataloging of the hang, a designated symbol will appear by the coordinates to denote that the reading was obtained from a process of coordinate conversion. It is quite possible that as time progresses, some obstructions will be eventually hit or located by various vessels. At this time, a hang can be documented as being fairly exact and marked with another designated symbol in the catalog.

Another problem which will affect coordinate conversion relates to the signal strength of the Loran-A system. In the two extremes of our fishing grounds, Brownsville and the Southwest Pass of the Mississippi River, a second Loran station often cannot be obtained. As a result, the primary Loran signal and a depth of water is used to document a hang. Although the shelf deepens rather rapidly in these areas, a single Loran reading and a depth of water is not very desirable. Differences in adjustment of the 0 depth line on the echosounder paper by fishermen introduces another variable. A water depth reading is sometimes reported as actual depth or sometimes is reported as being taken from the 0 line. Sometimes it is not known how the fisherman adjusts the mark on his recorder paper and a reading is obviously almost worthless. It is not known if these hang coordinates can be accurately converted. As we have approximately 750 hangs recorded in this manner, an evaluation of this type of coordinate conversion will be performed. It is doubtful that much success can be derived from converting a single l.o.p. and a corresponding depth of water.

The fishermen in the Northwest Gulf have some adjustments to make in the next several years. In addition to receiver purchases, the transition to Loran-C will probably initially cost the industry money due to lost gear. The added accuracy of Loran-C has the important possibility of being monetarily advantageous by ultimately enabling fishermen to drag closer to obstructions and more precisely locate areas of productive bottom. From the standpoint of commercial fishermen, the transition may be reflected as a "trade-off." The effectiveness of coordinate conversion will be an important factor to commercial Gulf fishermen in determining the impact of the Loran-C navigational system.

MANUAL TO AUTOMATIC -

OUTGUESSING THE NUMBERS GAME

by Clyde B. Kirlin, President, Clyde B. Kirlin, Inc.
and
Ernest Wilson, Owner, Wilson Communications/Electronics

The time of conversion from Loran-A to Loran-C is upon us and with conversion will come mistakes if guidelines are not followed and if a lay analysis of the system is not taken and understood. The mistakes, if made, will be frustrating, costly, and may even lead to disaster...something that none of us want at any time, let alone at sea.

The Coast Guard, having been assigned the task of bringing us the new Loran-C system on the West Coast, has done so with a design unique in its accuracy, not only in first fix accuracy but in repeatability accuracy as well. As an answer to the wanderings of man in the coastal confluence of the continental U.S.A., the landbased system generating this electronic navigational aid leaves little to be desired. Knowing now what the Coast Guard has placed on the air as electromagnetic radiation, the world's manufacturers have turned designers and production lines to the task of building receivers to gather the information from the air and present navigational data in usable format to the men who wander the trackless seas. And herein lies the gap which we wish to approach today. A gap between excellence in transmission equipment ashore and sometimes questionable receiver equipment afloat...a gap caused by misunderstnadings, by greed, by slick trade artists, but nonetheless a gap placing the lay boatsman in a position of frustration, one of not wanting to become involved in any more cost than is required to his needs during the changeover period. Two years ago, the gap was impossibly wide on one hand, due to the high costs of equipment touted as being proper for the task, and prominently displayed by the Coast Guard at Fish Expo of that year. On the other hand, low cost equipment was being displayed on the floor, equipment which we felt at the time had a potential inferiority as there were no details as to the merits of its performance, nor was there the opportunity to test the performance at sea, since the West Coast chain was not implemented at that time. Today, we see the gap beginning to narrow as more information is being developed on the landbased system of the Coast Guard and is being consumed at sea by users gingerly feeling their way through the complexities of current receiver offerings.

Manufacturers, who previous had quick schemes of low cost reception methods are either modifying their thoughts and designs to some degree or have backed away from the questionable designs altogether. Loran-A and -C combinations are being closed out and sold cheap due to the now realized inferiority of the product when faced with the true potential of Loran-C, and the previously highly touted " Buy A now, convert to C later" ads for conversions are disappearing from trade journals and the marketplace. In any event, the well worn phrase "caveat emptor" has reared its head and is becoming heard by manufacturer, dealer and government agency alike. For indeed, industry has been faced with increasing pressures from various consumer legislations, and while we feel that the buyer had indeed continue to beware, we come today to make the buyer more aware, and to twist the phrase to "caveat venditor"...let the seller beware!

My associate, Mr. Ernest Wilson,and I come to you today not as electronic designers of Loran-C equipment, nor as manufacturers of such equipment, but rather as being representative of the working marine electronics technician, the man who ultimately closes the gap between the suede shoe world of the factory salesman and that of operational reality on board a fishboat fighting a treacherous stormy sea some night 100 miles off the West Coast. With the information we bring to you today, we hope to close the gap just a little more and help you realize the futility of attempting to gain the full potential of what the Coast Guard has given you in getting the Loran-C signal on the air, only to have you attempt to sort out its information with a manual Loran receiver.

