THE WILD GOOSE ASSOCIATION

PROCEEDINGS OF THE TENTH ANNUAL TECHNICAL SYMPOSIUM

21-23 OCTOBER 1981

SAN DIEGO, CALIFORNIA

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PUBLISHED BY

THE WILD GOOSE ASSOCIATION
4 TOWNSEND ROAD
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THE WILD GOOSE ASSOCIATION

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

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Chuck Slocombe - Banquet Speaker
Topic: All About Whales

Lloyd Higginbotham, Addressing Luncheon Guests Topic: WGA History

Rear Admiral A.L. Manning, USCG, Addressing Luncheon Guests
Topic: The Future of Navigation

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LORAN-C CHART STATUS

LCDR John F. Weseman
Office of Navigation
U.S. Coast Guard Headquarters
Washington, D.C. 20593

ABSTRACT

The paper will briefly outline the 1974 Government decision to provide Loran-C service throughout the Coastal Confluence Zone of the United States. The paper will also include a nontechnical discussion of Loran-C propagation and secondary phase factors as they affect charting, along with procedures used to insure charts when Loran-C lattices are available and accurate.

BIOGRAPHICAL SKETCH

LCDR Weseman enlisted in the United States Coast Guard in 1960. He has served onboard the USCGC Courier, USCGC Mackinac, and at the Loran Monitor Station at Rhodes, Greece. LCDR Weseman was Commanding Officer of Nantucket Loran Station from 1970 to 1973, and served as the Coordinator of Chain Operations for the Mediterranean Sea Loran-C chain from 1975 to 1977. From 1973 to 1975 he attended DeVry Institute of Technology where he obtained an Associate in Applied Sciences in Electronic Engineering Technology. Since 1977 he has been attached to Coast Guard Headquarters where he is now serving as Chief, Radionavigation Information Branch.

CDR Tony Pealer presented LCDR John Weseman's paper

LORAN-C CHART STATUS

LCDR John F. Weseman
Radionavigation Division
U.S. CoastGuard Headquarters
Washington, D.C. 20593

ABSTRACT

This paper outlines the 1974 Government decision to provide Loran-C service throughout the Coastal Confluence Zone of the United States, and includes a non-technical discussion of Loran-C propagation and secondary phase factors as they affect charting, along with procedures used to insure availability and accuracy of charts with Loran-C lattices.

INTRODUCTION

In the early 1970's there was an apparent need for improved navigation service in the Coastal Confluence Zone (CCZ) of the United States. Traffic Separation Schemes and Traffic Fairways were becoming more and more necessary to promote the safe transit of larger and larger vessels through the increasingly congested coastal waters. The size of vessels mandated an ability to navigate accurately and continually, well to seaward of visual and piloting ranges. The only apparent solution was an improved radionavigation capability. The Coast Guard was forced into the key decision making role in this area for two principal reasons. First, Title 14 U.S. Code, authorizes the Coast Guard to establish, maintain and operate Electronic Navigation Systems required to serve the needs of maritime commerce. Second, the Coast Guard already operated a Loran-A system providing service throughout much of the CCZ.

Requirements

A major concern was to provide a safe navigation capability to vessels in traffic separation schemes. These traffic lanes can be as narrow as one mile at their terminus, which is usually in the vicinity of the pilot station. A statistical analysis showed that 1/4 nautical mile (95%) positioning accuracy could reduce the chance of 2 vessels in opposing traffic lanes passing within 200 feet of each other to one in one million.[1]

The Coast Guard felt this 1/4 nautical mile accuracy should be available continuously throughout the Coastal Confluence Zone (CCZ), at least 50 miles offshore or to the 100 fathom curve.

With area coverage and accuracy established, the remaining steps were to select a system and sell the plan to the Office of Management and Budget and Congress.

Alternatives

At least five government-provided radionavigation systems were in operation or under operational evaluation in the early Seventies. These included:

a. TRANSIT, the Navy navigation satellite system which provided periodic fixes of 1/4 nautical mile or better, but with fix intervals approaching 90 minutes.[2]

b. OMEGA, a low frequency global navigation system operated by the Coast Guard and other agencies in foreign countries which provided 2-4 nm accuracy nearly worldwide.[3]

c. Marine Radiobeacons whose accuracy is limited to about $\pm$ 3 degrees of arc in bearing.

d. Loran-A, a long range hyperbolic system operated by the Coast Guard since the 1940's to meet both civil and DOD needs.

The system did not provide groundwave fix coverage throughout the CCZ of the U.S., and accuracy was limited by transmitting and receiving equipment to about one to two nautical miles.

e. Loran-C, a low frequency long range hyperbolic system operated by the Coast Guard to meet DOD needs along the U.S. East Coast and in selected overseas areas.

Several private and foreign radionavigation systems were also candidates for selection as the government-provided radionavigation system for the the CCZ. These included differential OMEGA, which can provide 1/4 nautical mile accuracy up to 50 miles from the monitor station; DECCA, a low frequency hyperbolic System in wide use outside U.S. Waters; and RAYDIST which is a medium frequency hyperbolic system used widely for surveys.

Selection of Loran-C

The Coast Guard determined that the expense to modernize and improve the accuracy of Loran-A just couldn't compete with the cost to implement other candidate systems. These were Loran-C, DECCA, and differential OMEGA. Given these three options, the Coast Guard could not possibly be an unbiased judge. We therefore selected an unbiased expert in the field of navigation to analyze the benefits and limitations of each system. In July 1972 Bill Polhemus completed his analysis of these three systems, and recommended that Loran-C be selected for implementation.[4]

After considerable discussion between the Coast Guard, Department of Transportation (DOT), and the Office of Management and Budget, our Fiscal Year 1975 Budget was submitted to Congress including a request for nearly $17 million to establish Loran-C service on the West Coast of the United States. The lengthy hearing on this Appropriation Bill resulted in selecting Loran-C to serve the East, West and Gulf Coasts, and Congressional approval to terminate Loran-A after an 18-24 month period of overlapping service. The West Coast was selected to receive new Loran-C coverage first, anticipating the expected tanker traffic from Valdez, and because of poor Loran-A coverage in the area.[5]

Since the 1974 decision to adopt Loran-C as the primary radionavigation system throughout the CCZ, the Coast Guard has extended Loran-C coverage throughout the CCZ and Great Lakes areas of the U.S. The Loran-A system was phased out on December 31, 1980 after providing overlapping service for approximately two years.

Loran-C Charting

Loran-C signals are attenuated in amplitude and retarded in time when they propagate through or over mediums of less than perfect conductivity. A detailed discussion of this phenomenon is well beyond the scope of this paper. An understanding of the results is critical to planning Loran-C chain coverage and insuring that adequate charts are available. Minor errors in calculating the attenuation due to overland signal propagation are relatively inconsequential when compared to the large variations in atmospheric noise at 100 kHz, the Loran-C operating frequency. Small errors in calculating the retardation of signals when passing over land (additional secondary factor (ASF)) can be catastrophic. Most readers of this paper are probably somewhat familiar with the offsets in the first edition of five Loran-C charts which covered southern California waters. In these waters, the West Coast Loran-C chain provides a 2 drms fix accuracy of about 1000 feet with a sigma of 0.1 microseconds. The effect of an unpredicted 0.2 to 0.3 microsecond retardation over the signal propagation path is obvious.

Loran-C charts of the coastal waters of the United States are the product of a coordinated effort of three Government agencies. The Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) predicts Loran-C grid warpage in coastal waters using various predictive techniques. These predictions are used by the National Ocean Survey to produce coastal charts with Loran-C lattices that reflect actual behavior of Loran-C signals along our coasts. These predictions will, in the future, be more accurate upon completion of a warped hyperbola program being developed by DMAHTC. The Coast Guard has been conducting or funding for at-sea surveys to insure that first edition charts are accurate within 1/4 nautical mile and that the signal is useable by receivers. There are two opposing requirements in this effort. The public expects charts to be available the day service is established and also has the right to expect accurate charts. A further constraint is that National Ocean Survey reprints many charts on a two or three year cycle. To place the problem in its perspective, there are several hundred charts slated to have Loran-C overprints. Our common goal has been to insure that small scale general charts (scales 1:100,000 to 1:600,000) are available when service is established and that reasonably accurate (1/4 NM or better) coast charts (scale 1:80,000 to 1:100,000) are available as soon as possible after a chain is declared operational. In most cases a grid prediction verification survey is required before reasonably accurate coast charts can be printed.

In preparing predictions, DMAHTC computes ASF for coastal charts for an area of approximately 10 to 50 nautical miles from land. The approximate 10 NM limitation is for computer program convenience and because of the theoretical uncertainty of radio wave propagation near land/sea interfaces. The computation points are typically set at an interval of five minutes of latitude and longitude. A sufficient number of points are selected and arranged so that the resulting matrix from which the averaged correction can be determined, truly represents the charted area.

The individual master and secondary transmission path corrections (ASF's) for each point are then subtracted algebraically, yielding a single correction which can then 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 lattice is then tested by a 1/4 NM 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 NM. The test is run to ascertain whether or not a single averaged correction can adequately represent the ASF for a particular charted area. DMAHTC is currently developing a warped hyperbola program which will incorporate ASF corrections at any interval into the predicted lattice. This will enable systematic correction, for Loran-C lattices on charts.

The Loran-C verification surveys being conducted or funded by the Coast Guard are expensive in terms of capital investment and ship availability. Therefore once a survey has been accomplished for a particular region, a resurvey will not be performed, unless an anomalous situation exists which requires further investigation. Time and vessel availability permitting, these surveys are conducted between the Spring to early Autumn seasons as much as possible. Figure 1 contains a listing of Loran-C verification surveys already completed, as well as plans for additional surveys. As can be seen, the Coast Guard is approaching the end of this type of survey, since by mid-1982 verification surveys will have been completed throughout the CCZ and Great Lakes areas.

Figure 2 contains a listing of National Ocean Survey charts already overprinted with Loran-C lattices. Scheduled print dates for new charts containing Loran-C information as well as reprint dates for already existing charts, are included in the listing.

VERIFICATION SURVEYS COMPLETED:

AREA	YEAR ACCOMPLISHED	RATE	*DATA STATUS
Southern California (Pt. Arguello south)	1977	9940	1
Norfolk to Long Island	1978	9960	1
New England	1978	7980 less 7980-W	1
Gulf of Mexico	1978	9960	1
Lake Huron	1979	9960	1
Lakes Erie and Ontario	1979	9960	2
Southeast Coast	1979	7980	1
Western Gulf of Mexico	1980	7980	2
Lake Huron	1980	8970	2
Lake Superior	1980	8970	2
Lake Michigan	1980	8970	3
Norfolk, VA to Tampa, FL	1981	7980/9960	3
Lake St. Clair	1980	8970	1
Strait of Juan De Fuca - Puget Sound	1981	5990	3
Long Island to Canada	1981	9960/5930	3

VERIFICATION SURVEY SCHEDULED:

Pt. Arguello to Strait of Juan De Fuca	May 1982	9940

*1 - Included in current chart edition
*2 - Included on some charts - will be included on charts to be reprinted
*3 - Data being processed

FIGURE 1

ACKNOWLEDGEMENTS

1 Coast Guard Authorization - 1975
Hearings before the Subcommittee on
Coast Guard and Navigation (page 103)

2 The Transit Navigation Satellite
System, Thomas A. Stansell

3 DOT National Plan for Navigation

4 Radio Aids to Navigation for the U.S.
Coastal Confluence Region; Polhemus
Navigational Services, Inc.,
(DOT-CG-221-66A)

5 Development of Charting Corrections
for Loran-C Charts in the Coastal
Confluence Zone; Randolph J. Doubt,
Defense Mapping Agency Hydrographic
Center

EAST COAST AND GULF OF MEXICO NAUTICAL CHART LISTING FOR NATIONAL OCEAN SURVEY CHARTS CONTAINING LORAN-C OVERLAYS

CHART NUMBER	CHART TITLE	SCALE	CURRENT EDITION	DATE OF CURRENT EDITION	CONTAINS LORAN-C RATES 7980	9930	9960	NEXT EDITION DUE
411	GULF OF MEXICO	1:2,160,000	34	08/02/80	WXYZ			
11005	GULF COAST - MISS RIVER TO RIO GRANDE	1:866,300	02	10/11/80	WXY			
11006	GULF COAST - KEY WEST TO MISSISSIPPI RIVER	1:875,000	19	05/31/80	WXYZ			07/81
11009	CAPE HATTERAS TO STRAITS OF FLORIDA	1:1,200,000	27	08/30/80	WXYZ			09/81
11013	STRAITS OF FLORIDA AND APPROACHES	1:1,200,000	33	07/19/80	WXYZ			09/81
11300	GALVESTON TO RIO GRANDE	1:460,732	23	07/05/80	WXYZ			
11301	SOUTHERN PART OF LAGUNA MADRE	1:80,000	13	09/15/79	WXYZ	W--Z		10/81
11304	NORTHERN PART OF LAGUNA MADRE	1:80,000	09	09/15/79	WXYZ	W--Z		10/83
11307	ARANSAS PASS TO BAFFIN	1:80,000	26	08/17/79	WXYZ	W--Z		09/81
11313	MATAGORDA LIGHT TO ARANSAS PASS	1:80,000	14	06/09/79	-XYZ	W--Z		07/81
11316	MATAGORDA BAY AND APPROACHES	1:80,000	26	05/04/81	WXY-			
11321	SAN LUIS PASS TO E. MATAGORDA BAY	1:80,000	20	04/19/80	WXY-			
11323	APPROACHES TO GALVESTON BAY	1:80,000	44	04/26/81	WXY-			
11332	SABINE BANK TO EAST BAY INCLUDING HEALD BANK	1:80,000	17	11/22/80	-XY-			01/82
11340	MISSISSIPPI RIVER TO GALVESTON	1:458,596	42	03/28/81	WXYZ			
11341	CALCASIEU PASS TO SABINE PASS	1:80,000	26	07/04/81	-XY-			
11344	ROLLOVER BAYOU TO CALCASIEU PASS	1:80,000	21	08/09/80	-XY-			09/81
11349	VERMILION BAY AND APPROACHES	1:80,000	25	03/15/81	-XY-			
11351	POINT AU FER TO MARSH ISLAND	1:80,000	23	02/14/81	-XY-			
11356	ISLES DERNIERES TO POINT AU FER	1:80,000	21	02/21/81	-XY-			
11357	TIMBALIER AND TERREBONNE BAYS	1:80,000	21	03/28/81	-XY-			
11358	BARATARIA BAY AND APPROACHES	1:80,000	30	02/07/81	-XY-			
11359	LOOP DEEPWATER PORT	1:50,000	01	03/07/81	WXY-			
11360	CAPE ST. GEORGE TO MISSISSIPPI RIVER	1:456,394	25	02/21/81	WXYZ			
11361	MISSISSIPPI RIVER DELTA	1:80,000	44	02/07/81	-XY-			
11363	CHANDELEUR AND BRETON SOUNDS	1:80,000	21	03/07/81	-XY-			
11369	LAKES PONTCHARTRAIN AND MAUREPAS	1:80,000	31	11/15/80	-XY-			01/82
11371	LAKE BORGNE AND APPROACHES	1:80,000	23	05/02/81	WXY-			
11373	MISSISSIPPI SOUND AND APPROACHES	1:80,000	25	06/28/80	WXY-			
11376	MOBILE BAY	1:80,000	34	09/27/80	WXY-			
11382	PENSACOLA BAY AND APPROACHES	1:80,000	26	11/15/80	WXY-			
11388	CHOCTAWHATCHEE BAY	1:80,000	11	06/23/79	WXY-	W--Z		06/81
11389	ST. JOSEPH & ST. ANDREW BAY	1:80,000	21	02/07/81	WXYZ			
11400	TAMPA BAY TO CAPE SAN BLAS	1:456,394	20	01/03/81	WXYZ			
11401	APALACHICOLA BAY TO CAPE SAN BLAS	1:80,000	20	05/23/81	WXYZ			

EAST COAST AND GULF OF MEXICO NAUTICAL CHART LISTING FOR NATIONAL OCEAN SURVEY CHARTS CONTAINING LORAN-C OVERLAYS

CHART NUMBER	CHART TITLE	SCALE	CURRENT EDITION	DATE OF CURRENT EDITION	CONTAINS LORAN-C RATES 7980	9930	9960	NEXT EDITION DUE
11405	APALACHEE BAY	1:80,000	18	07/12/80	WXYZ			
11407	HORSESHOE POINT TO ROCKS ISLAND	1:80,000	10	05/02/81	WXYZ			
11408	CRYSTAL RIVER TO HORSESHOE POINT	1:80,000	19	08/15/81	WXYZ			
11409	ANCLOTE KEYS TO CRYSTAL RIVER	1:80,000	18	07/04/81	WXYZ			
11412	TAMPA BAY & ST. JOSEPH'S SOUND	1:80,000	26	07/04/81	WXYZ			
11420	HAVANA TO TAMPA BAY	1:470,940	16	05/26/80	WXYZ			
11424	LEMON BAY TO PASSAGE KEY	1:80,000	13	04/25/81	WXYZ			
11426	ESTERO BAY TO LEMON BAY INCL. CHARLOTTE H.	1:80,000	24	05/09/81	WXYZ			
11429	CHATHAM RIVER TO CLAM PASS	1:80,000	13	12/15/79	WXYZ			
11431	EAST CAPE TO MORMON KEY	1:80,000	09	08/11/79	WXY-			09/83
11434	FLORIDA KEYS - SOMBRERO KEY TO DRY TORTUGAS	1:80,000	17	06/16/79	WXYZ			
11439	SAND KEY TO REBECCA SHOAL	1:80,000	17	05/30/81	WXYZ			
11442	SOMBRERO KEY TO SAND KEY	1:80,000	20	05/30/81	WXYZ			
11452	ALLIGATOR REEF TO SOMBRERO KEY	1:80,000	13	12/15/79	WXYZ			01/82
11460	CAPE CANAVERAL TO KEY WEST	1:446,940	25	08/30/80	WXYZ			12/81
11462	FOWEY ROCKS TO ALLIGATOR REEF	1:80,000	17	07/26/80	W-YZ			
11466	JUPITER INLET TO FOWEY ROCKS	1:80,000	22	03/14/81	W-Z			
11474	BETHEL SHOAL TO JUPITER INLET	1:80,000	08	03/21/81	W-YZ			
11476	CAPE CANAVERAL TO BETHEL SHOAL	1:80,000	13	05/24/80	W-YZ			
11480	CHARLESTON LT. TO CAPE CANAVERAL	1:449,659	23	08/25/79	WXYZ	W YZ		05/81
11484	PONCE DE LEON INLET TO CAPE KENNEDY	1:80,000	14	11/01/80	WXYZ			12/82
11486	ST. AUGUSTINE LT. TO PONCE DE LEON INLET	1:80,000	10	10/04/80	WXYZ			11/84
11488	AMELIA ISLAND TO ST AUGUSTINE	1:80,000	14	12/29/79	WXYZ	W-Z		01/82
11502	DOBOY SOUND TO FERNANDINA	1:80,000	17	04/12/80	--YZ			
11509	TYBEE ISLAND TO DOBOY SOUND	1:80,000	18	03/21/81	W-YZ			
11513	ST. HELENA SD. TO SAVANNAH R.	1:80,000	15	07/21/79	W-YZ	W-YZ		08/81
11520	CAPE HATTERAS TO CHARLESTON	1:432,720	25	04/14/81	W-YZ		WXYZ	
11521	CHARLESTON HARBOR AND APPROACHES	1:80,000	15	02/23/80	W-YZ			
11531	WINYAH B. ENTRANCE TO ISLE OF PALMS	1:80,000	13	03/22/80	W-YZ			
11535	LITTLE R. TO WINYAH BAY ENTR	1:80,000	08	07/14/79	W-YZ			
11536	APPROACHES TO CAPE FEAR RIVER	1:80,000	09	12/01/79	W-YZ	W-YZ	-X-Z	12/83
11539	NEW RIVER INLET TO CAPE FEAR	1:80,000	14	02/28/81			WXYZ	
11543	CAPE LOOKOUT TO NEW RIVER	1:80,000	16	04/14/79		W-YZ	WXY-	06/81