Let us begin our story with a description of a usable signal on a manual receiver as being one in which the pulse or "pip" istwice as high as the level of the noise or "grass" being displayed on the cathode ray tube oscilloscope. We may refer to this as a presentation of a condition of signal to noise ratio of 2:1, and for purposes of simplification, we are not considering any losses to occur in the receiver, therefore, the signal strength at the antenna is also considered to be in the ratio of 2:1. In this condition, the signal is reasonably stable and a good match of the master and the secondary or slave signals can be made. You have all seen this condition and can appreciate the stability of the presentation I have described. If we were to only match the two envelopes, as we have always done in the Loran-A systems, the error in line of position would be reasonably consistent at 1, 2, or 3 microseconds, depending on the care used in making the match, and the typical mileage errors would be consistent with those of the Loran-A system.

If the reception conditions were to worsen, the signal could well be lowered into the noise level and a ratio of 1:1,or worse could prevail. Here, the signal is of the same height as the noise, or lower. Because of this lack of discrimination between signal and noise, matching becomes difficult due to the instability of the signal presentation when polluted with noise, and the error, if indeed the display can even be used, is far greater. I am sure that all of you have experienced this poor signal condition at one time or another in using the Loran-A system.

With the introduction of Loran-C several years ago, the on-board receivers were built as combination A/C units, and in general were only capable of matching the envelopes of the Master and Secondary pulses. Later developments introduced "cycle matching", wherein a single pulse of the 8-pulse format was magnified to the degree of showing the cycles within the pulse formation. If properly matched, cycle for cycle, Master and Secondary, errors of 0.1 microsecond were highly touted to exist. At any rate, the manner in which the last decade dial was numbered led the operator to believe that such was the case. By the time the equipment went to sea, it was noted that any slight contamination of a weak signal by noise made the display so unstable or jittery as to make proper matching almost impossible. At this point, only envelope matching could be used and with the guesswork required in many cases, and the resulting inaccuracies, I am sure that the salesman involved was mentally two-blocked at the masthead by the thumbs.

Further, where cycle matching was attempted by manual means, the viewing of the incorrect cycle when bringing the two wave-forms into coincidence often produced errors of 10, 20, and even 30 microseconds. When this amount of error was discovered by reference to a dead reckoning position, the operator often resorted to the use of envelope matching to achieve a better, though still questionable accuracy.

Let me dwell on this matter of cycle matching for the moment, for it is the essence of the source of accuracy for the Loran-C system. The third cycle within the pulse shape has been chosen as being the one to be used for matching purposes. In simple explanation, it is here that the pulse begins to take on its true form and it is here that skywave interference is less likely to occur. This then is the beginning of accuracy. If the shape of the pulse is malformed, due to contamination by noise, by skywave, or other interference, then inaccuracies are the result. One of these factors will be made known to the user of the older A/C combination receivers, in that the bandwidth of the receiver is, in many cases, too narrow to permit a true reproduction of the Loran-C pulse shape. In general, it becomes a matter of an uneven amount of gain at the beginning of the pulse. To view it with humor, it is quite analogous to trying to put a Cadillac into a garage built for a Volkswagen...distortion must result! And with distortion comes errors in the reading.

In essence, we are saying that a manual receiver may be used with some degree of success, if the errors produced by a weak signal in the face of average noise figures can be understood and the limits of the receiver known. Viewed with high noise levels and interference, the question of accurate fixes becomes questionable.

To describe this graphically, we have unfettered some of the information with the help of the Coast Guard and other agencies interested in putting the public's mind at ease on this subject of conversion. The Coast Guard was kind enough to show us the method by which they have calculated the coverage area of the Loran-C signal for various signal strengths. With this information, we have used data published by C.C.I.R. on various median levels of noise, both atmospheric and manmade for appropriate times of day, season and year. Asking ourselves the question" What can a manual receiver do under these conditions?" we have chosen to display the worst conditions for such operation, rather than the average or best conditions. The charts will show the calculated coverage area as it exists today for a 2:1 signal to noise ratio, this being the only usable level permissible for manual operation. The time of year is in the fall season and the time period shown is from 0000-0400 GMT.

To begin, many of our friends have asked why the antenna sites were located as far inland as they are. To answer this, is beyond the direct scope of our knowledge, but we can make certain assumptions. Perhaps, the Coast Guard can confirm these for us, for I am sure that there must have been monetary as well as technical considerations in making the final site location decision. Consider our first graphic which shows a simple configuration of a Master and two Secondaries, all located on the coastline. Two things are to be watched as our graphics develop. First, note the position of the baseline extension, an area to be avoided as being inaccurate in obtaining an LOP. Each is covering major coastal confluence areas of cruising. Second, note the limitation of coverage from mid-Oregon to mid-California.

Figure 2 takes into consideration the addition of LOP's from the Canadian chain to assist in coverage through the northwest. Be

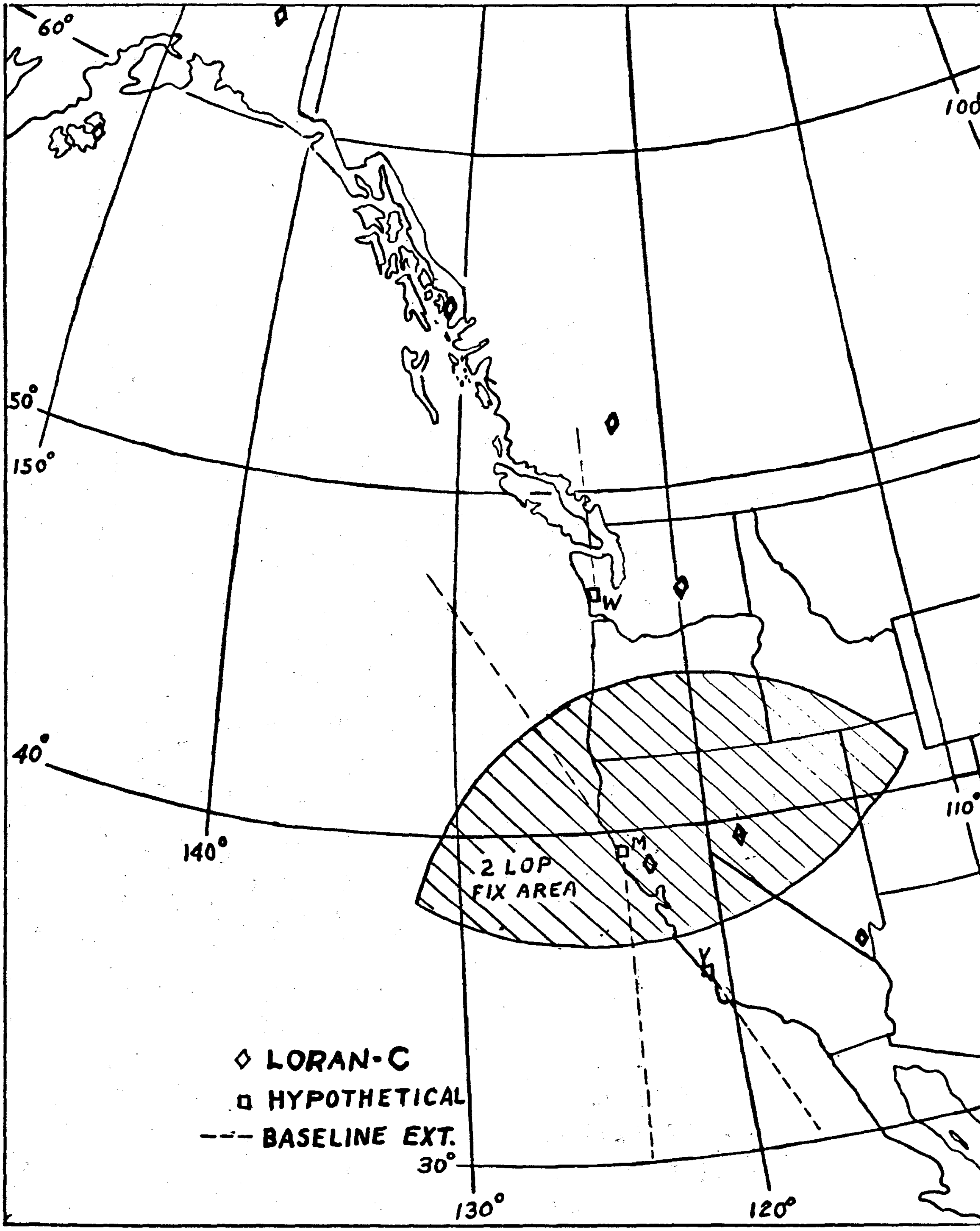

Fig. 1 Hypothetical West Coast Chain, Only.
No Fill-in Station
2:1 SNR, Worst case, 95%