EAST COAST AND GULF OF MEXICO NAUTICAL CHART LISTING FOR NATIONAL OCEAN SURVEY CHARTS CONTAINING LORAN-C OVERLAYS

CHART NUMBER	CHART TITLE	SCALE	CURRENT EDITION	DATE OF CURRENT EDITION	CONTAINS LORAN-C RATES 5930	9930	9960	NEXT EDITION DUE
11544	PORTSMOUTH ISLAND TO BEAUFORT	1:80,000	27	02/07/81			WXYZ	
11548	PAMLICO SOUND-WESTERN PART	1:80,000	28	04/18/81			WXYZ	
11555	CAPE HATTERAS-WIMBLE SHOALS TO ORACOKE IN.	1:80,000	27	12/06/80			WXYZ	
12200	CAPE MAY TO CAPE HATTERAS	1:416,944	33	10/25/80			WXYZ	
12204	CURRITUCK BEACH LT TO WIMBLE SHOALS	1:80,000	26	02/21/81			WXYZ	
12207	CAPE HENRY TO CURRITUCK BEACH LT.	1:80,000	15	08/15/81			WXYZ	
12210	CHINCOTEAQUE INLET TO GT. MACHIPONGO INLET	1:80,000	25	10/18/80			WXYZ	
12211	FENWICK ISL. LT TO CHINCOTEAQUE INLET	1:80,000	28	08/22/81			WXYZ	
12214	CAPE MAY TO FENWICK ISL. LT.	1:80,000	33	06/07/80			WXYZ	
12220	CHESAPEAKE BAY-SOUTHERN PART	1:200,000	29	03/14/81			WXYZ	
12221	CHESAPEAKE BAY ENTRANCE	1:80,000	50	07/18/81			WXYZ	
12225	CHESAPEAKE BAY - WOLF TRAP TO SMITH POINT	1:80,000	39	07/12/80			WXYZ	
12230	SMITH POINT TO COVE POINT	1:80,000	39	01/10/81			WXYZ	08/81
12260	CHESAPEAKE BAY-NORTHERN PART	1:197,250	22	06/21/80			WXYZ	
12263	COVE POINT TO SANDY POINT	1:80,000	33	06/21/80			WXYZ	08/81
12273	SANDY POINT TO HEAD OF BAY	1:80,000	37	01/24/81			WXYZ	
12300	APPROACHES TO N.Y. NANTUCKET SHOALS	1:400,000	29	06/27/81			WXYZ	
12304	DELAWARE BAY	1:80,000	27	03/28/81			WXYZ	
12318	LITTLE EGG INLET TO HEREFORD INLET	1:80,000	33	10/01/80			WXYZ	
12323	SEA GIRT TO LITTLE EGG INLET	1:80,000	19	11/15/80			WXYZ	
12326	APPROACHES TO N.Y. FIRE ISLAND LT. TO SEA GIRT LT	1:80,000	34	01/17/81			WXYZ	
12353	SHINNECOCK LIGHT TO FIRE ISLAND LIGHT	1:80,000	14	05/02/81			WXYZ	
12354	LONG ISLAND SOUND - EASTERN PART	1:80,000	24	05/23/81			WXYZ	
12363	LONG ISLAND SOUND - WESTERN PART	1:80,000	30	01/31/81			WXYZ	
13003	CAPE SABLE TO CAPE HATTERAS	1:1,200,000	34	02/28/81			WXYZ	
13006	WEST QUODDY HEAD TO N.Y	1:675,000	23	09/06/80			WXYZ	08/81
13009	GULF OF MAINE & GEORGES BANK	1:500,000	19	08/30/80	XY		WXYZ	
13200	GEORGES BANK AND NANTUCKET SHOALS	1:400,000	23	07/12/80			WXYZ	
13203	GEORGE'S BANK	1:220,000	08	09/29/79		-XYZ	WXYZ	10/83
13204	GEORGE'S BANK	1:220,000	08	08/25/79		-XYZ	WXYZ	10/83
13205	BLOCK ISLAND SOUND AND APPROACHES	1:80,000	26	02/21/81			WXYZ	
13218	MARTHA'S VINEYARD TO BLOCK ISLAND	1:80,000	24	11/29/80			WXYZ	
13237	NANTUCKET SOUTH AND APPROACHES	1:80,000	28	04/18/81			WXYZ	

EAST COAST AND GULF OF MEXICO NAUTICAL CHART LISTING FOR NATIONAL OCEAN SURVEY CHARTS CONTAINING LORAN-C OVERLAYS

CHART NUMBER	CHART TITLE	SCALE	CURRENT EDITION	DATE OF CURRENT EDITION	CONTAINS LORAN-C RATES 5930	9930	9960	NEXT EDITION DUE
13246	CAPE COD BAY	1:80,000	25	01/31/81			WXYZ	
13260	BAY OF FUNDY TO CAPE COD	1:378,838	27	06/20/81	-XY-		WXYZ	
13267	MASSACHUSETTS BAY	1:80,000	21	12/20/80			WXYZ	
13278	PORTSMOUTH TO CAPE ANN	1:80,000	18	03/14/81			WXYZ	
13286	CAPE ELIZABETH TO PORTSMOUTH	1:80,000	22	04/11/81			WXYZ	
13288	MONHEGAN ISLAND TO CAPE ELIZABETH	1:80,000	25	02/14/81			WXY	
13302	PENBSCOT BAY AND APPROACHES	1:80,000	13	03/28/81			WXY	
13312	FRENCHMAN & BLUE HILL BAYS AND APPROACHES	1:80,000	17	05/02/81			WXY	
13325	QUODDY NARROWS TO PETIT MANON I.	1:80,000	10	09/01/79		XYZ	WXY	10/81

GREAT LAKES NAUTICAL CHART LISTING FOR CHARTS CONTAINING LORAN-C OVERLAYS

CHART NUMBER	CHART TITLE	SCALE	CURRENT EDITION	DATE OF CURRENT EDITION	CONTAINS LORAN-C RATES 9960	9930	8970	NEXT EDITION DUE	PLANNED ADDITIONS
14500	GREAT LAKES	1:1,500,000	22	05/26/79		YZ		6/82	
14800	LAKE ONTARIO	1:400,000	25	03/21/81	WXYZ				
14802	CLAYTON TO FALSE DUCKS ISLANDS	1:80,000	26	03/28/81	WX-Z				
14803	SIX MI SO OF STONY PT TO PORT BAY	1:80,000	22	03/21/81	WX-Z				
14804	PORT BAY TO LONG POND	1:80,000	21	05/23/81	WXYZ				
14805	LONG POND TO THIRTY MILE POINT	1:80,000	20	03/14/81	WXYZ				
14806	THIRTY MILE PT TO PT DALHOUSIE	1:80,000	20	07/11/81	W-YZ				
14820	LAKE ERIE	1:400,000	36	03/01/80	WXYZ	YZ			
14822	APPROACHES TO NIAGARA RIVER	1:80,000	23	08/26/78				5/81	ADD 9960-W,X,Y,Z
14823	STURGEON PT TO TWENTYMILE CREEK	1:80,000	22	05/03/80				6/83	ADD 9960-W,X,Y,Z
14824	SIXTEENMILE CREEK TO CONNEAUT	1:80,000	21	05/09/81	WXYZ				
14825	ASHTABULA TO CHAGRIN RIVER	1:80,000	19	07/29/78				7/81	ADD 9960-W,X,Y,Z
14826	MOSS POINT TO VERMILION	1:80,000	21	02/03/79				7/81	ADD 9960-W,X,Y,Z
14828	ERIE TO GENEVA	1:100,000							
14829	GENEVA TO LORAIN	1:100,000							
14830	WEST END OF LAKE ERIE	1:100,000	16	04/26/80				5/81	ADD 9960-W,X,Y,Z

GREAT LAKES NAUTICAL CHART LISTING FOR NATIONAL OCEAN SURVEY CHARTS CONTAINING LORAN-C OVERLAYS

CHART NUMBER	CHART TITLE	SCALE	CURRENT EDITION	DATE OF CURRENT EDITION	CONTAINS LORAN-C RATES 9960	9930	8970	NEXT EDITION DUE	PLANNED ADDITIONS
14850	LAKE ST CLAIR	1:60,000	39	08/22/81			-XY-		
14860	LAKE HURON	1:500,000	27	02/09/80	W-YZ	--YZ	-XY-	9/81	
14862	PORT HURON TO PTE AUX BARQUES	1:120,000	23	07/29/78		--YZ		4/81	ADD 9960-W,Y,Z,8970-X,Y
14863	SAGINAW BAY	1:120,000	22	04/21/79				4/81	ADD 9960-W,Y,Z,8970-X,Y
14864	HARRISVILLE TO FORTY MILE POINT	1:120,000	21	05/03/80				12/81	ADD 9960-W,Y,Z,8970-X,Y
14880	FALSE DETOUR CHANNEL AND PRESQUE ISLE	1:120,000	25	10/20/79				5/81	ADD 8970-X,Y
14881	DETOUR PASSAGE TO WAUGOSHANCE PT	1:80,000	23	07/05/80				2/82	ADD 8970-X,Y
14900	LAKE MICHIGAN	1:500,000	28	02/23/80		--YZ	-XY-	9/81	
14901	LAKE MICHIGAN	1:500,000	05	08/02/80			-XY-		
14902	NORTH END OF LAKE MICHIGAN	1:240,000	22	04/11/81			-XY-		
14903	ALGOMA TO CHEYBOYGAN	1:120,000	18	09/08/79				10/82	ADD 8970-X,Y
14904	PORT WASHINGTON TO WAUKEGAN	1:120,000	19	09/29/79				10/82	ADD 8970-X,Y
14905	WAUKEGAN TO SOUTH HAVEN	1:120,000	21	03/03/79				7/81	ADD 8970-X,Y
14906	SOUTH HAVEN TO STONY LAKE	1:120,000	19	09/29/79				5/81	ADD 8970-X,Y
14907	STONY LAKE TO POINT BETSIE	1:120,000	19	03/22/80				4/81	ADD 8970-X,Y
14908	DUTCH JOHNS POINT TO FISHERY POINT	1:120,000	14	12/02/78				1/82	ADD 8970-X,Y
14909	UPPER GREEN BAY	1:80,000	14	07/07/79				5/81	ADD 8970-X,Y
14910	JACKSONPORT TO KEWAUNEE	1:80,000	15	03/17/79				11/81	ADD 8970-X,Y
14911	WAUGOSHANCE TO SEUL CHOIX PT	1:80,000	14	05/05/79				11/81	ADD 8970-X,Y
14912	PLATTE BAY TO LELAND	1:80,000	13	11/25/78				1/82	ADD 8970-X,Y
14913	GRAND TRAVERSE B TO LITTLE TRAVERSE R	1:80,000	13	10/06/79				10/82	ADD 8970-X,Y
14960	LAKE SUPERIOR	1:600,000	26	02/23/80		--YZ	-XY-	4/81	
14961	LAKE SUPERIOR	1:600,000	05	05/09/81			-XY-		
14962	ST MARYS R TO AU SABLE PT	1:120,000	16	08/15/81			-XY-		
14963	GRAND MARAIS TO BIG BAY POINT	1:120,000	15	09/15/79				5/81	ADD 8970-X,Y
14964	BIG BAY POINT TO REDRIDGE	1:120,000	15	06/14/80				1/82	ADD 8970-X,Y
14965	REDRIDGE TO SAXON HARBOR	1:120,000	15	09/08/79				10/82	ADD 8970-X,Y
14966	LITTLE GIRLS POINT TO SILVER BAY	1:120,000	18	12/22/79				1/83	ADD 8970-X,Y
14967	BEAVER BAY TO PIGEON POINT	1:120,000	18	03/01/80				5/81	ADD 8970-X,Y
14968	GRAND PORTAGE BAY TO SHESHEEB POINT	1:120,000	25	06/27/81			-XY-		

ALASKAN COAST NAUTICAL CHART LISTING FOR NATIONAL OCEAN SURVEY CHARTS CONTAINING LORAN-C OVERLAYS

CHART NUMBER	CHART TITLE	SCALE	CURRENT EDITION	DATE CURRENT EDITION	CONTAINS LORAN-C RATES 4990	5990	7960	9940	9990	NEXT EDITION DUE
16005	CAPE PRINCE OF WALES TO PT BARROW	700,000	06	10/16/76					XYZ	
16006	BERING SEA-EASTERN PART	1:534,076	26	06/24/78					XYZ	06/82
16011	ALASKA PEN & ALEUTIAN IS	1:023,188	28	05/13/78					XYZ	
16012	AMUKTA ISLAND TO ATTU ISLAND	1:126,321	19	09/17/77					XYZ	
16013	CAPE ST FLIAS TO SHUMAGIN ISLANDS	1:969,761	21	04/08/78			XY		XYZ	07/82
16016	DIXON ENT TO CAPE ST ELIAS	1:969,756	17	03/21/81			XY			
16200	NORTON SOUND	1:900,000	11	08/21/76					XYZ	09/88
16204	PORT CLARENCE AND APPROACHES	1:100,000	04	09/11/76					XYZ	10/88
16240	CAPE ROMANZOF TO ST MICHAEL	1:100,000	08	01/05/80					XYZ	02/82
16300	KUSKOKWIM BAY	1:200,000	07	09/18/76					XYZ	10/84
16322	BRISTOL HAY-NUSHAGAK BAY AND AP	1:100,000	05	07/24/76					-XY	08/84
16323	BRISTOL HAY-KVICHAK BAY AND AP	1:100,000	06	10/16/76					-XY	11/84
16343	PORT HEIDEN	1:80,000	05	06/19/76					XYZ	07/84
16363	PORT MOLLER AND HERENDEEN BAY	1:80,000	10	10/16/76					XYZ	11/84
16380	PRIBILOF ISLANDS	1:200,000	11	03/24/79					XYZ	05/83
16420	NEAR ISLANDS-BULDIR I TO ATTU I	1:300,000	07	09/18/79					XYZ	10/83
16421	INGENSTREM ROCKS TO ATTU ISLAND	1:160,000	07	12/18/76					XYZ	01/89
16440	SEMISOPOCHNOI I TO BULDIR I	1:300,000	11	08/11/79					XYZ	09/83
16441	KISKA ISLAND AND APPROACHES	1:80,000	06	11/06/76					XYZ	12/88
16460	TGITKIN ISLAND TO SEMISOPOCHNOI ISLAND	1:300,000	11	04/08/78					XYZ	05/82
16471	ATKA PASS TO ADAK STRAIT	1:120,000	07	12/18/76					XYZ	07/84
16480	AMUKTA ISLAND TO IGITKIN ISLAND	1:300,000	08	08/25/78					XYZ	04/82
16500	UNALASKA I TO AMUKTA I	1:300,000	06	08/04/79					XYZ	09/83
16501	ISLANDS OF FOUR MOUNTAINS	1:80,000	04	10/23/76					XYZ	12/84
16520	UNIMAK TO AKUTAN PASSES AND AP	1:300,000	19	06/16/79					XYZ	08/83
16531	KRENITZIN ISLANDS	1:80,000	05	12/18/76					XYZ	01/85
16535	MORZHOVOI BAY AND TSANOTSKI STRAIT	1:60,660	10	09/04/76					XYZ	09/84
16540	SHUMAGIN ISLANDS TO SANAK ISLANDS	1:300,000	09	07/09/77					XYZ	08/81
16547	SANAK ISLANDS TO SANDMAN REEFS	1:81,326	07	05/06/78					XYZ	06/86
16549	COLD BAY AND APPROACHES	1:80,000	12	12/18/76					XYZ	02/81
16551	UNGA ISLAND TO PAVLOF BAY	1:80,000	07	10/23/76					XYZ	12/84
16553	SHUMAGIN IS-NAGAI I TO UNGA I	1:80,000	01	10/21/78					-YZ	11/82
16556	CHIACHI ISLAND TO NAGAI ISLAND	1:80,000	01	01/07/78					-YZ	01/82
16566	CHIGNIK AND KUJULIK BAYS-ALASKA PEN	1:77,477	05	04/08/78					XYZ	05/82

ALASKAN COAST NAUTICAL CHART LISTING FOR NATIONAL OCEAN SURVEY CHARTS CONTAINING LORAN-C OVERLAYS

CHART NUMBER	CHART TITLE	SCALE	CURRENT EDITION	DATE CURRENT EDITION	CONTAINS LORAN-C RATES 4990	5990	7960	9940	9990	NEXT EDITION DUE
16568	WIDE BAY TO CAPE KUMLIK-ALASKA PEN	1:106,600	05	12/09/78					XYZ	01/87
16580	KODIAK ISLAND	1:350,000	07	03/11/78			XY		XYZ	04/82
16590	SITKINAK STRAIT AND ALITAK BAY	1:81,529	07	09/23/78			XY		XYZ	11/82
16592	GULL POINT TO KAGUYAK BAY	1:80,728	07	11/06/76			XY		XY-	07/83
16593	CHINIAK BAY TO DANGEROUS CAPE	1:80,000	08	09/23/78			XY			
16597	UGANIK AND UKUK BAYS	1:80,000	06	08/19/78			XY		XYZ	09/82
16598	CAPE IKOLIK TO CAPE KULIUK	1:80,000	06	11/05/77			XY		XYZ	12/81
16601	CAPE ALITAK TO CAPE IKOLIK	1:80,905	06	09/18/76			XY		XYZ	10/81
16604	SHUYAK AND AFOGNAK ISLANDS	78,000	08	10/20/79			XY			
16606	BARREN ISLANDS	77,062	07	10/20/79			XY			
16640	COOK INLET-SOUTHERN PART	200,000	17	04/07/79			XY			
16648	KAMISHAK BAY	100,000	01	10/11/80			XY		YZ	
16660	COOK INLET-NORTHERN PART	194,154	21	10/25/80			XY		YZ	
16680	POINT ELRINGTON TO E CHUGACH I	200,000	07	09/16/78			XY			
16681	SEAL ROCKS TO GORE POINT	83,074	08	07/28/79			XY			
16682	CAPE RESURRECTION TO TWO ARM BAY	81,847	11	05/28/77			XY			
16683	POINT ELRINGTON TO CAPE RESURRECTION	81,436	07	06/16/79			XY			
16700	PRINCE WILLIAM SOUND	200,000	20	05/19/79			XY			
16701	PRINCE WILLIAM SOUND-WESTERN ENTRANCE	81,436	12	10/16/76			XY		XY	02/84
16705	PRINCE WILLIAM SOUND-WESTERN PART	80,000	13	04/29/78			XY			
16708	PRINCE WILLIAM SOUND	79,291	15	09/16/78			XY			
16709	PRINCE WILLIAM SOUND-EASTERN ENT	80,000	18	06/28/80			XY			
16723	CONTROLLER BAY	100,000	12	04/09/77			XY			
16760	CROSS SOUND TO YAKUTAT BAY	300,000	06	12/01/79			XY			
16761	YAKUTAT BAY	80,000	12	04/19/79			XY			
17300	STEPHENS PASSAGE TO CROSS SOUND	209,978	21	03/17/79			XY			
17320	CORONATION ISLAND TO LISIANSKI STRAIT	217,828	10	02/14/81		XYZ	XY			03/81
17400	DIXON ENTRANCE TO CHATHAM STRAIT	229,376	12	12/27/80		XYZ	XY			
17420	HECATE STRAIT TO ETOLIN ISLAND	229,376	22	07/11/81		XYZ	XY			

WEST COAST AND HAWAII NAUTICAL CHART LISTING FOR NATIONAL OCEAN SURVEY CHARTS CONTAINING LORAN-C OVERLAYS

CHART NUMBER	CHART TITLE	SCALE	CURRENT EDITION	DATE OF CURRENT EDITION	CONTAINS LORAN-C RATES 4990	5990	7960	9940	9990	NEXT EDITION DUE
500	DIXON ENTRANCE TO UNIMAK PASS	1:3,500,000	03	05/19/79			-XY-		-XYZ	
501	NORTH AMERICA, WEST COAST MEXICAN BORDER TO DIXON ENT.	1:3,500,000	04	11/29/80		-XYZ	-XY-	WXY-		
513	BERING SEA - SOUTHERN PART	1:3,500,000	04	10/25/80					-XYZ	
514	BERING SEA - NORTHERN PART	1:3,500,000	04	04/11/81					-XYZ	
530	SAN DIEGO TO ALEUTIAN IS. AND HAWAIIAN IS.	1:4,860,700	20	01/26/80	-XY-	-XYZ	-XY-	WXY-	-XYZ	
531	GULF OF ALASKA - STRAIT OF JUAN DE FUCA TO KODIAK IS.	1:2,100,000	13	01/19/80		-XYZ	-XY-		-XYZ	
540	HAWAIIAN ISLANDS	1:3,121,170	14	04/19/80	-XY-					
18003	CAPE BLANCO TO CAPE FLATTERY	1:736,560	11	08/09/80		-XYZ		WXY-		
18007	SAN FRANCISCO TO CAPE FLATTERY	1:1,200,000	25	05/23/81		-XYZ		WXY-		
18010	MONTEREY BAY TO COOS BAY	1:811,980	12	06/07/80				WXY-		
18020	SAN DIEGO TO CAPE MENDOCINO	1:1,444,000	29	03/01/80				WXY-		
18022	SAN DIEGO TO SAN FRANCISCO BAY	1:868,003	21	10/27/79				WXY-		08/81
18460	STRAIT OF JUAN DE FUCA ENTRANCE	1:100,000	02	11/08/80		-XYZ				
18480	APPROACHES TO STRAIT OF JUAN DE FUCA	1:176,253	18	04/25/81		-XYZ				
18500	COLUMBIA RIVER TO DESTRUCTION ISLAND	1:180,789	19	11/15/80		-XYZ		WXY-		
18520	YAQUINA HEAD TO COLUMBIA RIVER	1:185,238	15	02/07/81		-XYZ		WXY-		03/81
18580	CAPE BLANCO TO YAQUINA HEAD	1:191,730	13	09/30/78				WXY-		
18600	TRINIDAD HEAD TO CAPE BLANCO	1:196,948	10	04/19/80				WXY-		
18620	POINT ARENA TO TRINIDAD HEAD	1:200,000	15	08/12/78				WXY-		
18640	SAN FRANCISCO TO POINT ARENA	1:207,840	16	08/18/79				WXY-		
18645	GULF OF THE FARALONES	1:100,000	17	05/17/80				WXY-		
18680	POINT SUR TO SAN FRANCISCO	1:210,668	20	09/09/78				WXY-		
18700	POINT CONCEPTION TO POINT SUR	1:216,116	12	06/03/78				WXY-		
18720	POINT DUME TO PURISIMA POINT	1:232,188	22	08/04/79				-XY-		
18721	SANTA CRUZ ISLAND TO PURISIMA POINT	1:100,000	06	06/03/78				-XY-		
18740	SAN DIEGO TO SANTA ROSA ISLAND	1:234,270	26	04/81				-XY-		
18746	SAN PEDRO CHANNEL	1:80,000	20	03/01/80				-XY-		
18747	SAN PEDRO CHANNEL	1:80,000								
18765	APPROACHES TO SAN DIEGO BAY	1:100,000	10	06/02/79				-XY-		
18774	GULF OF SANTA CATALINA	1:100,000	01	01/27/79				-XY-		
19004	HAWAIIAN ISLANDS	1:600,000	28	06/07/80	-XY-					
19007	HAWAII TO FRENCH FRIGATE SHOALS	1:1,650,000	11	05/19/79	-XY-					
19010	HAWAIIAN ISLANDS - SOUTHERN PART	1:675,000	10	05/10/80	-XY-					
19013	HAWAIIAN ISLANDS - NORTHERN PART	1:675,000	11	10/21/78	-XY-					
19016	NIIHAU TO FRENCH FRIGATE SHOALS	1:663,392	06	10/01/77	-XY-					