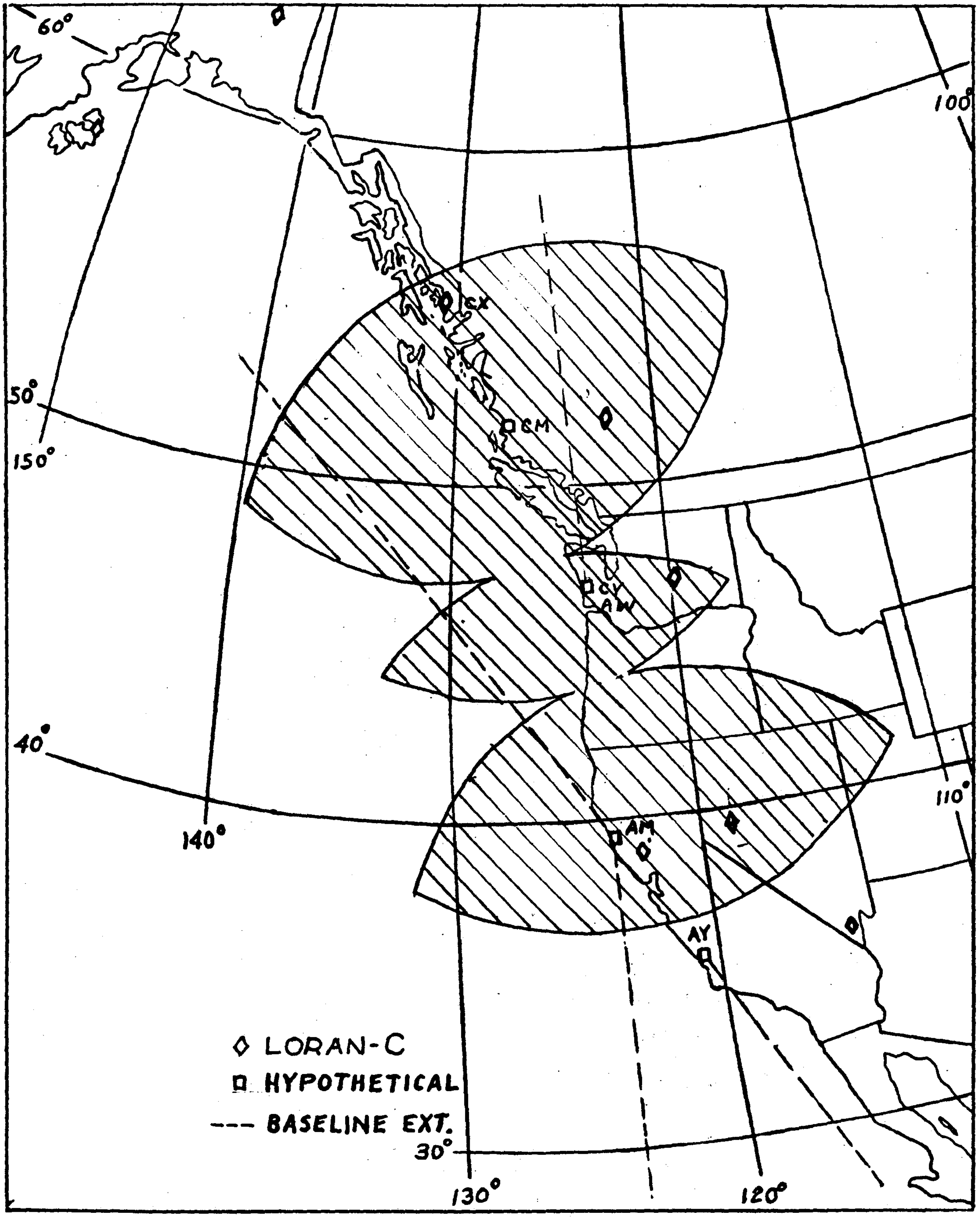

Fig. 2 Hypothetical Coast Chain, Incl. Canada
No Fill-in Station

aware, however, that this comes from a "cross-rate" application and receiver rate dials must be reset for the Canadian GRI.

Figure 3 returns to the West Coast chain with the hypothetical question of " What would happen if the original chain remained on the coast and another Secondary were added inland? " Note that the results extend the coverage substanially into both northwestern and southern waters, but the baseline extensions and the ensuing errors still exist in prime cruising waters.

Removing all stations of the simple configuration to inland areas has now moved the baseline extensions away from the coastal confluence, but has extremely limited the area of coverage for our desired 2:1 signal to noise ratio and is displayed quite effectively in figure 4.

Even figure 5, showing the existing Canadian chain working as a cross-rate solution does not begin to allow the user of manual equipment to gain much benefit from the system.

However, figure 6 now brings us to the existing configuration of the West Coast chain and the coverage to be expected under worst case conditions by a manual receiver user. Two LOP's may be expected in any area along the coast from the mouth of the Columbia River south to the Mexican border. But be aware of both the inaccuracies that may result in the area of Fort Bragg, California and the limited signal strength available at that location. Note that under these worst case conditions, vessels traversing Mexican waters and those working to the northwest may well be without enough signal to permit the manual matching of Master and Secondary.

These cases that we note are indeed the worst possible cases in theory, for purposes of illustration, but they are quite correct for that condition. The difficulty lies in the fact that they do occur in Autumn, and to a large degree in Summer. While your boat is laid up for the Winter, Mother Nature has played tricks on you by providing the best of conditions for the Loran-C signal.

And so, laying our case to rest on the matter of the Loran-C receiver, we hope we have made you AWARE of some of the facts, and that you will BEWARE as a buyer should.

Looking on to the automatic receiver, let's take a look at the manner in which it is capable of solving the problems voiced earlier, and learn if there are any gray areas to be considered.

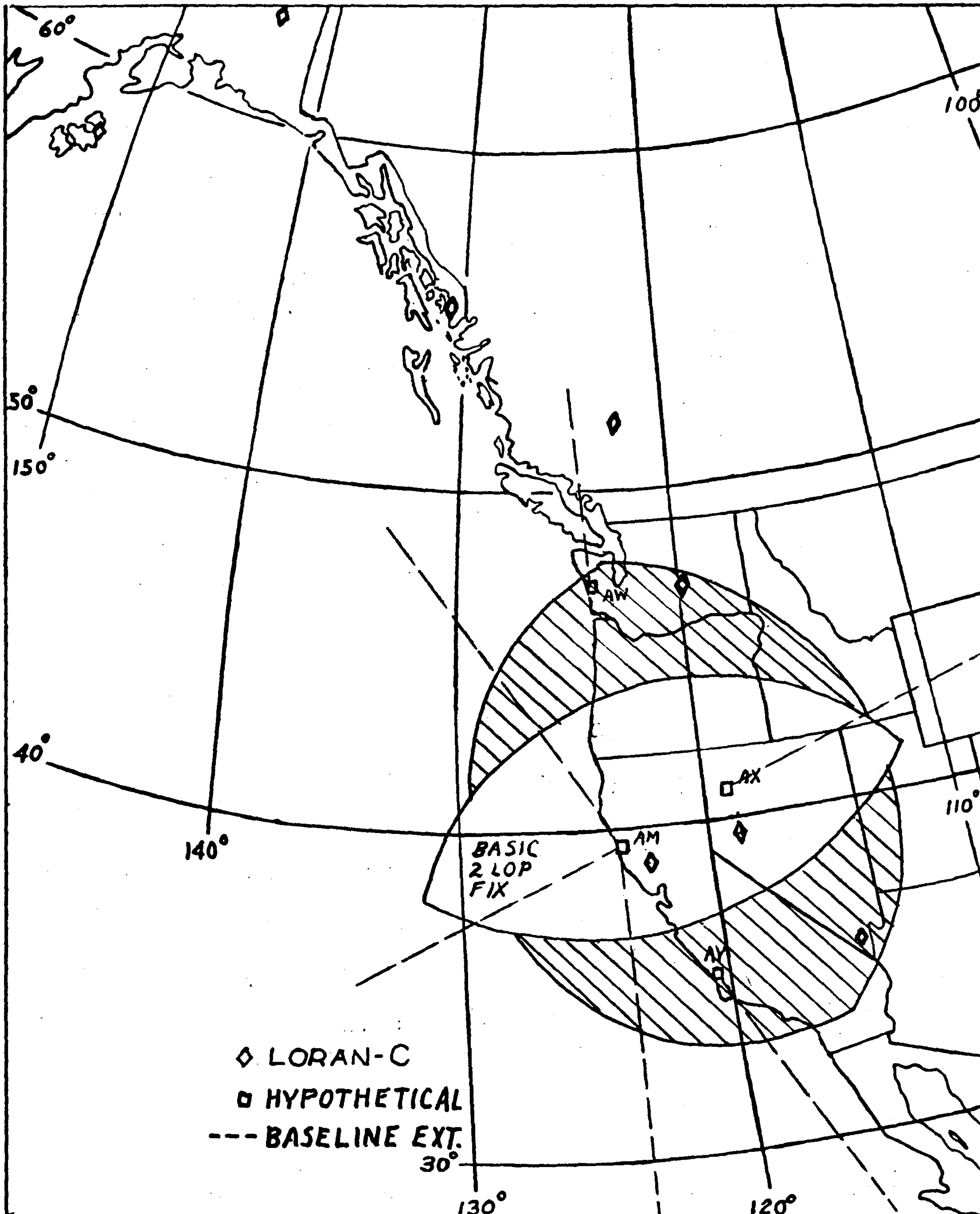

Fig. 3 Hypothetical Coast Stations
Inland Fill Station

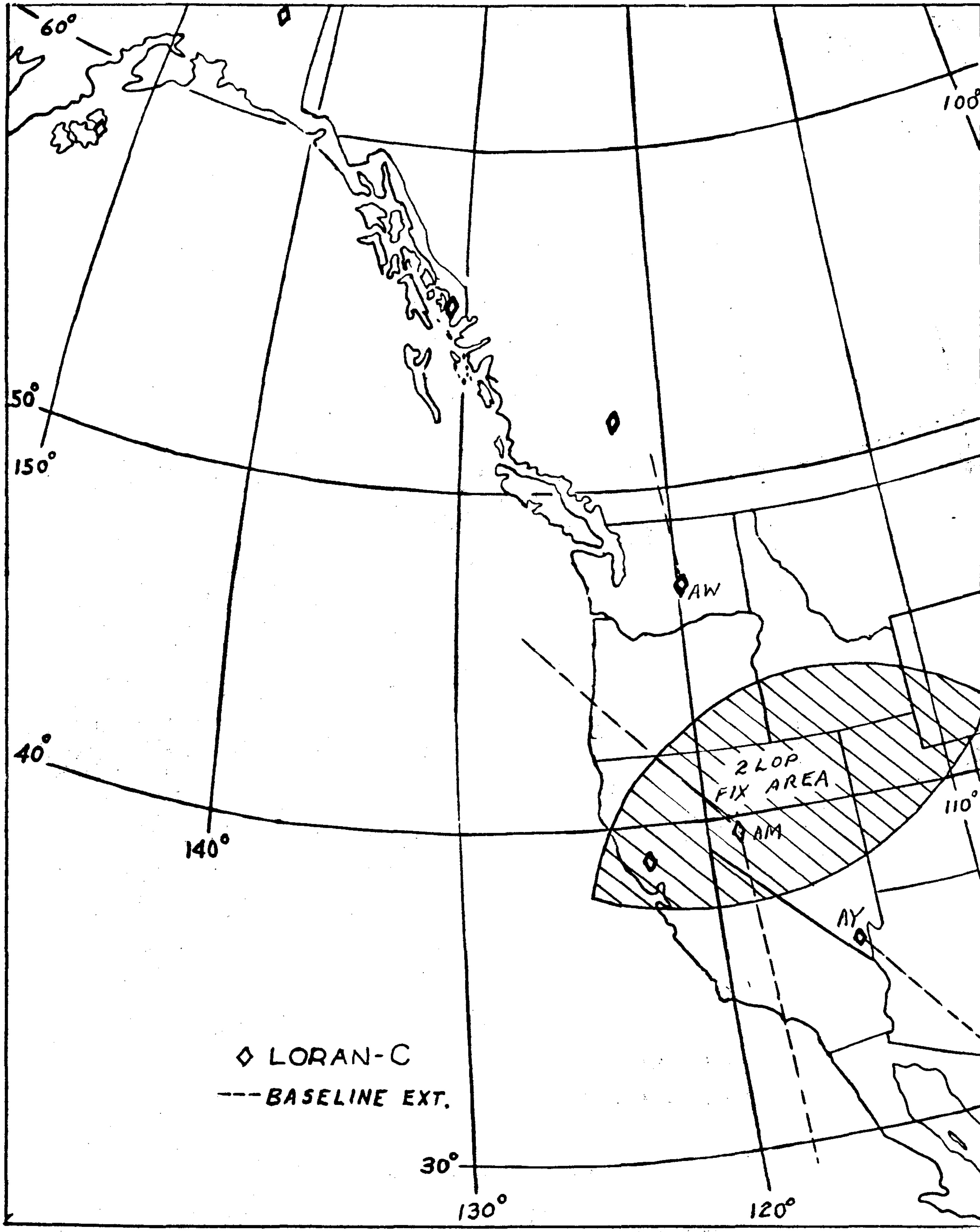

Fig. 4 West Coast Chain, Without Fill-in