WEST COAST AND HAWAII NAUTICAL CHART LISTING FOR NATIONAL OCEAN SURVEY CHARTS CONTAINING LORAN-C OVERLAYS

CHART NUMBER	CHART TITLE	SCALE	CURRENT EDITION	DATE OF CURRENT EDITION	CONTAINS LORAN-C RATES 4990	5990	7960	9940	9990	NEXT EDITION DUE
19019	FRENCH FRIGATE SHOALS TO LAYSAN ISLAND	1:653,219	06	07/23/77	-XY-					
19022	LAYSAN ISLAND TO KURE ISLAND	1:642,271	08	08/01/81	-XY-					
19320	ISLAND OF HAWAII	1:250,000	12	06/17/78	-XY-					
19327	WEST COAST OF HAWAII - COOK POINT TO UPOLU POINT	1:80,000	07	07/09/77	-XY-					
19340	HAWAII TO OAHU	1:250,000	19	10/20/79	-XY-					
19347	CHANNELS BETWEEN MOLOKAI, MAUI, LANAI, AND KAHOOLAWE	1:80,000	11	05/05/79	-XY-					
19351	CHANNELS BETWEEN OAHU, MOLOKAI, AND LANAI	1:80,000	06	11/06/76	-XY-					
19357	ISLAND OF OAHU	1:80,000	15	09/08/79	-XY-					
19375	KAUAI TO MOLOKAI	1:250,000	03	06/06/81	-XY-					
19380	OAHU TO NIIHAU	1:247,482	11	05/10/80	-XY-					
19381	KAUAI	1:80,000	05	08/21/76	-XY-					
19401	FRENCH FRIGATE SHOALS	1:80,000	06	06/09/79	-XY-					
19421	GARDNER PINNACLES	1:100,000	05	03/24/79	-XY-					
19441	MARO REEF	1:80,000	05	12/22/79	-XY-					
19480	GAMBIA SHOAL TO KURE ISLAND INCLUDING APPROACHES TO MIDWAY	1:80,000	05	09/25/76	-XY-					

GULF COAST AND EASTERN SEABOARD LORAN-C CALIBRATION

J.D. Illgen
Kaman Tempo
816 State Street
Santa Barbara, CA 93102

LCDR J.F. Weseman
Office of Navigation
U.S. Coast Guard Headquarters
Washington, DC 20593

R.E. Pozega and R.H. Miller
Kaman Tempo
1613 University Blvd, NE
Albuquerque, NM 87102

CWO4 E.F. Nuzman
Office of Navigation
U.S. Coast Guard Headquarters
Washington, DC 20593

A.R. Falconer
Marinav Corp.
1140 Morrison Drive
Ottawa, Ontario, Canada

I. Thompson
Marinav Corp.
1140 Morrison Drive
Ottawa, Ontario, Canada

ABSTRACT

In some areas Loran-C users obtain line-of-position (LOP) values that are different from the theoretical LOP values shown on nautical charts published by the National Ocean Survey. The U.S. Coast Guard is obtaining independent positioning data to provide corrections for those charts. As part of that effort, a calibration of Loran-C in the Gulf of Mexico and the Southeast seaboard was conducted in January 1981.

Simultaneous position fixes were recorded with Loran-C equipment operated by Coast Guard Electronics Engineering Center personnel and with Maxiran equipment operated by Kaman Tempo. The position fixes were taken at 3-minute intervals along a vessel track of some 2250 nautical miles from Tampa Bay, around the Florida Keys, to the sea buoy at Norfolk, VA. The survey was completed in a total lapsed time of 16 days which included diversions of the vessel USCGC Ingham to meet Coast Guard operational requirements. Four land-based Maxiran transmitter sites were moved sequentially along the shoreline to provide full coverage of the data track. A total of 27 previously surveyed land sites were used by the transmitter stations.

This paper describes the equipment used and the operational aspects of the survey, including calibration, installation, and data acquisition.

BIOGRAPHICAL SKETCHES

John D. Illgen - Mr. Illgen received his MSEE from the Technical University of Denmark in 1967. Specialist in Loran-C and satellite navigation and communication systems engineering, his experience spans application to space systems, oceanographic navigation, and defense systems, to name a few. He has conducted over 15 major Loran-C experiments and tests successfully during the past 10 years which have included pretest analysis, test planning, test execution, data reduction and processing, and data analysis. He is editor of the Wild Goose Newsletter and member of the WGA Board of Directors.

Robert E. Pozega - Mr. Pozega received his BA degree in Mathematics from the University of Montana. His experience covers a broad range of communication application for defense systems such as: NIKE-X, SAFEGUARD, and various air-to-air missiles. He has also been involved with the design and analysis of several EMP test facilities at Kirtland AFB, New Mexico.

Robert H. Miller - Dr. Miller received his Ph.D. in Chemistry from Pennsylvania State University in 1965 and is a retired officer of 22 years' service in the U.S. Army. He is a licensed commercial pilot with an instrument rating and has experimented with several RNAV and Loran-C receiver systems for aerial and shipboard navigation systems.

A.F. Falconer - Mr. Falconer's experience in navigation includes polar Arctic work in multidisciplined surveys. He had designed computer interfaces for hydrographic surveys and has developed microprocessor systems for data acquisition.

I. Thompson - Mr. Thompson attended Leith Nautical College and served in the British Merchant Navy from 1943 to 1956, achieving the rank of Chief Officer. He is an experienced hydrographer and navigation specialist in operations at sea and on land over most of the northwestern hemisphere of the world.

J. Illgen presented this paper for Dr. R. Miller who was ill. Photograph shown earlier.

LORAN-C CALIBRATION
GULF COAST AND EASTERN SEABOARD

by

R. Miller, Kaman Tempo
J. Illgen, Kaman Tempo
J. Weseman, USCG
R. Falconer, Marinav Corp.

SUMMARY

The objective of this project was to compare Loran-C signals (Time Differences) to signals from a position reference system for the Gulf Coast and the Eastern Seaboard up to Norfolk, VA. To achieve this goal a Loran-C calibration was conducted using a position reference system known as Maxiran wherein Loran-C (time Difference) and Maxiran (range/range) signals were measured simultaneously. This paper describes the entire operation, which included land site selection, land site positioning, equipment calibration, logistics, equipment definition and operation, and a description of data collected. This paper focuses on the operation of such a Loran-C calibration. The test results will be reflected in the new NOS Loran-C nautical charts now being prepared for the Eastern Seaboard and Gulf Coast.

The site survey was conducted by Kaman Tempo personnel using an MX 1502 satellite surveyor in the point positioning mode. All site positions were surveyed to third-order accuracy or better. Section 2 describes the site selection process and use of the MX 1502 satellite geoceivers in the point positioning mode.

Equipment calibration, land site, and shipboard installation descriptions are provided.

Also described are the shipboard data collection operation and calibration. Sufficient detail is provided to allow proper use of the computer printouts and cassettes. Problems encountered and remedial action taken are presented.

SITE SELECTION

Sites are selected based on the following criteria:

1. Proximity to shoreline.
2. Accessibility.
3. Unobstructed propagation paths between the antenna and the vessel to include the absence of land masses, trees, buildings, or any other obstacle in the propagation path. Absence of obstacles over the full range of antenna orientations from each site to the vessel is to be considered by examining the nautical charts that show site locations and their associated data

track lines. (Reference is also made to topography maps.)

4. Proper distances from power cables, telephone lines, and other transmitters.

Visual checks for the above were made during the site selection process.

SITE POSITIONING

The coordinates of each land site were obtained using the Magnavox MX 1502 Satellite Surveyor or were derived from the U.S. Geodetic Service (USGS) horizontal control point data. All USGS survey data were third order or better. The MX 1502 satellite geoceiver was used in the point positioning mode. The MX 1502 satellite geoceiver consists of a portable antenna unit, a main unit, and a 12-volt battery. The MX 1502 is designed around a microprocessor that controls essentially every function of the instrument. The main unit combines the microprocessor, keyboard, display function, magnetic-tape cassette, dual-channel receiver, crystal oscillator, rechargeable backup batteries, and power supply in a single lightweight, rugged, field portable enclosure.

The MX 1502 computes and displays a three-dimensional (3-D) position fix result. This result is accomplished in the field and verifies proper system operation, assuring the location has been determined to the desired accuracy. The results computed in the field provided an indication to the operator that sufficient data have been collected and a move to the next site can be made with assurance. The MX 1502 includes a thorough self-test capability to assure proper operation. If the self-test function detects a problem, the specific module causing the problem is indicated. However, it should be noted that there were no malfunctions during the satellite survey. After each record was placed on magnetic tape, it was immediately read back to assure no recording mistakes. If an error had been detected, that portion of data would have been re-recorded.

The MX 1052 can acquire the orbital parameters of all transit satellites by reading a previously recorded tape cassette (alert tape). Thereafter, it shifts automatically to a minimum power mode between satellite passes to reduce battery consumption.

SOFTWARE

A two-dimensional (2-D) position was computed after each pass. This position was displayed as latitude and longitude in degrees, minutes, and seconds referenced to the World Geodetic System 1972 (WGS-72) datum.

Additionally, a 3-D position was calculated after each pass. This position was also displayed as latitude and longitude in degrees, minutes, and seconds (WGS-72) and height above mean sea level in meters.

The 3-D position is more accurate than the 2-D position as it is based upon all usable satellite pass data since the survey site was established. In general, the more satellite pass data, the more accurate the position. Both the 2-D and 3-D positions are available about one-half minute after the end of a satellite pass.

A computation of the statistical uncertainty in the position is made after each fix computation which enables the surveyor to determine precisely when enough data has been accumulated to satisfy the desired accuracy requirements.

RESULTS

The coordinates of all sites are listed in Table 1. All locations are in WGS-72 coordinates. The latitude, longitude, and altitude in meters are listed for each site that was surveyed using the MX 1502. Sites 6, 7, 23, and 24 were obtained from USGS data.

EQUIPMENT AND INSTALLATION DEFINITIONS

Maxiran Propagation Definition

A recent arrival to the growing family of offshore navigation systems is the medium-range positioning system known as Maxiran, developed over the last 5 to 6 years from the long established Shoran series of equipment. The incorporation of high-technology techniques, solid-state design, and utilization of the 400-MHz band for transmission and reception ensures a precise, lightweight, highly portable navigation system for use offshore by surveyors, resource development industries, and research and surveillance agencies.

Propagation Media

Research into electromagnetic wave propagation over water masses has established that frequencies between 50 and 500 MHz can be propagated along the air-sea interface. Under normal conditions, the refractive index of the atmosphere decreases with height so that the radio waves travel more slowly near the sea surface than at higher altitudes. This variation in velocity with height results in the bending of the radio rays.* The decrease in the refractive index with height may be so great that the ray is bent down with a radius equal to that of the earth so that the ocean surface may then be considered to be flat. A further increase in the refractive-index gradient results in the radio ray being bent down sufficiently to be reflected from the surface and appearing to be "trapped," as in a duct between the reflecting layers. Under these circumstances, the ray can be considered to be traveling in a manner analogous to microwaves in a waveguide extending over the sea surface between transmitter and receiver antenna elements.

Therefore, when bending conditions are particularly favorable, a surface duct may be formed that can propagate radio waves over remarkable distances with very little attenuation. The height of the duct

*One can use the analogy of rays in optics when looking at radio wave propagation paths.

over the water's surface may be only 20 to 50 feet, or it may be 1,000 feet or more depending upon the local atmospheric conditions. Ducts exhibit a low-frequency cutoff characteristic similar to that encountered in a waveguide, which is determined by the strength of the discontinuity in refractive index at the upper surface of the duct.

These aspects tend to confirm the existence of worldwide, strong surface ducts, though with some degree of variability and subject to varying influences.

Maxiran Specifications

Operating in the UHF band, this equipment is designed as a medium-range, portable survey aid. In standard form, each system comprises:

2 Identical sets of shore-based transmitting/receiving stations called beacons

1 Mobile transmitting/receiving station called an interrogator

1 Mobile display monitor.

In practice, for dynamic survey operations, four sets of shore-based beacon stations are used in order to maintain constant contact with the mobile system.

Positional data in the form of ranges between the mobile unit and each fixed shore station are displayed continuously on the front panel of the mobile monitor.

Data-recording facilities are provided in the form of a line printer that is included in the system. An HP 9825 desk-top calculator and an X-Y plotter have been interfaced to the monitor. The range data are converted to WGS-72 coordinates in near real time and recorded on cassette tape using a Texas Instruments Silent 733 ASR (TI-733) data terminal.

Each shore-based station consists of:

Beacon Transmitter/Receiver Model P6033

Log Periodic Antenna, Dual 10 Element

12-volt power source

Beacon control box

Thermoelectric generator (and fuel)

Spares

Manuals

Miscellaneous paraphernalia (guy rope, tower base, anchors, hose clamps, etc).

The mobile station consists of:

Interrogator Transmitter/Receiver Model P6002

Log Periodic Antenna, Dual 10 Element (2 each)

Antenna rotor and control box (2 each)

Monitor Receiver, Model P6001

Texas Instruments (TI) Silent 733 ASR data terminal

TI Printer Model 743 KSR complete with (c/w) power cable and data I/P cable and short cable

HP Calculator Model 9825A, Opt. 002, A02972 c/w AC power cable

HP 98210 Adv. Program ROM No. M915

HP 98216 Gen. I/O Ext. I/O Plotter ROM No. M920

HP 9872A I/O Expander c/w AC power cord

HP 98036A RS232C I/O Opt. 001 No. M903

HP 98035A Opt. 001 Real Time Clock No. M918

HP 98036A RS232C I/O USIR No. 46097

Spares

Manuals

Miscellaneous paraphernalia (TI data cable, extension cable, paper, tool kit).

Principles of Operation

The monitor, which is normally installed on the survey vessel, generates a two-pulse code that is fed to the cylindrical interrogator located on the antenna mast. The time interval between each of the pulses in the two-pulse group determines which of the three possible beacons will be interrogated. Intervals are selectable between 26 and 60 usec.

At the interrogator, the pulse group is converted to a pair of 25-usec UHF pulses, transmitted at 441 MHz via a 4-pole filter incorporated in the transmitter output circuit to a vertically polarized high-gain antenna. Each pulse represents a burst of CW* that carries a 127-bit code to serve as an identifying signal, recognizable by the receiver in any of the beacons. The modulation takes the form of a phase reversal of the RF carrier such that logic 1 is represented by a phase reversal condition and the logical 0 by an in-phase condition. The clock rate for the code is 5.76 mHz. A sample of the transmitted waveform is shown in Figure 1.

Pulse groups are transmitted at the rate of 150 per second, the complete pulse train being time-shared between selected beacon codes.

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*Continuous Wave.

If all three shore-based units, for example, Beacons A, B, and C, are selected at the monitor, then each beacon will be interrogated 50 times per second in the sequence ABCABCA, . . . etc. If only Beacons B and C are selected, then each remote unit will be interrogated 75 times per second in the sequence BCBCBC, . . . etc. Similarly, selection of only one remote will result in 150 interrogations of that unit per second.

At the shore-based beacon, the pulse train is received via its common transmit-receive antenna and 4-pole filter, amplified and mixed with a 321-MHz local oscillator to produce an IF of 120 MHz. After further amplification and filtering, the signal is routed through a surface-acoustic-wave (SAW) delay line in which the pulse components undergo a correlation and code recognition process. Signal enhancement in the SAW device amounts to an improvement in signal-to-noise ratio of 21 dB and a width compression of the pulse from 25 μsec to 100 nsec.

The signal then passes through further acceptance tests wherein pulses below a predetermined signal strength are rejected. Finally, the signal reaches the beacon decoder section where the interval between the pair of pulses forming each group is measured. If the time interval matches the beacon code, which has been manually set on the thumbwheel code switch, a trigger pulse is sent to a transmitter section that in turn generates a responding pulse of 25 μsec duration at the beacon transmitting frequency of 420 MHz. This pulse receives a modulation characteristic identical to that generated by the interrogator and it is subjected to an identification and signal enhancement process in the interrogator similar to that of the mobile transmission on its arrival at the beacon.

The time of arrival of the return pulse at the monitor is stored in a counter, using a clock of 150 MHz for measuring the interval between transmission and reception. This becomes a measure of the distance between the two locations. The contents of the clock counter are scaled in meters and fed to the data output circuits for parallel and serial formatting. The built-in, real-time clock and event counter provide reference information that may be included in the output data string if desired.

Range measurements for all three beacons may be displayed simultaneously on the digital display of the monitor. Also displayed is Julian date, time, survey line number, and shot point (event) number.

In the event that two or more mobile units are operating simultaneously, sharing the same set of remote beacons, the incidence of mutual interference between the mobiles may be greatly reduced by adjustment of the SCRAMBLE control on the monitor front panel. This permits the interrogation interval to be varied by a small amount either side of 1/150 second in discrete steps of 13.3 μsec.

Equipment Calibration

System calibration is performed to remove all the unwanted delays from the electronic circuitry and cabling so that the equipment will read true distance as accurately as possible. We will discuss the initial calibration when the system was first installed as well as the subsequent continuous calibration checks that were done from site to site.

INITIAL CALIBRATION. The initial Maxiran system calibration consists of one major and two minor adjustments. The major adjustment accounts for the overall error from the monitor to the interrogator to the base beacon and back, and this value is dialed in on the back of the Maxiran monitor. The two minor adjustments are in the interrogators and in the beacons to permit their interchangeability, that is, one beacon with another and one interrogator with another. The minor adjustments cannot be greater than about ±25 meters.

Having performed the initial calibration, a unique net should exist in which all the base station beacons are interchangeable and all the interrogators are interchangeable. Any addition to the net, for example, a new spare beacon, usually, will have to be checked and possibly adjusted to be compatible with the rest of the net.

METHOD. The mobile monitor, interrogator interface, and interrogators are set up at one end of an accurately surveyed line (usually a baseline) and the base station beacons are set up at the other end. The calibration distance should be approximately the same as the distance from the base stations to the interrogators, if possible, to allow for curvature of the ray path over the surface of the earth. The monitor and interrogators are then powered on and allowed to warm up and settle out. The monitor is then checked to ensure that the autotrack zero is zero and that there is zero delay dialed in on the thumbwheel switches on the rear of the unit. After recording several range measurements for each beacon and interrogator, a table of uncorrected range readings can then be set up. From the table of range readings, one can determine (1) if any of the beacons need adjusting, (2) if any of the interrogators need adjusting, and (3) the overall correction constant to be dialed in on the rear of the monitor unit.

A PRACTICAL EXAMPLE. A system was calibrated over a baseline distance of 124,330 meters. Since both survey points were of equal elevation (and close to sea level), no elevation correction was necessary. The true value of the baseline distance was obtained from prior surveys. Autotrack zero was checked to be zero and zero delay was entered on the rear of the monitor unit. The following table was then obtained.

It can be seen that (1) Interrogator #043 was reading 10 meters longer than Interrogator #042, and (2) Beacon #115 was reading 10 meters longer than Beacons #111, #116, and #114. Interrogator #043 was adjusted to read the same as interrogator #042; Beacon #115 was adjusted to read the same as Beacons #111, #116, and #114. The uncorrected range measured between any interrogator and any beacon then reduced to 129066, 129067, and 129067. Knowing that the true range should have been 124330, the difference between observed range and true range were the correction factors required to be dialed in on the rear of the monitor unit; that is, 129066 - 124330 = 4746 meters, 129067 - 124330 = 4747 meters, and 129067 - 124330 = 4747 meters.

Beacon #	Interrogator #042	Interrogator #043
111	129066	129076
	129067	129077
	129067	129077
116	129066	129076
	129067	129077
	129067	129077
115	129074	129083
	129075	129084
	129075	129084
114	129066	129075
	129067	129076
	129067	129076

INTERROGATOR AND BEACON ADJUSTMENT. The adjustment to these two units is quite straightforward and easy. However, it does mean that the canisters have to be opened to access the trimpot on the inside. Again, the monitor and interrogators must be set up at one end of a line and the beacons at the other end. The distance is not critical as long as it does not change; that is, there is no reason why the mobile to the nearest convenient base station cannot be used as long as the mobile is stationary.