2:1 SNR, Worst case, 95%

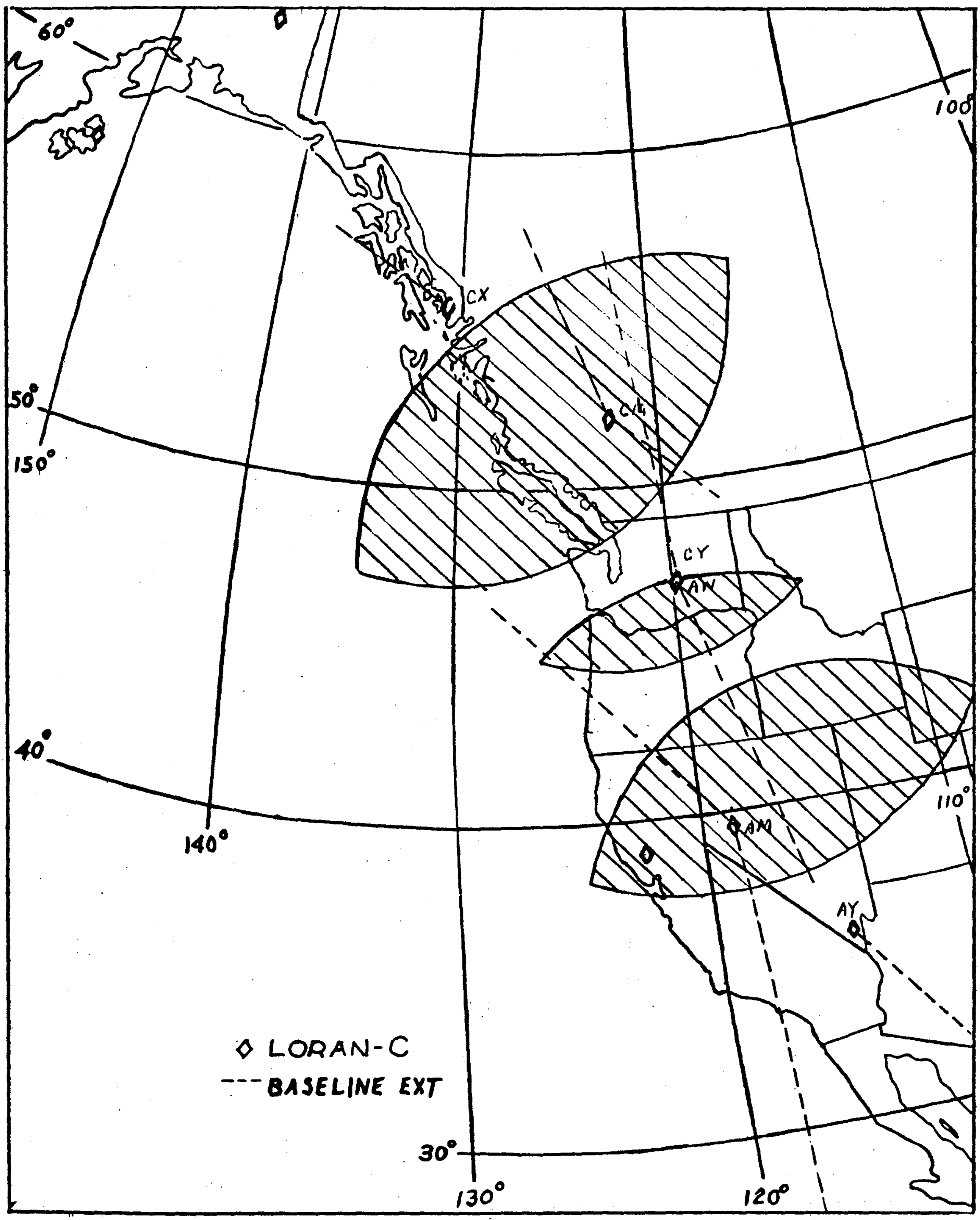

Fig. 5 West Coast Chains, Incl. Canadian,
But Without Fill-in.
2:1 SNR, Worst case, 95%

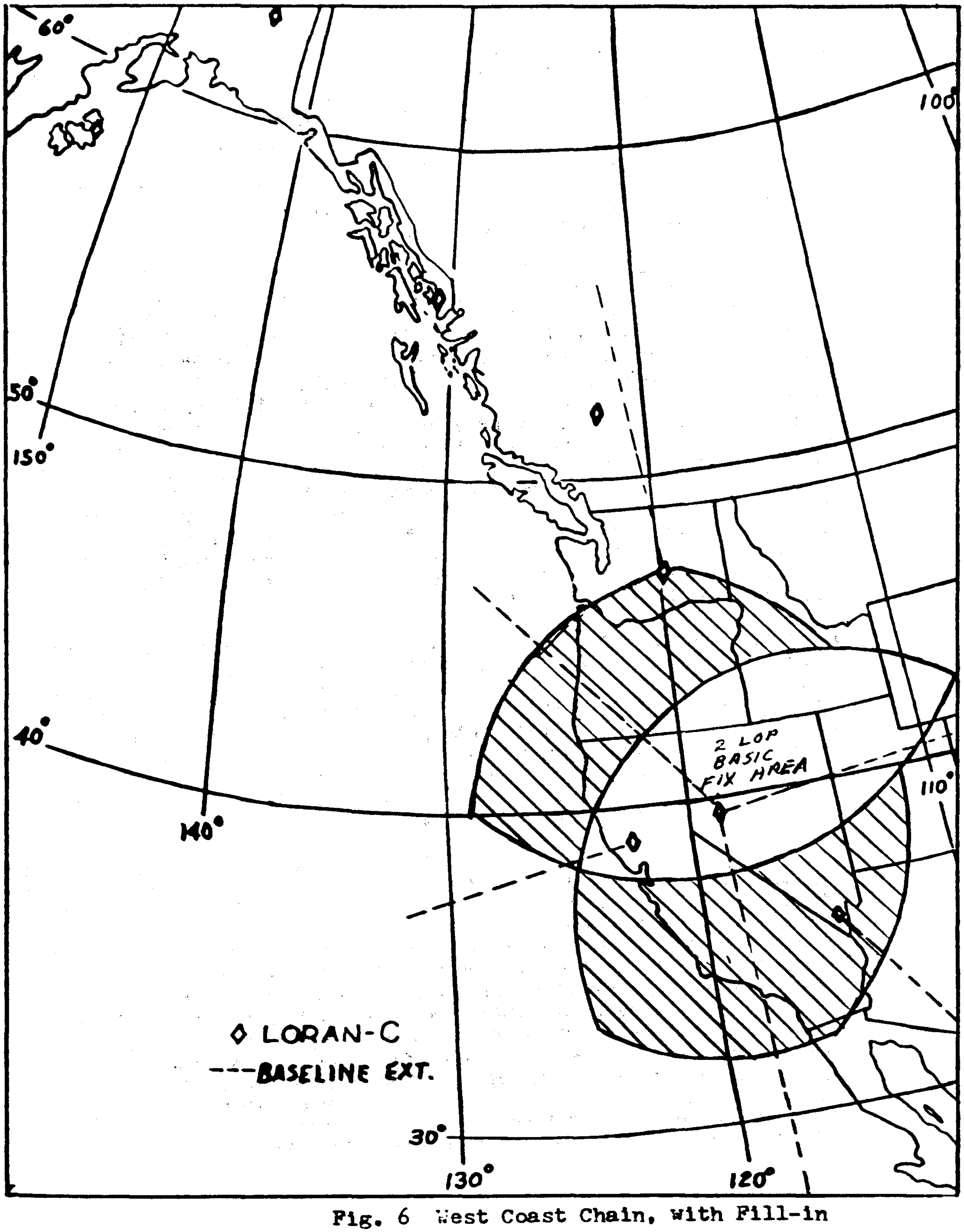

Fig. 6 West Coast Chain, with Fill-in

First of all, realize that there are nine pulses being transmitted by the Master station and eight pulses by the Secondary. While using the manual receiver, only one of these pulses within the group was used for matching purposes, either cycle or envelope matching. With the automatic receivers, each of the eight or nine pulses may be examined individually to gain as much information as is possible from each for purposes of accuracy in the match of but two. The information gained may be averaged and the results presented as superb accuracy.

The automatic receiver is quite capable of working in an environment dictated by a signal condition that is one-third the strength of the noise level. This condition of signal being buried under noise is unheard of in manual operation, but it could be an everyday activity for the automatic unit. Having this backward signal to noise ratio of 1:3, the receiver handles it with ease. To have this capability, the receiver is designed in such a manner as to have a predetermined idea of what the pulse shape of the signal is to be and to look only for this shape, rejecting all other shapes such as noise that might come down the antenna. Also, remember that it does not just look at one pulse, but has the capability of looking at a series of eight pulses in its search for the correct shape. Thus it can piece together many parts of the puzzle to form a desired pattern and will reject anything else that may pollute the observation.

Once having solved the puzzle of reception of the signal under these extreme conditions, the same electronic circuitry that has gone to all the effort to identify the correct pulse and its characteristics may be used to track the time difference of the two signals. In this way, it is never bothered by noise interference when attempting to give a display of time difference. It is this small add-on feature that comes along at no charge and is so paramount in responding to the accuracy established by the Coast Guard at the antenna site.