To make the adjustments to the interrogator, one interrogator is selected as the "reference" canister:

1. Let the system warm up and settle out before taking note of the "reference range" (the distance between the two reference canisters)
2. Take out the interrogator and make note of the range reading
3. Turn the system off, open up the interrogator canister to make a small adjustment to the trimpot, close the canister, and remount it
4. Turn the power back on and note the new range.

To perform the autotrack zero check, turn the monitor on and allow it to warm up and settle out. When it is warmed up, go to the test mode (if you have been using the monitor and it is already warmed up, go straight into the test mode). The test pulses are automatically injected into the input of the monitor so they will be found at zero range. Manually dial in a range of about 350 meters, that is, 000350 on each channel, and switch each channel into autotrack. The autotrack circuitry* will take over the position the marker pulse over the test pulse.

* In the test mode, the autotrack circuitry can only count down. The test pulse cannot be determined if the range is less than 1000000.

All three channels should be within 1 meter of each other and within 1 meter of zero range. Repeat this test two or three times. If large differences exist, adjust the monitor at the first opportunity. Note in the daily log what the range readings are (for example, ±2 meters long).

GUIDE TO THE GULF COAST AND EASTERN SEABOARD LORAN-C CALIBRATION DATA

A diagram of the Gulf Coast and the Eastern Seaboard is presented in Figure 2. This figure shows the Maxiran radio beacon sites located along the shore. The calibration experiments were started just south of Tampa, FL, with a beacon (Site 1) located on Passage Key. These data were collected onboard the U.S. Coast Guard vessel *Ingham* between 5 and 27 January 1981 from transmissions received from radio beacons located at different sites along the Gulf Coast and Eastern Seaboard of the United States. The calibration data were collected from Sites 1 through 27 and the *Ingham* sailed a southerly course, rounding the Florida Keys and proceeding north to Norfolk, VA. As the calibration experiment progressed, the Maxiran radio beacons were sequentially moved from site to site in increasing numerical order.

In the data presented, and in the Operations' Log Books, reference is made to the word "baseline." As an example, Figure 2 shows a straight line connecting radio beacon Site 4 to Site 5B. The *Ingham* position could be either west or east of that line, depending on whether the *Ingham* sailed in the Gulf of Mexico or the Atlantic Ocean, with a heading toward, away from, or parallel to that baseline while collecting beacon transmission signals from Sites n and n+1 simultaneously (see Figure 3). The rate of data acquisition was very close to one range/range datum point every 3 minutes, sequentially numbered as events.

In the data, the term "baseline crossing" is used to indicate that as the *Ingham* approached and crossed the baseline it continued to acquire range/range data up to a short distance on either site of the baseline.* However, these "baseline crossing" data were useless in computing the latitude and longitude positions of the vessel at succeeding range/range points because the angles ϕ and θ (Figure 3) approached zero. Below a certain threshold value of ϕ and θ the computer software used in the computations was unable to obtain a closed solution to the equations of position and simply displayed the message "no range closure." Consequently, the data points near the baseline as the vessel crossed it are of no value. The data given in Tables 5 and 6 usually include one datum point on either side of the baseline, or in some of the vessel course plots the trace connecting events is simply interrupted.

Table 2 lists the Maxiran site locations along the Gulf Coast and

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*Baseline crossing occurred only twice, as one of the authors recalls (R. Miller). Baseline crossings can be kept to a minimum based on good calibration planning.

the Eastern Seaboard. Each site position is defined by eastern and northern coordinate points, X(E) and Y(N) respectively, in meters; the radio beacon antenna height is also given; and the computed latitude and longitude angles are shown. Also indicated is the center meridian used in the range/range to latitude/longitude conversion computations. The radio beacon positions were determined with the use of the Transit satellite system through a Magnavox 1502 Geoceiver Satellite Surveyor used in the point positioning mode. This system, with the number of satellite passes used in these position measurements, resulted in a maximum deviation from true position of ±20 meters in latitude, longitude, and altitude (see Table 1). For the most part the standard deviation was less than that value but greater than ±5 meters.

Table 3 shows the relationship among the time sequences of acquired calibration range/range data, the radio beacon sites, and the data tapes upon which the range/range values and latitude/longitude conversion results may be found. As indicated in Table 3, the time is given as the start and end time. For example, for Sites 2 and 3 on data tape #1, the time is indicated as five sets of numbers separated by colons. Their meaning is shown below, reading from right to left:

01 : 11 : 17 : 42 : 03

seconds
minutes
hour of the day (GMT*)
day of the month
month

For various reasons, such as minor system malfunctions of the equipment onboard the vessel or due to the need for changing chart paper (however, even with these minor interruptions only a 2-percent data loss occurred during the operation) on the course plotter during the tests, not all range/range calibration data were recorded on the magnetic tapes (cassettes). Consequently, much of these range data were later keypunched by hand into the computer (HP 9825S), converted to WGS-72 latitude/longitude values, printed on a TI-733 terminal, and loaded on data tapes. The Texas Instruments' (TI) Silent 733 ASR data terminal and interface malfunctioned only twice. A temperature problem occurred and was corrected with a fan. It was replaced with a spare unit the second time.

Table 4 shows the TI-733 printout made onboard the <u>Ingham</u> during the entire calibration experiment. For convenience, this continuous printout was cut up and pasted on successively numbered sheets of paper

*GMT is also referred to as Zulu (Z) in the Operation Log Books.

(Sheets 1 through 86 that appear in the project final report). The first column is the month and day of the month.* The next column is the time of day in hours, minutes, and seconds. The third column has no significance. The fourth column is the event number, which can be matched to the event numbers on each chart showing the course of the vessel. The next two columns, labeled Ranges A and B, represent the distance in meters to the site locations. The numbers in the columns are the ranges to the sites. For example, on Sheet 1 for Event 6 (fourth column shown as 0006), 035855 is the range in meters from the vessel to the radio beacon at Site 1, and 085657 is the range from the vessel to the radio beacon at Site 2. The last column has no particular significance.

After the calibration was completed post-processing was conducted to place the data in a special format.

PRESENT SURVEY TECHNIQUE FOR THE CCZ

There has been much said about different Loran-C surveying techniques. The data collected in the Gulf Coast and Eastern Seaboard resulted in only a 2-percent data loss. The total measurement error is only about 12 to 15 meters. Kaman Tempo used a similar technique to survey San Francisco Harbor as part of an experiment to prove the validity of measuring Loran-C Time Difference data and data from a position reference system (where the position reference system has known accuracy based on equipment calibration before, during, and after the survey). Proper calibration of the position reference system, and establishing geodetic control on shore (to position the reference system transponders or beacons) is a requirement for successful Loran-C surveys. The shore sites must be marked professionally. Proper instructions must be prepared to relocate shore sites (discrete location or marker). This required meticulous documentation. The Loran-C survey in San Francisco Harbor provided an accuracy of ±3 meters.

As stated earlier the measurement error for the calibration described herein (CCZ) is about 12 to 15 meters. The ability to conduct these surveys and process data is now completely automated. Finally, these surveys only provide the data to compensate for spatial error that is a one-time fix to the Loran-C grid (warped). To compensate for temporal fluctiations requires the use of Differential Loran-C.

ACKNOWLEDGMENTS

The authors want to gratefully acknowledge the excellent suggestions provided by Mr. Warren Chan (Assistant General Manager, Kaman Tempo) during the conduct of this effort.

*The first digit should be unity for "January."

Table 1. Coordinates of Gulf Coast and Eastern Seaboard sites.

Site No.	Latitude	Longitude	Height (meters)
1	27°31'31.640"	82°44'14.846"	9.694
2	27°4'39.849"	82°27'8.448"	4.166
3	26°29'14.173"	82°11'6.925"	13.586
4	25°54'29.833"	81°43'43.261"	12.030
5A	24°43'50.978"	81°03'27.697"	2.544
5B	24°45'58.159"	80°54'44.583"	10.076
6	24°33'1.967"	81°48'3.680"	24.38
7	24°37'41.224"	82°52'20.630"	1.9
8	25°4'33.257"	80°26'36.094"	3.549
9	26°2'56.427"	80°6'45.890"	8.901
10	26°35'21.954"	80°2'15.571"	21.001
11	27°14'39.030"	80°11'26.536"	14.940
12	28°1'15.476"	80°32'5.739"	9.957
13	29°5'4.431"	80°55'31.604"	11.382
14	29°59'28.002"	81°18'54.338"	15.175
15	31°2'35.745"	81°24'42.605"	10.407
16	31°59'16.384"	80°51'0.187"	11.294
17	32°30'9.970"	80°17'47.157"	5.776
18	32°47'49.684"	79°45'28.894"	-2.357
19	33°32'23.839"	79°1'26.572"	5.186
20	33°52'46.946"	78°27'47.285"	8.411
21	34°0'36.557"	77°54'5.471"	7.965
22	34°27'43.220"	77°28'56.554"	11.235
23	34°37'21.521"	76°31'25.856"	Sea Level
24	35°06'32.033"	75°59'10.344"	24.38
25	35°50'1.959"	75°33'28.850"	5.986
26	36°10'55.280"	75°45'4.779"	18.498
27	36°37'50.709"	75°53'30.699"	2.970

Table 2. Maxiran sites around the Southeastern Seaboard (see Figure 2).

Site Number	Coordinates: Eastern X(E) (meters)	Coordinates: Northern Y(N) (meters)	Antenna Height[a] (meters)	Latitude, α (degrees)	Longitude, λ (degrees)	Center Meridian (degrees)
1	328,411.19	3,045,838.24	15.694	27°31'31.640"	82°44'14.846"	-81
2	355,995.32	2,995,875.30	10.166	27°04'39.849"	82°27'08.448"	-81
3	381,995.81	2,930,191.99	19.586	26°29'14.173"	82°11'06.925"	-81
4	427,017.31	2,865,729.29	18.03	25°54'29.833"	81°43'43.261"	-81
5A	494,165.54	2,735,143.68	8.5	24°43'50.978"	81°03'27.697"	-81
5B	508,857.95	2,739,056.98	16.1	24°45'58.159"	80°54'44.583"	-81
6	418,875.80	2,715,416.80	30.4	24°33'01.967"	81°48'03.680"	-81
7	310,470.10	2,725,060.93	7.9	24°37'41.224"	82°52'20.630"	-81
8	556,136.43	2,773.467.46	9.5	25°04'33.257"	80°26'36.094"	-81
9	588,759.48	2,881,412.18	14.9	26°02'56.427"	80°06'45.890"	-81
10	595,825.87	2,941,321.79	27.0	26°35'21.954"	80°02'15.571"	-81
11	580,121.79	3,013,738.60	60.94	27°14'39.030"	80°11'26.536"	-81
12	545,718.52	3,099,611.19	15.96	28°01'15.476"	80°32'05.739"	-81
13	507,255.68	3,217,356.11	17.38	29°05'04.431"	80°55'31.604"	-81
14	469,607.15	3,317,841.35	21.175	29°59'28.002"	81°18'54.338"	-81

Note:

[a]Coast Guard vessel antenna height was 21.3 meters above mean sea level.

(continued)

Table 2. (continued)

Site Number	Coordinates Eastern X(E) (meters)	Northern Y(N) (meters)	Antenna Height[a] (meters)	Latitude, α (degrees)	Longitude, λ (degrees)	Center Meridian (degrees)
15	460,607.14	3,434,468.45	16.41	31°02'35.745"	81°24'42.605"	-81
16	514,165.26	3,539,101.66	17.294	31°59'16.384"	80°51'00.187"	-81
17	566,091.21	3,596,383.21	11.776	32°30'09.970"	80°17'47.157"	-81
18	616,288.56	3,629,479.89	6.0	32°47'49.684"	79°45'28.894"	-81
19	683,466.92	3,712,896.42	11.186	33°32'23.839"	79°01'26.572"	-81
20	734,632.90	3,751,714.03	14.411	33°52'46.946"	78°27'47.285"	-81
20	179,662.632	3,754,217.97	14.411	33°52'46.946"	78°27'47.285"	-75
21	786,156.40	3,767,611.32	13.965	34°00'36.557"	77°54'05.471"	-81
21	232,039.72	3,767,077.92	13.965	34°00'36.557"	77°54'05.471"	-75
22	823,149.18	3,819,000.53	17.236	34°27'43.220"	77°28'56.554"	-81
22	271,980.69	3,816,179.28	17.236	34°27'43.220"	77°28'56.554"	-75
23	360,305.08	3,832,251.70	6.0	34°37'21.521"	76°31'25.856"	-75
24	410,124.91	3,885,563.40	30.38	35°06'32.033"	75°59'10.344"	-75
25	449,602.03	3,965,665.91	11.968	35°50'01.959"	75°33'28.850"	-75
26	432,440.02	4,004,398.13	24.498	36°10'55.280"	75°45'04.779"	-75
27	420,262.75	4,054,281.03	8.970	36°37'50.709"	75°53'30.699"	-75

Note:
[a]The Coast Guard vessel antenna height was 21.3 meters above mean sea level.

Table 3. Maxiran sites around the Southeastern Seaboard (see Figure 2) -- data tape index.

Start Time[a]	End Time[a]	Event Number	Range A[b]	Range B[b]	Data Tape Number
01:11:17:42:03	01:12:01:30:04	6 - 153	Site 1	Site 2	1
01:12:01:33:26	01:12:09:24:02	154 - 308	Site 2	Site 3	1
01:12:09:27:03	01:12:15:38:02	309 - 443	Site 3	Site 4	1
01:13:07:54:02	01:13:18:24:01	582 - 743	Site 5A	Site 4	1
01:14:12:24:01	01:14:13:54:04	745 - 774	Site 5A	Site 6	2
01:14:15:42:03	01:14:16:51:02	781 - 804	Site 5A	Site 6	2
01:14:16:54:02	01:14:17:27:02	805 - 816	Site 6	Site 7	2
01:14:18:18:05	01:14:20:06:01	833 - 869	Site 6	Site 7	2
01:14:20:40:04	01:15:06:12:02	881 - 1074	Site 6	Site 7	2
01:15:07:24:00	01:15:09:03:02	1095 - 1122	Site 6	Site 5B	2
01:16:22:51:06	01:17:03:51:02	1141 - 1241	Site 5B	Site 6	2
01:17:03:54:03	01:17:16:03:02	1242 - 1385	Site 5B	Site 8	2
01:17:17:36:02	01:17:23:48:04	1413 - 1536	Site 9	Site 8	2
01:17:23:51:15	01:18:00:15:06	1537 - 1545	Site 9	Site 10	2
01:19:12:27:01	01:19:13:30:03	1547 - 1568	Site 9	Site 10	3
01:19:13:33:04	01:19:19:12:00	1569 - 1680	Site 9	Site 10	3
01:19:19:18:00	01:20:01:09:00	1681 - 1792	Site 11	Site 10	3
01:20:01:11:59	01:20:17:18:02	1793 - 1962	Site 11	Site 12	3
01:20:20:27:07	01:20:23:30:03	2027 - 2088	Site 12	Site 13	3
01:20:23:39:00	01:21:02:30:03	2090 - 2148	Site 13	Site 12	3
01:21:11:53:29	01:21:14:14:59	2149 - 2198	Site 13	Site 12	3
01:21:15:06:03	01:22:02:50:59	2200 - 2409	Site 13	Site 14	3
01:22:12:06:02	01:22:14:42:03	2419 - 2471[c]	Site 14	Site 15	3
01:22:16:48:00	01:22:18:12:02	2472[d]- 2770	Site 15	Site 14	3
01:22:18:38:59	01:23:02:15:01	2771 - 2923	Site 15	Site 16	3
01:23:02:21:03	01:23:06:30:00	2924 - 3007	Site 16	Site 15	3

(continued)

Table 3 (continued)

Start Time[a]	End Time[a]	Event Number	Range A[b]	Range B[b]	Data Tape Number
01:23:14:27:01	01:23:14:45:01	3009 - 3015	Site 16	Site 15	4
01:23:15:04:02	01:23:22:48:03	3017 - 3171	Site 17	Site 16	4
01:23:22:54:00	01:24:17:36:03	3172 - 3344	Site 17	Site 18	4
01:24:17:45:01	01:24:21:24:00	3346 - 3419	Site 18	Site 19	4
01:24:21:42:02	01:25:02:42:02	3423 - 3521	Site 20	Site 19	4
01:25:11:27:02[e]	01:25:13:23:59	3530 - 3568	Site 19	Site 20	4
01:25:13:32:59	01:25:16:54:23	3569 - 3631	Site 21	Site 20	4
01:25:17:00:34	01:25:19:47:59	3632 - 3688	Site 21	Site 22	4
01:26:13:57:01	01:26:15:39:00	3689 - 3723	Site 21	Site 22	4
01:26:15:44:58	01:26:16:23:59	3724 - 3737	Site 23	Site 22	4
01:26:17:20:59	01:26:21:26:58	3756 - 3838	Site 23	Site 22	5
01:26:21:32:59	01:27:06:39:00	3839 - 4021	Site 23	Site 24	5
01:26:06:45:00	01:27:07:45:01	4022 - 4042	Site 24	Site 23	5
01:27:12:29:59	01:27:18:03:01	4044 - 4155	Site 25	Site 24	5
01:27:18:15:02	01:27:23:09:01	4158 - 4256	Site 25	Site 26	5
01:27:23:15:00	01:28:00:24:01	4257 - 4280	Site 26	Site 25	5
01:28:00:30:11	01:28:02:06:01	4281 - 4313	Site 26	Site 27	5

Notes:

[a]See text for explanation of these numbers.

[b]For details of measured range values and computed latitude and longitude values corresponding to these range values, see Table 6.

[c]Ten data points shown on Tape 3 (Table 6) but not in Table 5.

[d]Unexplained jump in event count -- see Table 5.

[e]Discrepancies between times shown here and times shown in Table 5. This discrepancy is for Events 3523 through 3543. Table 5 shows notation that Maxiran clock did not function correctly.

Table 4. Maxiran sites around the Southeastern Seaboard (see Figure 2) -- data computed by hand not appearing on Tapes 1 through 5 and on Table 3. Data on Tape 6 and Table 7.

Start Time[a]	End Time[a]	Event Number	Range A[b]	Range B[b]
01:12:22:51:03	01:13:00:00:02	448 - 471	Site 3	Site 4
01:13:00:03:07	01:13:04:30:00	472 - 549	Site 3	Site 4
01:13:04:07:00	01:13:06:45:00	541 - 581	Site 3	Site 4
01:13:15:50:25	01:13:15:57:00	692 - 695	Site 5	Site 4
01:14:17:30:05	01:14:18:15:05	817 - 832	Site 6	Site 7
01:14:20:09:00	01:14:20:39:00	870 - 881	Site 6	Site 7
01:14:23:21:00	01:15:00:45:02	935 - 965	Site 6	Site 7
01:15:06:18:00	01:15:07:21:00	1077 - 1094	Site 6	Site 5B
01:16:21:51:01	01:16:22:48:04	1124 - 1140	Site 5B	Site 6
01:17:16:12:00	01:17:17:33:00	1386 - 1412	Site 9	Site 8
01:20:17:21:00	01:20:18:36:00	1963 - 1989	Site 11	Site 12
01:20:18:39:00	01:20:20:09:00	1990 - 2021	Site 13	Site 12
01:20:20:12:00	01:20:20:15:05	2022 - 2023	Site 12	Site 13
01:26:16:30:01	01:26:17:18:04	3739 - 3755	Site 23	Site 22

Notes:

[a]See test for explanation of the meaning of these numbers.

[b]For details of measured range values and computed latitude and longitude values corresponding to these range values, see Table 6.

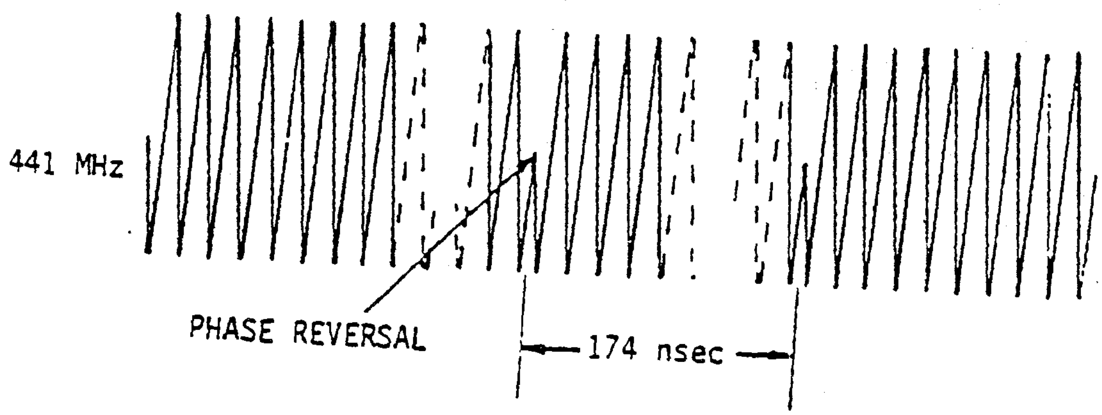

Figure 1. Transmitted waveform from interrogator.

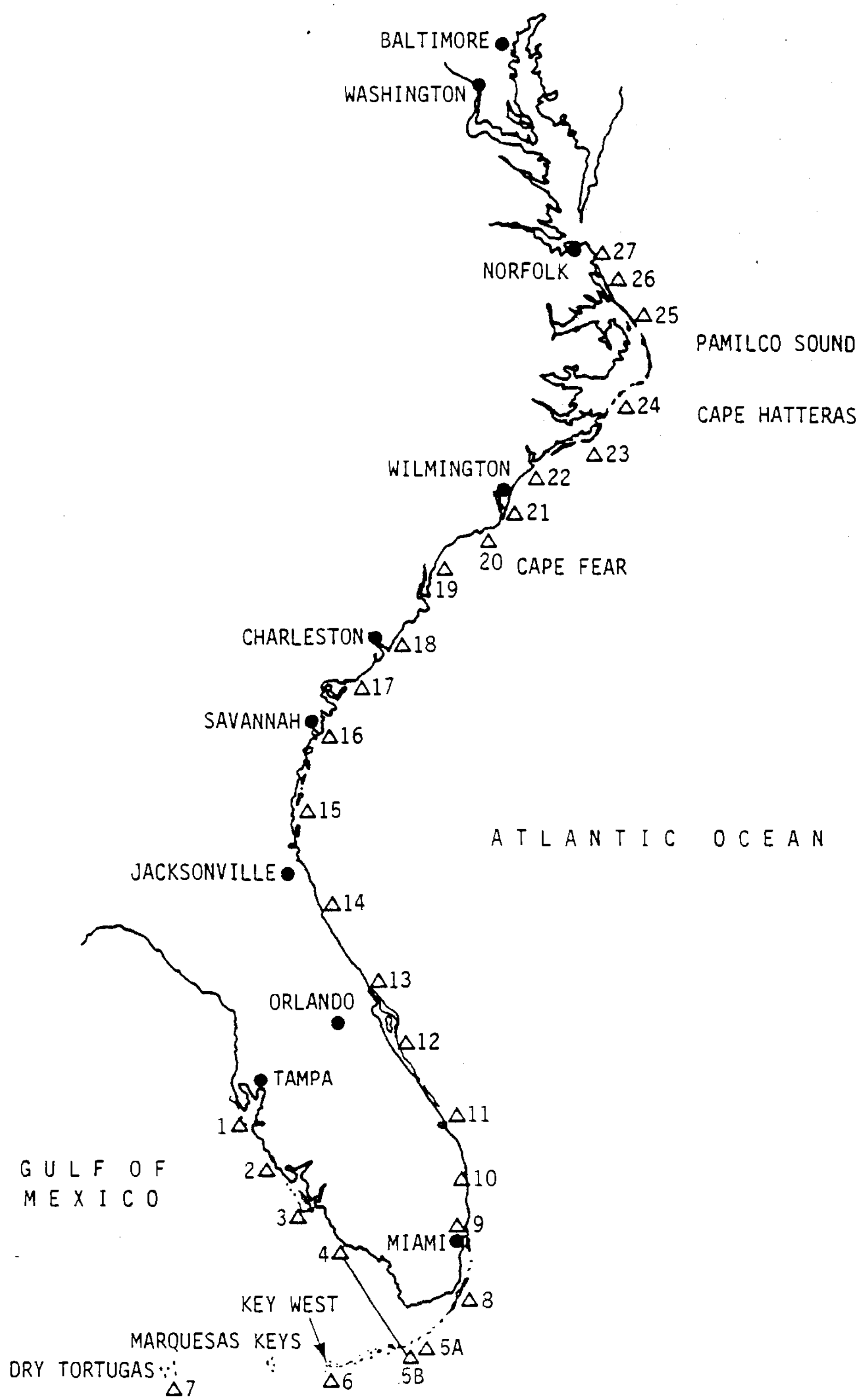

Figure 2. Maxiran sites along the Gulf Coast and Eastern Seaboard. (Site coordinates are given in Table 2.)

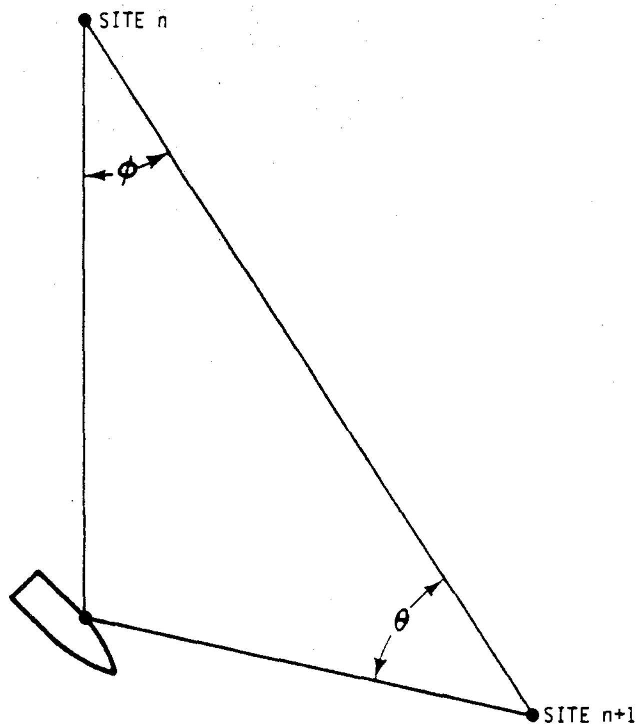

Figure 3. Coast Guard vessel course relative to the baseline.

ON THE CIRCLE OF UNCERTAINTY

W. E. Hoover
United States Department of the Interior
Geological Survey
Office of Marine Geology
Woods Hole, MA 02543

ABSTRACT

LORAN-C is a position location system in which the coordinates of an arbitrary point are determined with respect to known reference points. The observed position is defined as the intersection of two lines of position, each of which may be in error. This paper considers the estimation of the probability that the true position lies within a circle of specified radius centered at the observed position.

BIOGRAPHICAL SKETCH

Wayne E. Hoover is a Mathematician with the U.S. Geological Survey, Office of Marine Geology, Atlantic-Gulf of Mexico Branch, Woods Hole, MA. In 1977 he received his Ph.D. in numerical analysis from Michigan State University. Prior to joining the U.S. Geological Survey, Dr. Hoover was system administrator of the toxics computer system located at the National Computer Center, U.S. Environmental Protection Agency (EPA), Research Triangle Park, North Carolina.

Wayne Hoover

SESSION 2

TECHNOLOGY

Session Chairman: Capt. J. Culbertson, 11th Coast Guard District

THE ORIGIN AND EVOLUTION OF LORAN PHASE CODING

R.L. Frank, PE
Electronic Systems Consultant
30795 River Crossing
Birmingham, MI 48010

ABSTRACT

The history and theory of Loran phase coding is traced from the original Cyclan and Cytac polyphase coding to the present Loran-C and Loran-D bi-phase coding, with hindsight applied to what might have been. As an interesting example of the evolution of an idea, critical decisions, incidental offshoots, and independent parallel developments are described, including "complementary coding," radar pulse compression, and Hadamard matrices.

The structure behind Loran phase codes is explained, and properties such as skywave, CW interference, and cross-rate interference rejection are considered. The complexities of "code balance" are reviewed and effects of linear and hard-limiting signal processing are reviewed. Finally, some old but unexploited ideas for interference rejection are mentioned and low probability problems of phase coding use are considered. Extensive references are given.

R. Frank

BIOGRAPHICAL SKETCH

Mr. Frank received his BSEE from the University of Michigan in 1938 and MSEE from Massachusetts Institute of Technology in 1939. He attended Navy Radar School at Harvard and MIT and the first Loran school at MIT Radiation Laboratory in 1942 and has worked primarily in radio navigation since then, including Loran-A, -B, -C, and -D. He was Lieutenant, USNR, and project officer on Loran receivers in the Navy Bureau of Ships until 1946, then joined Sperry Gyroscope where for many years he was Senior Research Section Supervisor, Advance Radio Navigation Systems. Since 1974 he has been an independent consultant. His clients have included Sperry, Lear Siegler, GE--TEMPO, the U.S. Coast Guard, New York State Department of Motor Vehicles, and the University of Michigan Radiation Laboratory. His Loran work is described in about 30 papers and 28 patents. He has received Commendation of Navy, IEEE Fellow, IEEE AESS Pioneer Award, Wild Goose Association Medal of Merit, and Fellow of Engineering Society of Detroit awards.

THE ORIGIN AND EVOLUTION OF LORAN PHASE CODING

by

Robert L. Frank, PE
Electronic Systems Consultant
30795 River Crossing
Birmingham, Michigan 48010

ABSTRACT

The history and theory of Loran phase coding is traced from the original Cyclan and Cytac polyphase coding to the present Loran-C and Loran-D biphase coding, with hindsight applied to what might have been. As an interesting example of the evolution of an idea whose time had come critical decisions, incidental offshoots, and independent parallel developments are described, including "complementary coding," radar pulse compression, and Hadamard matrices.

The structure behind Loran phase codes is explained, and properties such as skywave, cw interference, and cross-rate interference rejection are considered. The complexities of "code balance" and effects of linear and hard-limiting signal processing are reviewed. Finally, some old but unexploited ideas for interference rejection are mentioned and low probability problems of phase coding use are considered. Extensive references are given.

INTRODUCTION

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+ + - - + - + -   +
+ - - + + + + +   -
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The Loran-C phase code: The sequence of plus and minus phases extending over two Master or two Secondary station pulse groups appears as a mysterious fact-in-being in the Loran-C Handbook and Transmitted Signal Specifications. The present paper traces the history and evolution of the phase code, its relation to other applications and theory of coding, and discusses the finer points of actual and potential uses in Loran-C.

Last year I published a paper in the IEEE Transactions on Information Theory titled "Polyphase Complementary Codes" (32) which included as a small tail on the dog the development and properties of Loran-C coding. Several friends read it, and found it "more about phase coding than you really wanted to know." Here, I have interchanged tail and dog, and emphasized the Loran aspects. But to help those who still want to pursue the more esoteric angles I have retained the nomenclature and numbering of references in the first paper in this one also. Additional references start from (32).

POLYPHASE CODING

In the development of Cyclan, the grandfather of Loran-C, we at Sperry Gyroscope about 1947 recognized that it would be desirable to apply coherent detection in lieu of diode detection to the pulse envelope but it was just too late to build it into the first field test equipment. In a little history skipped by Gifford Hefley (24), in 1950 a contract was given to Sperry to add coherent detection (33). As Hefley relates, the competitor to Cyclan was a frequency modulated (wobulated) hyperbolic navigation system acronymed WHYN being developed. Now that we had coherent detection for both cycle and envelope why not add frequency modulation? As a result of the sharp pulses being transmitted we already had basically the same spectrum as WHYN and hence same anti-jamming capability. And there was not additional spectrum width to spare or to be easily obtained with the technology. So what we did was to make more and denser side bands by adding a slow fm extending over a number of pulse repetition intervals. The fm was done by adding a motor driven capacitor to the system oscillator. Then it occurred to us that the phase shift during each pulse was negligible, that the shift was occurring when the transmitter was off, and therefore the phase could be switched abruptly between pulses, in a pattern simulating fm. This was designated "phase coding" -- to my knowledge the first use of the term anywheres.

We happened to have a drawer-full of capacitor-type phase shifters and also had a 25-position telephone-type stepping switch. So the first phase coder was a Rube Goldberg device built with these in a couple of days; it is shown in a number of patents -- but all subsequent ones we built were really entirely electronic. The phase coding did indeed provide additional interference rejection, as predicted (33).

Another idea developed during Cyclan was multiple pulsing -- sending a burst or group of pulses from each station to improve the ratio of average power to peak power. The first idea was to separate the pulses in each group enough to let all skywaves decay before the next ground wave, but by 1952 we realized (4) that phase coding provided another way to get rejection, allowing closer pulse spacing. We deliberately allowed enough spacing for the very large first few skywaves -- the coding circuitry then only had to be good enough to handle the residuals.

For Cyclan, the father of Loran-C, we proposed an 8-pulse group with 1000 microsecond spacing of pulses. (This was changed during development to 1280 microseconds = 10 microsecond carrier cycle x 2^7.) The scheme for skywave rejection was to code the N=8 pulses so that each of the pulses in the group had a different effective carrier frequency. The phases are described by a matrix as shown in Figure 1a. If the numbers represent multiples of 1/N of a cycle of phase or 45° the successive pulses then would have carrier frequencies which differ by 1/8 of the group repetition rate. Originally the GRR was proposed as 25 Hz, but changed during development to 19.8 ... Hz = 100 kHz divided by (5 x 2^{10}). Then we made the phase shifts three times as large so the effective separation was 3/8 times the GRR, as shown in Figure 1b.

If we have a matrix generator in the receiver which is synchronized with that in the transmitter, we can receive the signals just the same as if they were not coded--but any skywave which falls on any following groundwave has just the sum of phases to completely cancel over the matrix period. Also, if the receiver sampling is not aligned with the pulse group, the phases also cancel--so we have an inherent pulse group synchronizer!

GROUP NUMBER	PULSE NUMBER 1	2	3	4	5	6	7	8
1	0	0	0	0	0	0	0	0
2	0	1	2	3	4	5	6	7
3	0	2	4	6	0	2	4	6
4	0	3	6	1	4	7	2	5
5	0	4	0	4	0	4	0	4
6	0	5	2	7	4	1	6	3
7	0	6	4	2	0	6	4	2
8	0	7	6	5	4	3	2	1

NUMBERS ARE UNITS OF PHASE SHIFT, 1 = 135° (= 3 X 45°)

Figure 1a. Coding sequence (slave or secondary).

PULSE NUMBER	1	2	3	4	5	6	7	8
SLAVE FREQ.	0	3	6	1	4	7	2	5
MASTER FREQ.	4	7	2	5	0	3	6	1

THESE NUMBERS SHOW MULTIPLES OF 25/8 CYCLES, THE FREQUENCY BY WHICH THE 100-KC CARRIER IS SHIFTED.

Figure 1b. Frequency Order.

In the Cytac proposal we also recognized that we would need a way of synchronizing the receiver with the transmitters on a group-by-group basis so that when horizontal row #1 was transmitted, the receiver was set to receive that row and not another one. One day about a year later we set about to design the method, and were pleasantly surprised to find after a little analysis that when the group repetition intervals were not in step, the phase differences all summed to zero for all full and partial misalignments. In other words, both groups and pulses within the groups had to be aligned to get a response--it was inherent in the matrix structure!

When it came to distinguishing Master from Slave (Secondary) station, we merely interchanged the coding of the first four and the last four pulses in each group. We then separately integrated the first four (which we called M1) and second four (which we called M2). When the two had similar polarity response, i.e., when M1xM2 was positive, we had detected the Master signal (6).

When the group repetition intervals of station and receiver coding were not synchronized, no signal was detected, but Zadoff noted that distinctive frequencies were generated in such cases (34) and special filters provided fast detection. Nowadays, with microprocessors it would be much simpler just to provide separate detection calculations for each timing condition, rather than use the special filters.

The computer engineers at Sperry devised a quite simple way of generating the phase code matrix; see Figure 1c. A binary phase shifter was built, capable of shifting phase by combinations of 45°, 90°, and 180°, modified to 135°, 270°, and 180° by additional phase shifts. The control signals were generated by a three-stage variable-radix counter capable of counting by 1's, 2's, ... 7's; this counted the triggers for the pulses within the group. The radix was controlled by a pulse group counter.

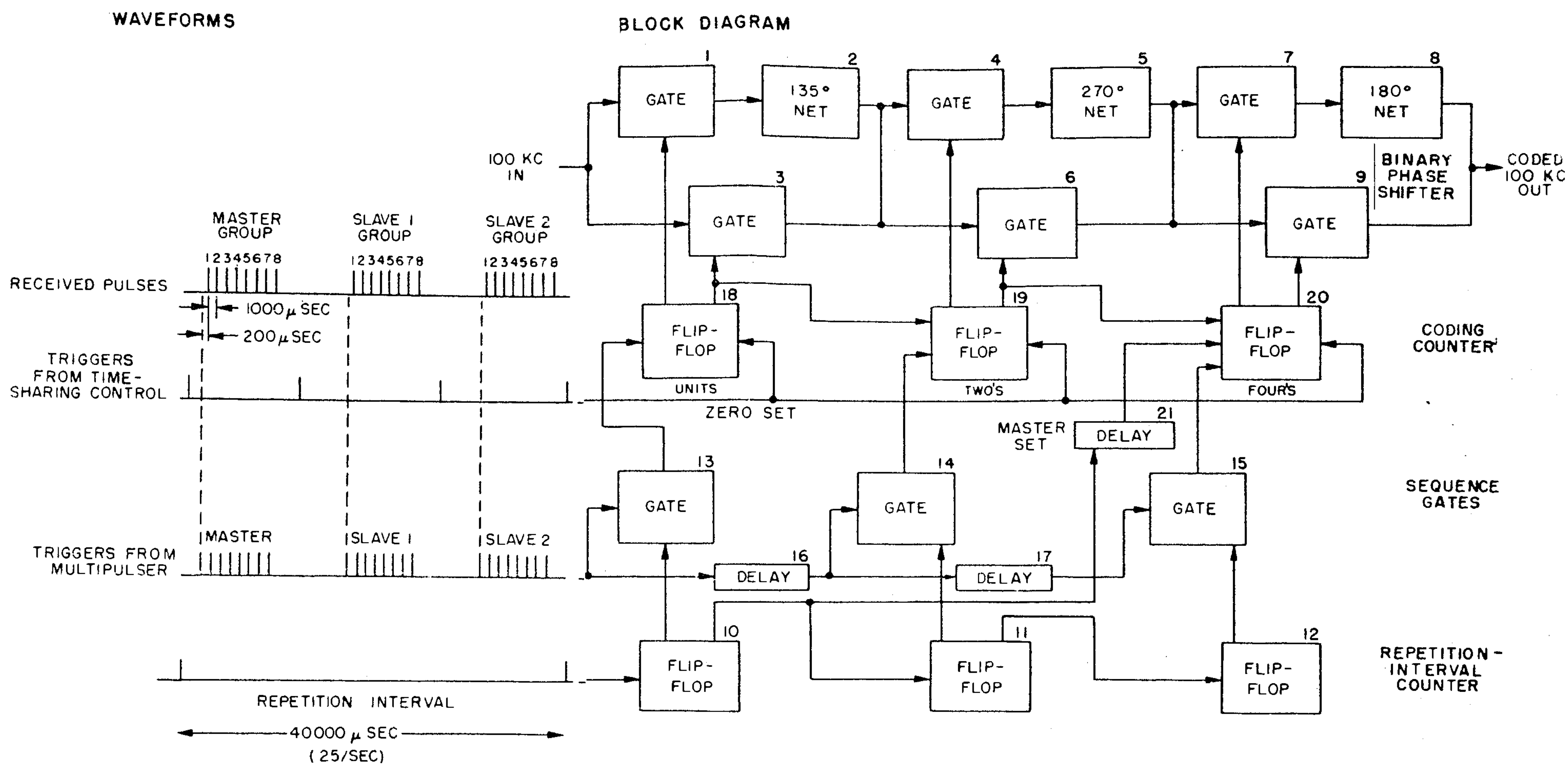

Figure 1c. Code Generation.

The phase coding also has some powerful interference rejection properties, which are considered later. The coding was considered too good a secret to use for original field testing, and the system was operated with the coding turned off. Then there was evidence of inter-pulse skywave contamination, which the coding had been designed to eliminate, so it was used on the air for a short period in 1955. The test data did show a considerable improvement (24, p.65), but the results are not as convincing as described, as propagation variations were also caused by weather conditions, which were worse when the uncoded signals were tested. Laboratory test data (56 p. 149) does however show almost 40 db improvement with the coding operating.

SIMPLIFIED CODING

In 1956 Cytac was converted to Loran-C and made a civilian system. To permit reception on Loran-A receivers with frequency converters the repetition rates were converted back to those of Loran-A, and to make it easier to build multi-pulse receivers (we thought) the pulse separation was converted back to the originally proposed 1000 microseconds. At that time we also devised a scheme to make simpler phase codes still having the skywave rejection and search and identification properties of the polyphase codes. The new codes could be made with just binary phase shifts: 0° and 180°, (25). This first publication deliberately did not explain the theory behind the generation of the code.

Here is the theory: The simplest form of Cytac-like phase coding would be that for a two-pulse-per-group system. Depending upon which row we wrote first, the 2 x 2 matrix takes two forms, as shown in Figure 2, labeled "i" and "j". As true in the polyphase form also, not only are the first and second columns orthogonal, but the complete matrices are orthogonal: if we detect the coded pulses in a phase-sensitive receiver system, the phases sum to zero in all cases except when signal i is completely aligned with receiver i, or j is aligned with j.

$$\begin{matrix}0&0\\0&1\end{matrix}\ \text{or}\ \begin{matrix}+&+\\+&-\end{matrix} = i \qquad \begin{matrix}0&1\\0&0\end{matrix}\ \text{or}\ \begin{matrix}+&-\\+&+\end{matrix} = j$$

Figure 2. Binary Code Matrices.

$$\begin{array}{cccccccc}\multicolumn{8}{c}{M}\\ +&+&-&-&+&-&+&-\\ +&-&-&+&+&+&+&+\\ \multicolumn{2}{c}{i}&\multicolumn{2}{c}{-i}&\multicolumn{2}{c}{j}&\multicolumn{2}{c}{j}\end{array} \qquad \begin{array}{cccccccc}\multicolumn{8}{c}{S}\\ +&+&+&+&+&-&-&+\\ +&-&+&-&+&+&-&-\\ \multicolumn{2}{c}{i}&\multicolumn{2}{c}{i}&\multicolumn{2}{c}{j}&\multicolumn{2}{c}{-j}\end{array}$$

Figure 3a. Phase Code and Code Patterns.

$$\begin{array}{cccc}\multicolumn{4}{c}{\overline{M}}\\ j&-j&i&i\end{array} \qquad \begin{array}{cccc}\multicolumn{4}{c}{\overline{S}}\\ j&j&i&-i\end{array}$$

Figure 3b. Code Pattern, Receiver and Transmitter GRI out of step.