The one gray area that we can see prevailing will apply to users in the northwest when both the Canadian chain and the West Coast chain is applied as a cross-rate LOP. Here, the dials on the receiver must be reset to the opposite GRI, resulting in the loss of a continuous update of one LOP and an error resulting from the delay in acquiring the other LOP, an error that can be corrected by manually plotting an advance in time and speed on the chart. As an example, as long as two and one half to three minutes delay can result in shifting from one GRI to another and waiting for the unit to acquire the signal. A 10 knot boat can experience an error of 0.5 miles in this time alone, let alone the error increase due to time of plotting, etc. Those cruising the northwest should be aware of this mechanical error stemming from the time delays of cross-rate operation.

In conclusion, we hope to have established our case for use of automatic receivers by showing some of reasoning behind the inaccuracies that may be gained in the use of the manual types. Look carefully before buying, analyse the limitations placed before you and satisfaction will come from the use of your selection.

Appendix

The figures are constructed using noise data from C.C.I.R. Report 322, related to miles by use of a nomograph available from U.S. Coast Guard System Development Branch. The hypothetical coast configurations consider a sea water path. The contours for land paths were not reduced. The inland configuration was adjusted to make allowance for a partial land path, using the dry soil scale of the nomograph, and the sea water scale. A value between the two thus obtained was used. The value was roughly interpolated for the proportion of over land to over water on an average basis, and a contour that is an arc of a circle was drawn. Again, no reduced radius was used for totally over land paths.

A summary of the noise data follows:

$$E_e = F_a - 67.7$$

E_e is the required value of signal field strength for 2:1 SNR for 95% of a given time block. The constant has been adjusted for a 100 kHz center frequency and for a 30 kHz receiver bandwidth. F_a is the effective antenna noise factor which results from the external noise power available from a loss-free antenna. It is derived from F_{am}, median value contours within a time block, modified to 100kHz, and to a value that the average noise power will not exceed for 95% of the hours within the time block.

	E_e in dB above 1 microvolt/meter			
Time Block	Winter	Spring	Summer	Autumn
0000-0400	50	57	56	60
0400-0800	53	52	52	57
0800-1200	35	41	47	47
1200-1600	33	53	55	49
1600-2000	46	55	59	59
2000-2400	49	58	58	58