With the two orthogonal matrices, identified by symbols "i" and "j", patterns can be formed which also are orthogonal or have no net response except when perfectly aligned. Two examples are shown in Figure 3a; these just happen to be the Loran-C master and secondary phase codes (excluding the 9th master pulse).

When we start with the second rows in Figure 3a, then write the first row, the codes convert to forms shown in Figure 3b which we will designate $\overline{M}$ and $\overline{S}$ and use in later discussion.

The binary phase codes shown in Figure 3a were first used on the air in 1957 when the East Coast chain, using modified Cytac equipment went into operation (25). To aid the operator who was using a receiver with a scope for manual search and identification, we added a 9th master pulse, originally at 600 microseconds spacing from the 8th (because it was easy to do). This was subsequently changed to the present 2000 microsecond spacing when some possible errors in automatic identification were noted under certain skywave conditions.

To cover the possibility of low power Loran-C, similar to the present "minichains," a "simple" pulsing (7, 25) was devised with two master pulses coded by a 2x2 matrix and single secondary pulses. Reception of such an arrangement was specified and provided in some early receivers such as AN/SPN-28 and AN/WPN-3, but was never used in any transmitters and was soon dropped as a receiver requirement.

When Loran-D was under development in the early 1960's, we decided to double the duty cycle by changing the pulse group to 16 pulses at 500 microsecond spacing (44). Elmer Lipsey suggested a novel requirement: make the coding such that a Loran-C receiver would be responsive only to eight of the pulses at 1000 microseconds which would have standard Loran-C coding. With the theory then available (35) it was then easy to pick out such a code which not only provided compatibility with Loran-C but used the same search logic as that used with Loran-C. Such a code is shown in Figure 4. The added Loran-D odd pulses are coded for two additional symbols which are orthogonal to the original Loran-C symbols.

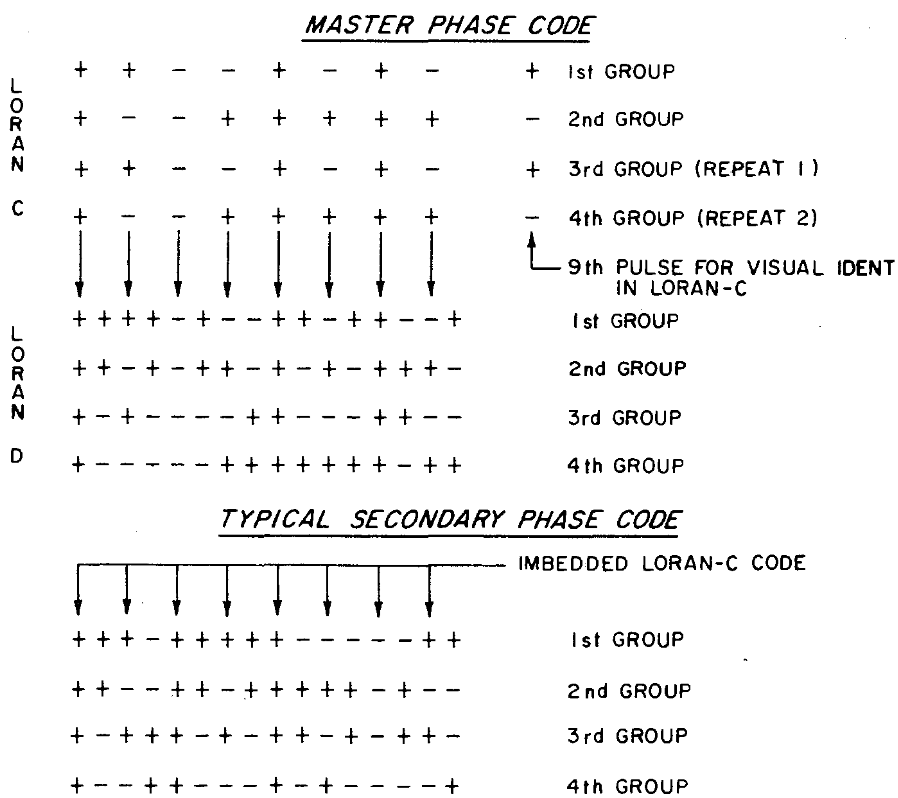

Figure 4. Loran-D Code.

AN IDEA WHOSE TIME HAS COME

Originally all the Cyclan and Cytac work was classified confidential or secret. Then in 1956 the Air Force removed all restrictions except on "antijamming techniques," the Navy awarded a receiver contract to Sperry which said the code in use was unclassified but that "sophisticated codes" were still classified. Then when patent applications were filed, the U.S. Patent Office put them under Secrecy Order prohibiting any disclosure. We were working under three different sets of rules at the same time! Our confusion and concern is reflected in the first paper on Cytac ("A precision multi-purpose navigation system") presented at the 1957 IRE National Convention which mentioned neither multiple pulsing nor phase coding. We obtained clearance to publish the first paper on these subjects (25) only by restricting discussion to the biphase code on the air and by not discussing the general methods of designing the code (35).

But the time had come for the phase coding idea and the techology was ripe--it was not to be stopped by mere secrecy orders! The same month I published in IEEE Trans. on ANE, Welti published his independently developed "quaternary coding for radar" in the IEEE Trans. on Information Theory. He devised the same patterns I had found for Loran-C master and secondary codes, but proposed upward and downward sweeping fm for the i and j symbols. Then a year later Golay (2) published his ideas on "complementary series" which were identical with the Loran-C codes! He had worked them out ten years earlier for an infrared spectrometer, where the coding made multiple light-slits look like one narrow slit, and now was suggesting there might be some electronic application for the codes. Incidentally, Golay had started his thinking with sine- and cosine-modulated slits --closely akin to polyphase coding--but practicality forced him immediately to binary coding (36). He called his coding "complementary" because his two binary sequences had autocorrelations with identical main peaks, but with opposite polarity residuals or "side lobes." Thus everything except the main peaks cancel. Golay also described sets of four sequences (1) which had cancelling sidelobes; he called these sequences "supplementary," but that term never caught on--"generalized complementary" is more often used. He also made the interesting discovery that binary complementary codes are not restricted to lengths which are a power of 2.

There have been a number of other independent rediscoveries of complementary codes. Erickson's report (23) is interesting in having a complete listing of possible binary codes of length 2^n up to n=4.

From the above discussion it will now be apparent that the Cytac polyphase code can be considered a form of complementary code. Certain of the correlation properties of polyphase codes based on the N^2 matrix were independently rediscovered by Heimiller in 1961 (10). As a consequence of all this, the secrecy restrictions on all the codes were removed by 1963. At the same time, the Sperry patent department gave up trying to patent any specific phase codes. Just after I had submitted the 1980 paper, I found the mathematical properties of the N^2 matrix with the numbers representing powers of Nth roots of unity were discussed by Sylvester in a paper published in 1867 (37). Also, the matrix has been widely considered as a representation of the Discrete Fourier Transform, widely used in digital signal processing. Sylvester went from the complex number matrix form to the binary form in what is probably the real discovery of Hadamard matrices. Those familiar with these matrices will recognize the 2 x 2 elements in the Loran-C code as Hadamard matrices also.

As a spin-off from the Cytac phase codes, it was noted that the N^2 polyphase code could be written as one N^2-long burst with correlation properties considerably better than any similar length binary codes (22). Such codes have had considerable discussion and application in connection with radar pulse compression (38) and communication synchronization systems (39). I learned in my investigations that all this coding belongs in mathematics to the branch of "combinatorics" of which "orthogonal designs" is a sub-branch. Turyn (14) has enlarged the capabilities of complementary codes far beyond the needs of existing or foreseeable systems by showing they can be derived from "delta-codes," which are a generalized form of patterns of symbols as in Figure 3 which we had used in Loran C/D, and I managed to stretch things a little further (32). Does anybody need a 6-phase code extending over three groups of 19 pulses?

But let us return to practical Loran coding matters.

INTERFERENCE REDUCTION AND REJECTION

Pulse systems basically have sideband frequencies separated from the carrier frequency by multiples of the pulse repetition rate. When the pulses are processed by sampling, any cw interference which has the same phase as the pulses whenever sampling occurs acts just like interfering pulses. Reduction of interference, as we have seen, was the initial incentive toward development of phase coding. With the 8-phase Cytac coding, each pulse of the group had effectively a different carrier frequency. Any single cw interference can be synchronous with only one pulse out of 8, therefore there is a N to one or 18 db reduction in the case of 8 pulses.

In going from the 8-phase 8-pulse 8-group cytac code to the 2-phase 8-pulse 2-group Loran-C code, the inherent cw rejection was reduced from 18 db to 12 db (4 to 1). Six of the 12 db come from the existence of two effective frequency families: one is 100 kHz ± S (GRR) where S is any integer, for pulses that have the same phase from one group to the next; the other is 100 kHz ± (T/2)(GRR) for T odd for pulses which reverse phase from one group to the next. The other 6 db comes from the phase reversal pattern within the group. The total 12 db improvement may be seen from Figure 5, where the Master code is compared with two different cw interferences--phases shown at the times of sampling. In the case of either interference, only 3/4 of the samples of the cw balance out between same and opposite phase compared to the Loran code, and the maximum unbalanced residual is 1/4 of the samples. In the sense of interference rejection, it seems that the Loran-C code is the most nearly balanced that is possible--but I have never seen this proved.

		same or opposite with respect to M	
M	+ + − − + − + −		
	+ − − + + + + +		
100kHz	+ + + + + + + +	s s o o s o s o	Net = 4 same
	+ + + + + + + +	s o o s s s s s	
100kHz + ½ GRR	+ + + + + + + +	s s o o s o s o	Net = 4 opposite
	− − − − − − − −	o s s o o o o o	

Figure 5. Interference Reduction.

Figure 5 is slightly simplified. The fact that the pulses are confined to groups rather than uniformly spaced results in fine structure in the rejection ratio, which can be found by Fourier analysis. The result is shown in Figure 6. The fine structure repeats over 500 Hz intervals, plus and minus about 100 kHz. Note that odd and even curves should not be added since a single cw affects only one or the other.

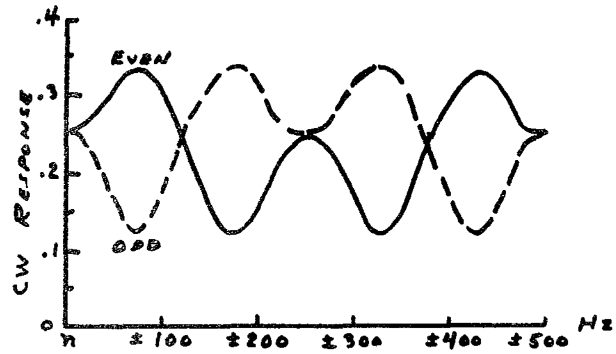

Figure 6. Interference Response Details.

Loran D coding may be shown to have three inherently separate frequencies. The interleaved pulses added to the C-code to make the D-code are all really coded with just one new pattern that repeats over four pulse groups. The two different symbols differ only in that the pattern is shifted one group for those in the second half of the Loran-D code. To produce two really distinctive additional frequencies for Loran-D, it would have been necessary (and in retrospect a good idea) to have made the Loran-D code 4-phase.

The Cytac proposal (4) made an additional suggestion rather too complex to implement in 1952. The samples for each pulse of the group could be integrated in separate integrators or filters; then the 8 data could be separately amplitude-limited and then all the data could be summed. Such a scheme is now called frequency-selective limiting; it would prevent any one cw from producing an error greater than 1/8 cycle, or 0.6 microsecond.

It became apparent at some later date that the error due to synchronous cw could be eliminated by selectively deleting samples of one or more pulses (columns) of the N^2 matrix; if the code is a pattern of similar matrices (as with the Loran-C code) then corresponding columns in all the matrices are deleted (26). Such a scheme was included in the ITT AN/FPN-43 Loran-C timer-synchronizer, with manual switching. Meranda and Phillips (12) invented a method of automatic selective sampling first used in the AN/ARN-78 and AN/ARN-85 receivers built in the middle 1960's which automatically eliminated odd- or even-pulse data when synchronous interference is present. This odd-even selective sampling technique has been generally taken into account when designing systems to add communications to Loran-C (42, 43).

Other combinations of pulse samples can also be deleted to produce specific interference rejection (41), but no general rules have been provided; such a scheme was used in the AN/SPN-30 receiver to eliminate internally generated 100 kHz interference.

The basic coding interference rejection techniques were worked out assuming receivers which respond linearly to variation in signal level. The phenomena is different when receivers are hard-limited (26). That paper, as well as many papers published in the last fifteen years, indicates that Loran-C (and other systems) work better when there is both limiting and interference if the coding is at least 4-phase. Loran-C would be a better performing system today if code designers had not been so clever in going from polyphase to binary! A code consisting of concatenated N=4 4-phase matrices would be better for interference rejection and would provide at least several distinctive secondary station identification patterns, to simplify master-independent signal tracking.

CROSS-RATE INTERFERENCE AND CODE BALANCE

The complaint is sometimes heard that the Loran-C code is not optimum for cross-rate interference between Loran-C chains because it is not "balanced," i.e., there are not equal numbers of plus and minus code elements. Hopefully the discussion above will provide some insight into the ways in which the present code is indeed "balanced" in special senses to long-delayed skywaves and with selective sampling to synchronous cw interference. The present proliferation of Loran-C was not conceivable at the time the codes were designed.

That the combination of better balance and selected Group Repetition Intervals (GRI) does reduce cross-rate interference has been described in several recent papers (45, 46, 47). Non-standard balanced codes have been used for low power commercial Loran-C chains (Megapulse Accufix and Pulse-8). However, I understand that there are no present plans to further implement modified Loran-D codes such as tested to the SE USA (47).

The modified balanced codes do have a limitation of providing rejection of skywaves out to several thousand microseconds only. This appears to be good enough for most of the world. However longer-delayed skywaves have been encountered in SE Asia (42, 49). From similar experience with the Omega station in Liberia, it appears that this phenomena depends upon proximity and certain directions of propagation with respect to the magnetic equator.

Codes similar to the type investigated for Loran-C crossing rates were independently found at about the same time in connection with radar pulse compression work (50, 51), where such codes are called "quasi-complementary."

SEARCH TECHNIQUES

As mentioned previously, the original Cytac 8-phase code was designed to be identified as master or secondary by separate filtering or integration of first and last halves of the pulse groups; all present standard Loran-C and Loran-D codes were designed to retain that feature to ensure compatibility between system and older receivers. When fully automatic search was thoroughly investigated, some minor problems were found which required further improvements.

The master and secondary (slave) phase codes were designed in accordance with complementary code theory to be entirely orthogonal or mutually rejecting <u>when</u> the receiver and transmitter phase coders have their GRI's in step, even if pulses with the group are misaligned. But some funny things can happen at certain time-difference combinations when the GRI's are misaligned.

```
          S̄                                   -S̄
j    j    i    -i              -j   -j   -i   +i      Two secondaries
                i   -i    j    j                      Receiver Master code
                ───────  ───────
                  M1       M2
```

Figure 7. False Identification of Portions of Two Secondary Signals as a Master Signal.

As shown in Figure 7, when two secondaries have time differences such that their separation is 6005 microseconds and GRI of receiver and transmitters are out of step, the identification logic based on same polarity for M^1 and M^2 can falsely identify such a secondary combination as a master. Additional logic, such as some means of sensing the gap, is necessary.

In the case of Loran-D, a detailed analysis showed even more low probability but possible cases of false identification. To help this situation, early in the Loran-D development the code for the second secondary following the master was modified by slipping the interleaved Loran-D pulse code portion by one GRI and the AN/TRN-21A transmitters were so operated. However, the specification for the later AN/TRN38-39 equipment calls for all secondaries to be coded identically; and all the equipment in Europe is so operated (48).

PSEUDORANDOM CODING

The astute literature searcher will find reference to pseudorandom coding for Loran C/D (52, 53) to indicate that there has been some thought in that direction. I have been informed that there are no present plans to operate Loran-D in that manner (48) and omit here any references to classified reports.

Actually, the idea of pseudorandom "programmed" code occurred independently to us when first investigating phase coding for Cytac (33). But I have recently learned that patents describing the use of random coding were filed as early as 1938 (54). In 1958 Motorola started development of a continuously pulsed pseudorandom coded low frequency navigation system for drone control (55). Subsequently, this system was called Multi-User Tactical Navigation System (MUTNS), and for a while during the Loran-D proposal and evaluation phase MUTNS was called "Loran-F" by the U.S. Army. (I have been unable to determine if there ever was anything called "Loran-E.") Loran-D came out ahead in evaluation, and no further work was done on MUTNS/Loran-F.

CONCLUSION

This paper has attempted to broaden the outlook and understanding of Loran-C/D phase coding and of the phase coding field in general, and to record many small but important incidents of coding history.

The Loran engineer who wants to keep up on new developments in coding which may or could affect his system now has a list of words and names to watch for: complementary and quasi-complementary codes, delta-codes, Golay, Welti, Hadamard, Turyn.

ACKNOWLEDGMENT

Special thanks to Alan Phillips of Sperry Sytems Management for supplying Figure 6 which he recomputed and replotted; similar earlier work by Elmer Lipsey could not be found. Dalton Szelle of Sperry supplied me with copies of Cytac interim and final reports.

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LORAN-C RECEIVER SYSTEM FILTERING AND GROUNDING

David E. Smoler
SRD Laboratories, Inc.
381 McGlincey Lane
Campbell, CA 95008

ABSTRACT

Several years' experience has shown that the installation of Loran-C receivers can have as much to do with the received signal quality as the signals themselves. In order to properly install a Loran-C receiver, the vessel and all other installed equipment must be considered as systems. Radiated and conducted interference must be suppressed and the maximum amount of received signal impressed on the antenna terminals.

When a Loran-C receiver is utilized in an environment in which other equipment is operating, some EMI conflicts are bound to exist. This paper covers the use of filters and grounding methods to support the receiver, especially where it must be connected to ancillary equipment such as autopilots and plotters. Solutions are applicable equally to boats, aircraft, and in land-based applications. A unique method of applying a common-mode filter to the author's receiver is presented.

This paper presents empirically tested methods that have produced dramatic results.

David Smoler

BIOGRAPHICAL SKETCH

Mr. Smoler holds a BEE degree from Renssalaer Polytechnic Institute. He was a founder of Electro-Metrics Corporation where he designed EMI test equipment. Becoming Chief Engineer of Electro-Metrics, he was active in industry activities defining EMI specifications. In 1971, Mr. Smoler founded SRD Labs to manufacture Loran-A receivers and has been active in the design of all SRD Labs' products since that time. He is a licensed pilot with an instrument rating and regularly uses Loran-C for navigation in his aircraft.

SPEED DERIVATION FROM LORAN-C FOR MARINE USERS

Gerald F. Sage
Navigation Technology, Inc.
2327 Double "O" Mine Trail
Cool, CA 95614

ABSTRACT

Marine users of Loran-C equipments derive substantial benefits from speed derived from the Loran-C measurements. To achieve maximum benefits, an accuracy of a few tenths of a knot is needed when speed is held constant. At the same time, a quick response to changes in speed is desired. Since the speed is found by filtering noisy position measurements, these are conflicting requirements. Three linear filters are considered:

1. Filtering position changes;
2. Second-order fixed gain filtering of position; and
3. Kalman filter.

It is shown that the second-order filter or the Kalman filter produce superior results to filtering position changes. Filtering with a long time constant produces accurate speed estimates, but has poor response to changes in speed. Quick response to changes in speed but poor accuracy can be achieved with short time constant filters. A system that contains both a long time constant filter and a short time constant filter has been synthesized which has superior speed estimation characteristics. Both the long time constant filter and the short time constant

Gerald Sage

filter continually filter position. If the filtered positions differ by more than is expected from the noise, a large speed change is assumed to have occurred. The long time constant filter is then reinitialized by the short time constant filter and converges on the new speed.

BIOGRAPHICAL SKETCH

Gerald Sage is President of Navigation Technology, Inc. He provides consulting services for the analysis, design, and test of radio navigation systems. His more than twenty years of experience in the navigation and communications field include the design of user equipment for Loran-C, Omega, Transit, and GPS systems. He has designed multisensor navigation systems using Kalman filtering and suboptimal filters. These equipments have been designed for military, civil aviation, and civil marine users. Mr. Sage received a BSEE from the University of Michigan and completed graduate studies for a MSEE at the University of Maryland.

SPEED DERIVATION FROM LORAN-C FOR MARINE USERS

by

Gerald F. Sage

Navigation Technology Inc.
2327 Double "O" Mine Trail
Cool, California 95614
(916) 885-1089

One of the useful functions provided by modern Loran-C equipments is the derivation of speed. While the speed is useful in a variety of applications, two typical cases are examined. The first is a fishing vessel. The area being worked is covered by a series of straight passes linked by short turns. During the straight passes it is desired to know the speed to approximately a tenth of a meter second. During turns high accuracy is not required, but after completion the return to high accuracy should be as soon as possible. The second application is a high speed boat which will run from one area to another with rapid starts and stops. Here the high accuracy is not required, rather a quick response to the changes in speed is needed.

These general observations of the desired characteristics of the derived speed have lead to two test profiles for evaluating speed derivation tehcniques. In the first test profile a constant speed of 2.5 meters/second is held for 300 seconds representing the completion of a leg of a fishing pattern. Then an 180 degree turn is made in 100 seconds at constant speed, followed by 300 seconds of travel at 2.5 knots in the opposite direction. In the second profile the vessel is at rest for 300 seconds and then accelerates to a speed of 15 meters per second in 30 seconds.

When comparing systems, a criterion is needed for determining the best system. The performance criterion used, based on the user requirements are 1) noise variation with constant vessel velocity and 2) the time required to reach small transit errors after a change in velocity. In the simulations of the systems, all have been desiged to give the same steady state noise variation with constant input velocity. Evaluation of the systems is then a comparison of the transient responses.

Derivation of Speed

Three methods of deriving speed are examined. They are 1) averaging position changes 2) fixed parameter second order filter and 3) the Kalman filter.

Speed can be found by averaging position changes. Over a time period DT the position change is DP. The speed V is

$$V = \frac{DP}{DT}$$

If the noise on the position measurements is independent with variance var(p), the variance on N consecutive measurements for a total time T = N * DT will be

$$VAR\ (V) = \frac{2*VAR(P)}{DT}$$

The averaging could be performed by a variety of filtering techniques, but still yields inferior performance that obtained by other methods and will not be considered further.

A second order filter is used to filter position using position and velocity as the state variables. Figure 1 is a block diagram of the system. The noise variation on velocity can be shown to be approximately

$$VAR\ (V) = \frac{\omega_n^3}{4\,\xi} * n * DT$$

Wn is the natural resonate frequency and ξ is the damping factor. The averaging time of the filter is related to 1/Wn. The variance of the velocity measurement reduces as the inverse cube of the averaging time as compared to the inverse of the averaging time in the position change averaging. Transient responses to changes in speed will usually require several time constants before becoming small.

A Kalman filter using two state variables, position and velocity, can be used to derive the velocity. Figure 2 illustrates the filter. The filtering equations are similar to the second order filter with the gains computed from the covariance matrix and the measurement noise matrix. The steady state variance on velocity measurements will be the same as the second order filter having the same parameters. With correct initialization and constant velocity only a single time period is required to reach the best measurment accuracy for that time period.

Simulation of Non Adaptive Filters

Using arbitary but reasonable values for the parameters of the second order filter and the Kalman filter produced the results of Figures 3 and 4. The first test profile and noise representative of good Loran-C conditions has been used. The parameters of the two systems were adjusted to give identical steady state gains. In Figure 3 the transient response of the second order filter to both the initial conditions and the turn is larger than desired. In Figure 4 the Kalman filter transient response to the initial condition is good, but during the turn the filter has reached steady state and has an identical response to the second order filter.

Adaptive Modifications

Modifications are now added to the velocity measurement system to allow adaptation to the dynamics encountered. One method of measuring dynamics is described. A velocity error monitoring system is run in parallel to the velocity measurement system. If a velocity error is detected, the velocity measurement system is reinitialized. Velocity error is detected by keeping a running dead reckoning position using the derived speed. If the difference between the DR position and the input position become large, the measurement system is reinitialized.

For the simulations the following parameters are used for the DR system. The running DR position is kept for 130 seconds. The DR position each itteration is

$$\text{DR Position} = \text{DR Position} + DT * V$$

If

$$\text{DR Position} - \text{Present Position} > 100 \text{ meters}$$

then the velocity measurement system is reinitialized.

Simulation of Adaptive Filters

For the second order system, reinitialized consists of replacing the DR position with the present position and computing a new velocity by

$$\text{velocity} \leftarrow \text{velocity} + \text{constant} * (\text{DR Position} - \text{Present Position})/DT$$

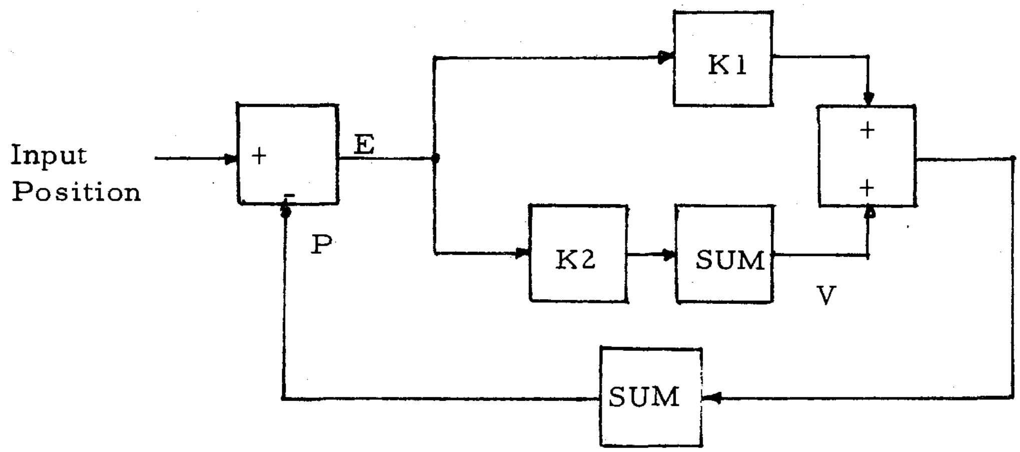
When the constant in the velocity equation is one, the simulation results for the first test profile are shown in Figure 5. The corrections provided by the velocity update are too large, overshooting the correct value. When a constant of .5 is used, the simulation results of Figure 6 are obtained. The same steady state accuracy is achieved as with the non adaptive filter with a shorter transient response.

For the Kalman filter the reinitialization is achieved by reseting the covariance matrix allowing the filter to converge on a new value. The results of the simulation using the first test profile are given in Figure 7. Excellent transient and steady state performance are obtained.

Simulations showing the response of the systems to the second test profile are shown in Figures 8, 9 and 10. Similar results to the first profile are obtained.

CONCLUSION

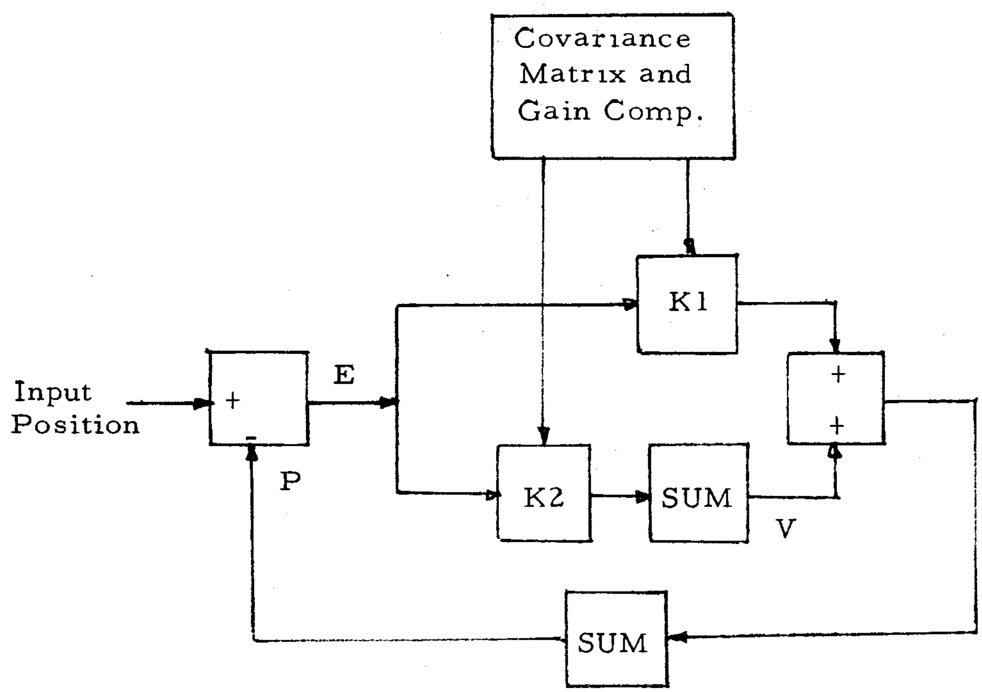
Simulations of adaptive and non-adaptive speed measurement systems indicate that more desirable speed measurement characteristics can be achieved using adaptive systems. The presence of dynamics can be detected and the speed measurement process reinitialized to allow rapid convergence on a new speed.



$V = V + K2 * E$
$P = P + DT * V + K1 * E$
$K1 = 2 \xi \omega_n DT$
$K2 = \omega_n^2 \, DT$

P is the position
V is the velocity
K1 is the position gain
K2 is the velocity gain
DT is the itteration interval
ω_n is the equivalent natural resonate frequency
ξ is the equivalent damping factor

Figure 1. Second order speed measurement system.




```
Extrapolate Covariance
P11 = P11 + 2 * DT * P12 + DT * DT * P22
P12 = P12 + DT * P22
P22 = P22 + Q2
Gain Computation
K1 = P11/(P11+R)
K2 = P12/(P11+R)
Update Covariance
P11 = P11 - K1 * P11
P22 = P22 - K2 * P12
P12 = P12 - K1 * P12

P11,P12,P22     are the covariances
Q2              is the system driving function covariance
R               is the measurement noise covariance
```

Figure 2. Kalman filter speed measurement system.

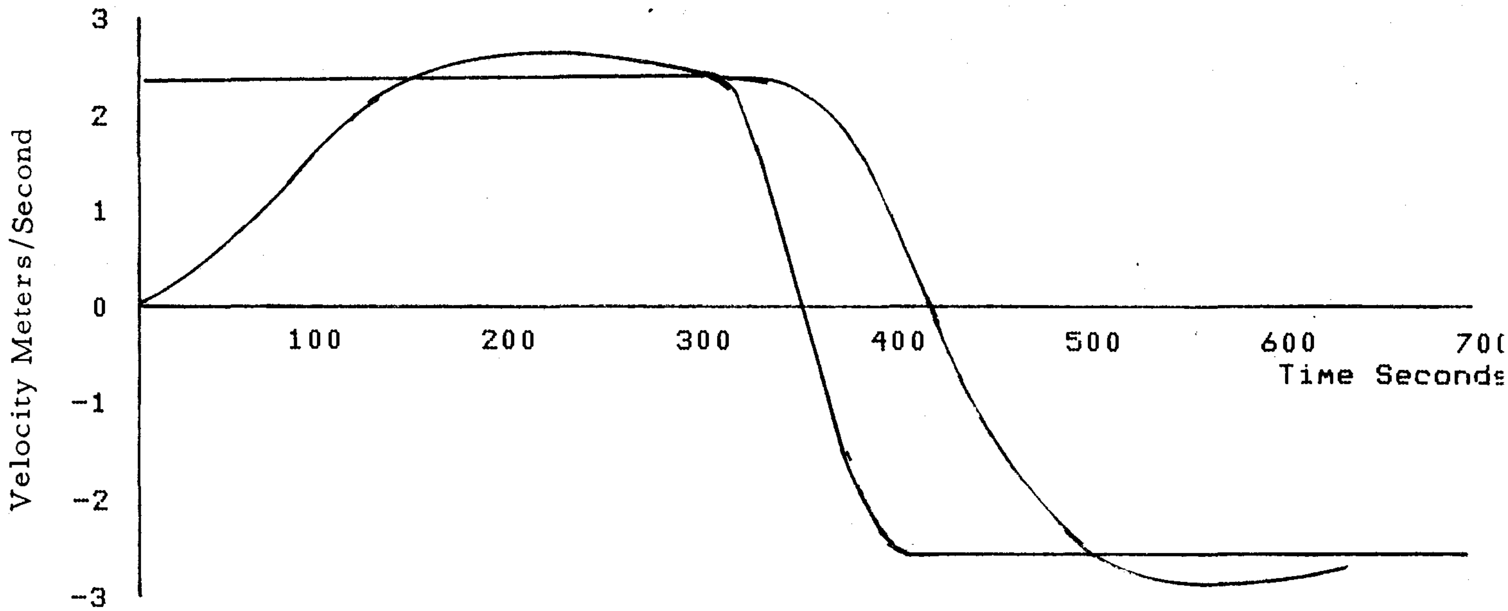


Figure 3. Fixed gain filter response to 180 degree turn.

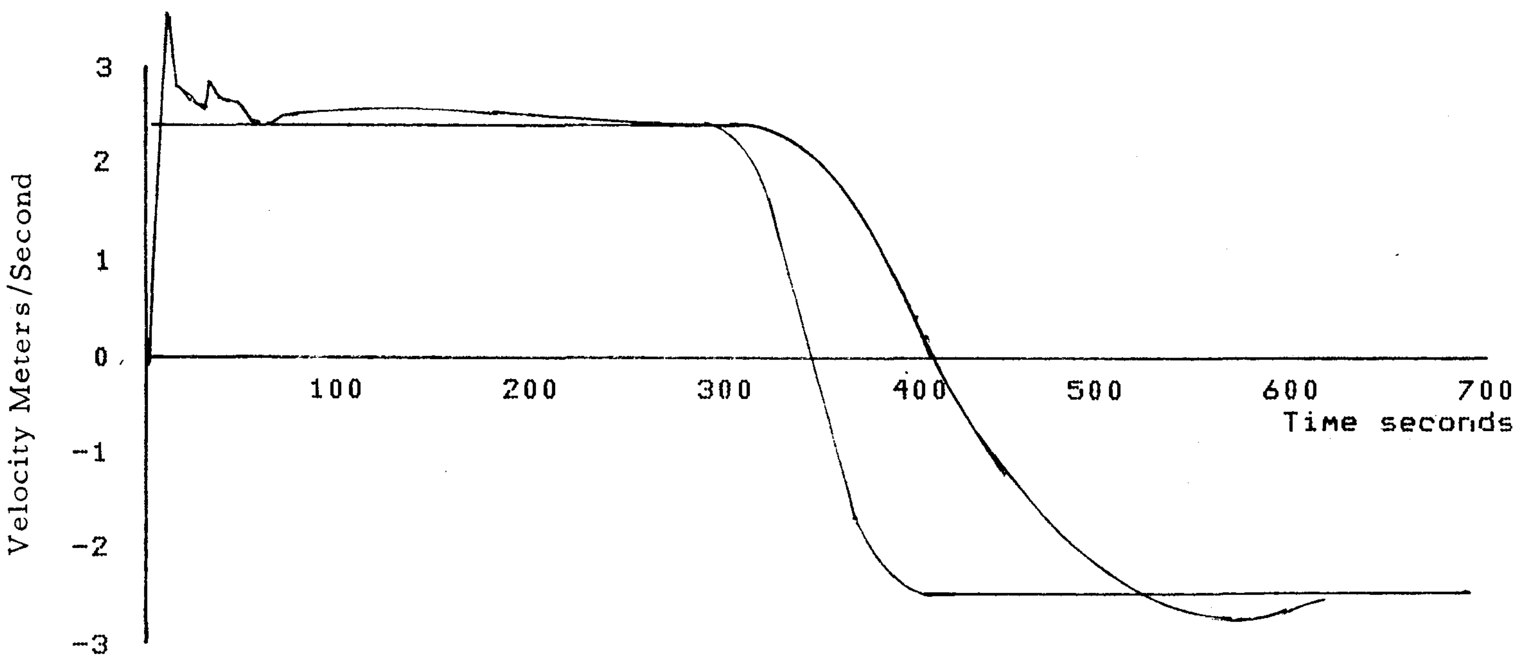


Figure 4. Kalman filter response to 180 degree turn.

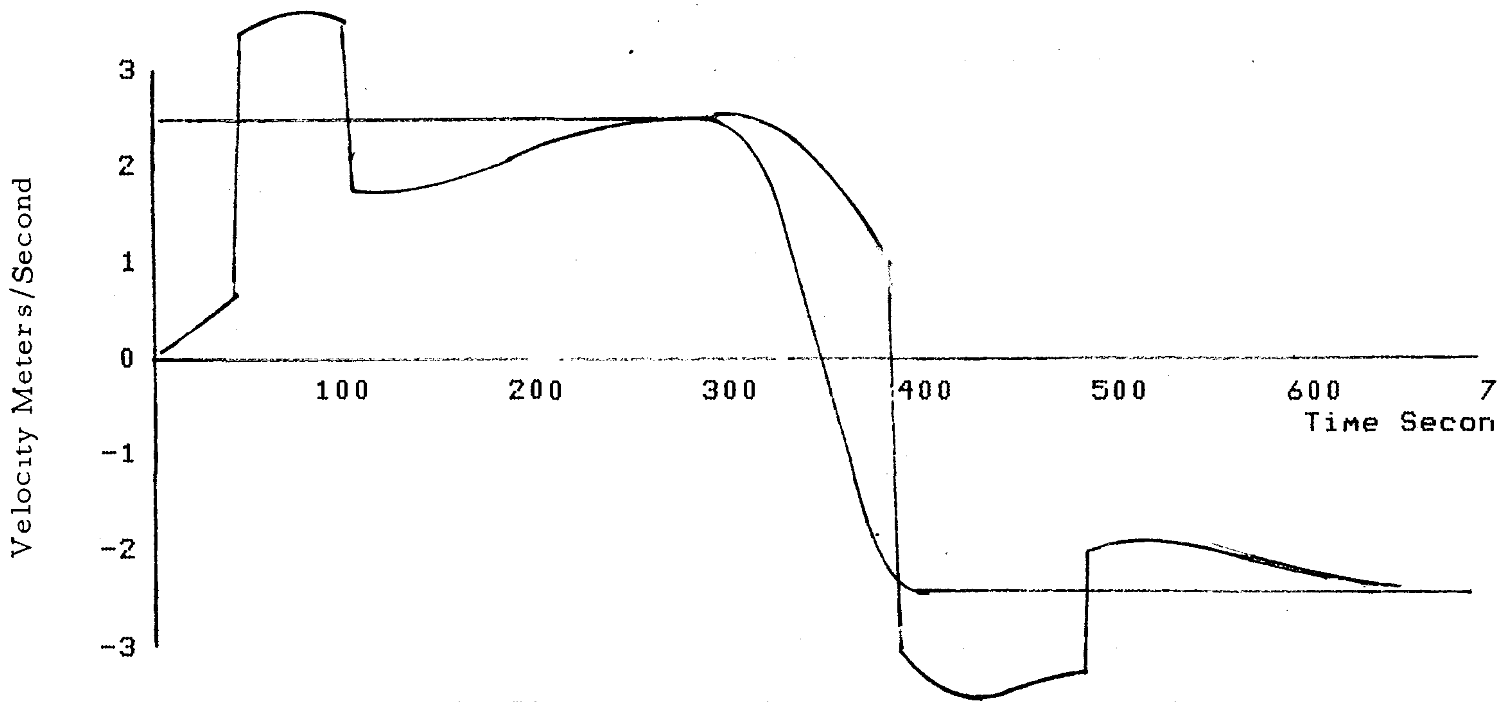


Figure 5. Fixed gain filter with full velocity update response to turn.

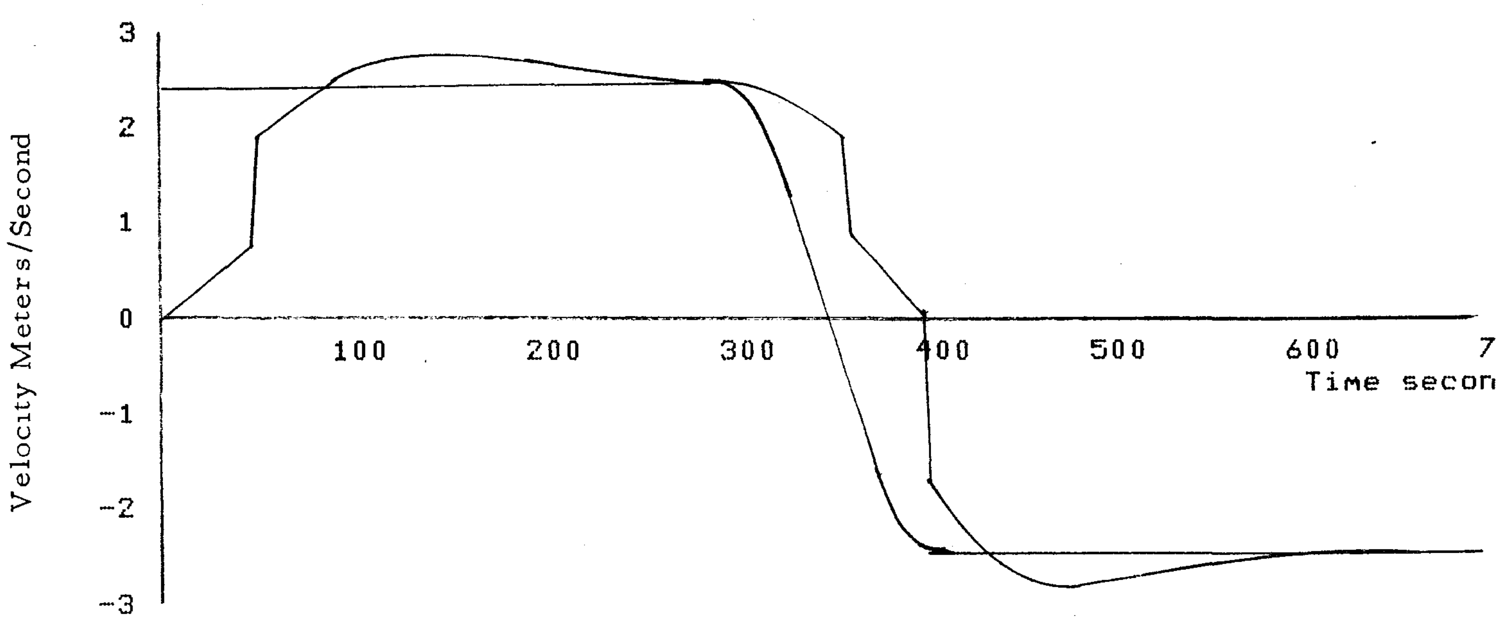


Figure 6. Fixed gain filter with .5 velocity update response to turn.

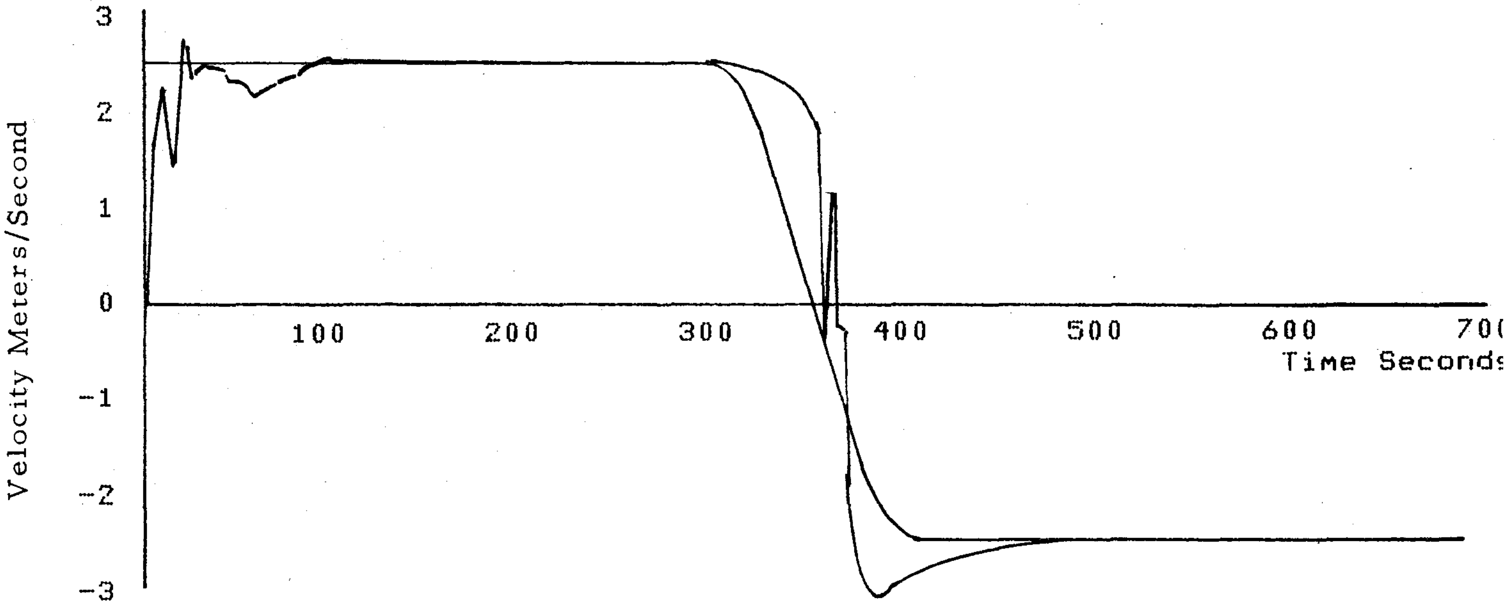


Figure 7. Kalman filter with reset for dynamics response to turn.

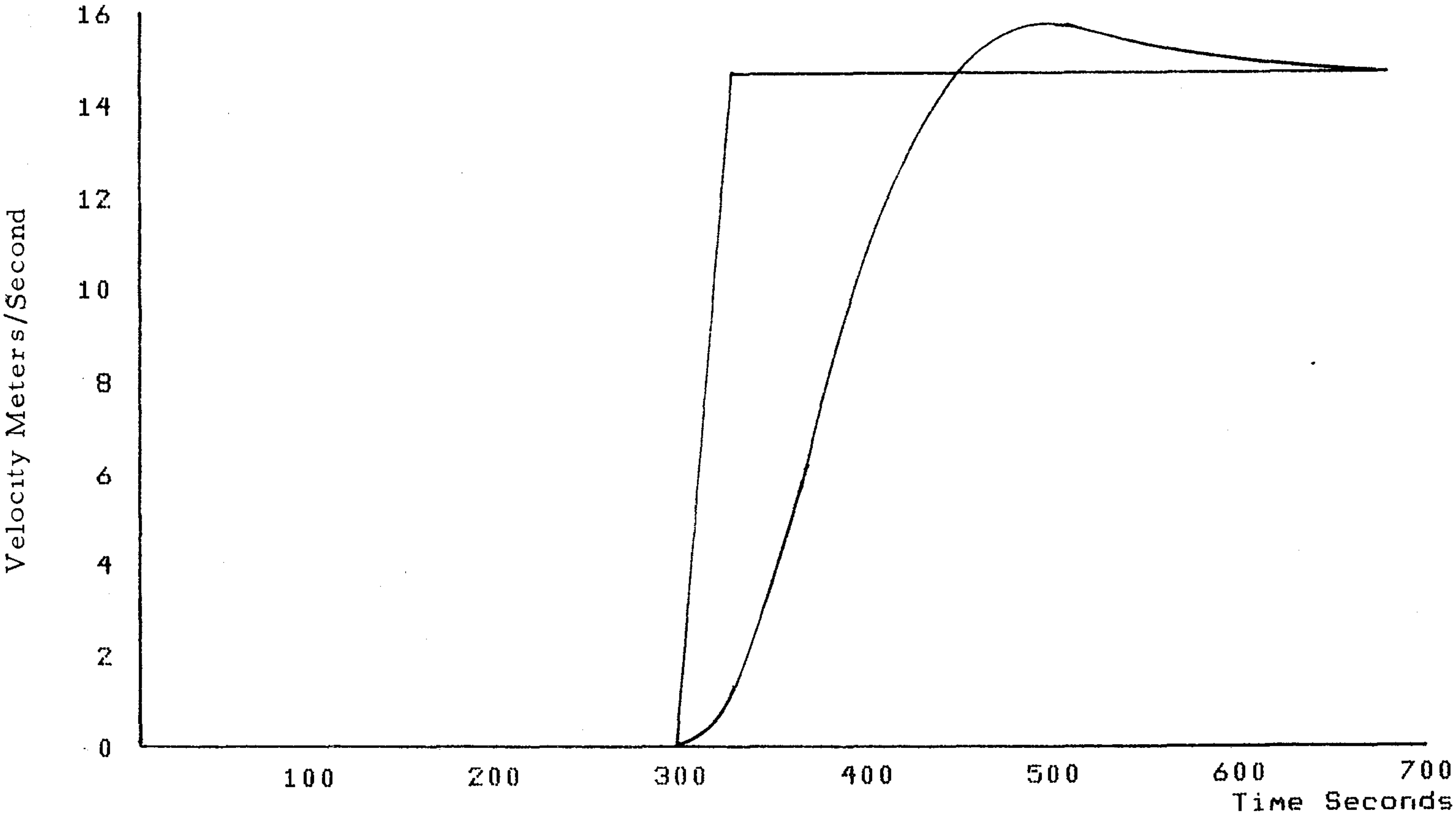


Figure 8. Fixed gain filter response to sudden speed increase.

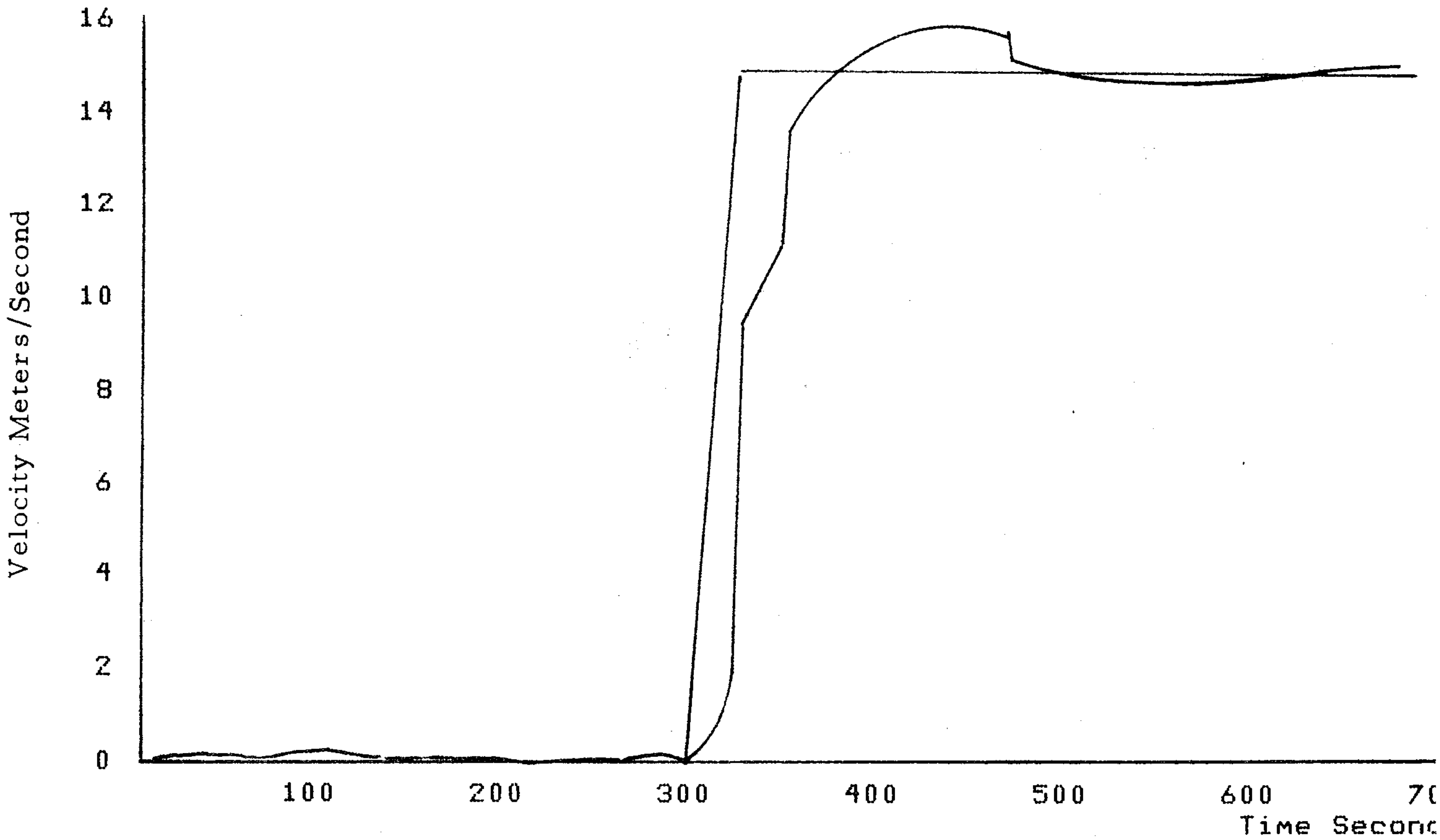


Figure 9. Fixed gain filter with .5 velocity update response.

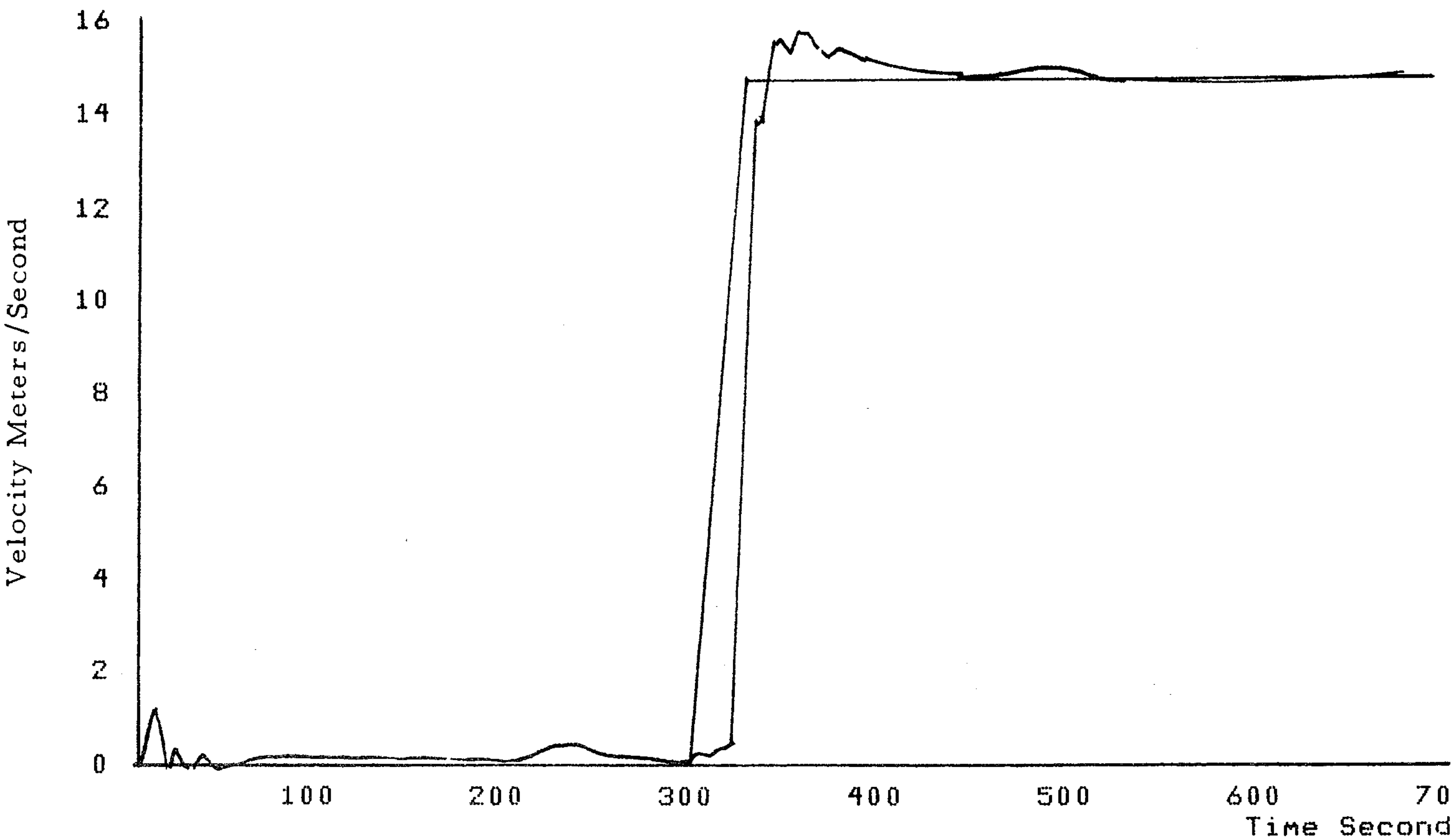


Figure 10. Kalman filter with reset for dynamics response.

SESSION 3
GRID STABILITY

Session Chairman: Tony Mortimer,
Canadian Hydrographic Service

LORAN-C GRID STABILITY AND WARPAGE TESTS FOR AIRCRAFT NAVIGATION ACCURACY ASSESSMENT

L.M. DePalma and P.M. Creamer
The Analytic Sciences Corporation
One Jacob Way
Reading, MA 01867

R.H. Erickson
FAA Technical Center
Tilton Road
Atlantic City, NJ 08405

ABSTRACT

The Federal Aviation Administration (FAA) is conducting Loran-C tests to assess the impact of Time Difference (TD) grid instability and warpage on aircraft navigation accuracy. These procedures and preliminary test results are discussed in this paper. The equipment is entirely ground-based, consisting of three Micrologic ML-220 receivers used as fixed-site monitors and one Austron-5000 receiver mounted in the FAA Technical Center Test Van. Two of the monitors are stationed permanently at the London, KY, and Buffalo, NY, Flight Service Stations, locations expected to exhibit worst-case grid instability for Northeast U.S. Chain signals. The third monitor is stationed temporarily at each of five airports, during Test Van operations designed to measure grid warpage along current and projected worst-case airport approach profiles. The selected airports represent different signal propagation conditions (eg, Rutland, VT, for mountainous terrain, Columbus, OH, for relatively flat terrain, and Atlantic City, NJ, for the sea/land interface). The Loran-C data are analyzed to estimate propagation-related nonprecision approach errors, and the results are compared to previous gound-based and airborne test results. The current tests, which are scheduled for completion by May 1982, will provide major inputs to the FAA decision data base in support of the Federal Radionavigation Plan. (Supported under Contract DTFA01-81-C-10031.)

BIOGRAPHICAL SKETCHES

Leon M. DePalma - Dr. DePalma has been engaged in the evaluation of the Loran-C radionavigation system and its applications for four years at the Analytic Sciences Corporation. These projects include data-oriented and theoretical analyses of low-frequency propagation, and evaluation of proposed Loran-C system applications. His efforts related to signal propagation have involved Time Difference grid calibration for the St. Marys River and Mediterranean Sea Loran-C chains. System studies have included applications of Loran-C to buoy position auditing and civil aircraft navigation. In 1972, Dr. DePalma received a BS degree in Electrical Engineering from the University of Pittsburgh. He received a PhD degree in Computer, Information, and Control Engineering from the University of Michigan in 1977.

Paul M. Creamer - In the past three years, Mr. Creamer has been involved in a number of radionavigation-related efforts at the Analytic Sciences Corporation. In the St. Marys River Loran-C data analysis project, he designed and implemented a data-base management system that was successfully used to maintain, edit, and display large volumes of data. Previously, he was involved in the development of a TD grid prediction model for the U.S. West Coast Loran-C chain. In addition, Mr. Creamer has participated in several Omega Navigation System projects including development of a signal amplitude prediction model and evaluation of a new force-fit algorithm. Mr. Creamer received his BS degree in Mathematics from Trinity College in 1977 and is currently pursuing an MS degree in Systems Engineering at Boston College.

Robert H. Erikson - Mr. Erikson has been working on the evaluation of short- and long-range radionavigation systems for eight years at the Federal Aviation Administration Technical Center (formerly NAFEC). His current projects involve test planning equipment interfacing, and data collection in support of Loran-C and Omega system evaluations for civil aircraft navigation applications. He has been responsible for outfitting and maintaining the FAA Technical Center Test Van employed in the current Loran-C tests and directs all in-field Test Van operations. Mr. Erikson received a BS degree in Electrical Engineering from Drexel University in 1973 and has since published two technical papers and participated in several conferences.

Leon DePalma

Paul Creamer

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L.M. DePalma and P.M. Creamer
The Analytic Sciences Corporation
One Jacob Way
Reading, Massachusetts 01867

R.H. Erikson
FAA Technical Center
Tilton Road
Atlantic City, NJ 08405

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The Federal Aviation Administration (FAA) is conducting Loran-C tests to assess the impact of Time Difference (TD) grid instability and warpage on aircraft navigation accuracy. Test procedures and preliminary test results are discussed in this paper. The equipment is entirely ground-based, consisting of three Micrologic ML-220 receivers used as fixed-site monitors and one Austron 5000 receiver mounted in the FAA Technical Center Test Van. Two of the monitors are stationed permanently at the London, KY and Buffalo, NY Flight Service Stations, locations expected to exhibit worst-case grid instability for Northeast U.S. Chain signals. The third monitor is stationed temporarily at each of five airports, during Test Van operations designed to measure grid warpage along current and projected worst-case airport approach profiles. The selected airports represent different signal propagation conditions -- e.g., Rutland, VT for mountainous terrain, and Atlantic City, NJ for the sea/land interface. Preliminary results indicate that grid warpage errors can be reduced to acceptable levels for non-precision approach, by bias measurement or mixed-path modeling. The tests, which are scheduled for completion by May 1982, will provide major inputs to the FAA decision data base in support of the Federal Radionavigation Plan.

INTRODUCTION

Background

The Federal Aviation Administration (FAA) is evaluating Loran-C as a candidate aircraft navigation system, for possibly replacing or supplementing the VOR/DME network (see Fig. 1). The evaluation is motivated by the Federal Radionavigation Plan (Ref. 1). The Plan requires that FAA recommendations regarding the future airborne use of radionavigation systems be formulated by December 1982. The FAA Loran-C evaluation program includes ground and flight tests, and three equipment development activities: low-cost airborne receiver, signal simulator, and Notice-to-Airmen monitor. Loran-C ground tests being conducted by the FAA Technical Center (FAATC), under the direction of the FAA Systems Research and Development Service, are the focus of this paper.

FAA Advisory Circular AC-90-45A contains airborne equipment error requirements for operation in the U.S. National Airspace System (Ref. 2).

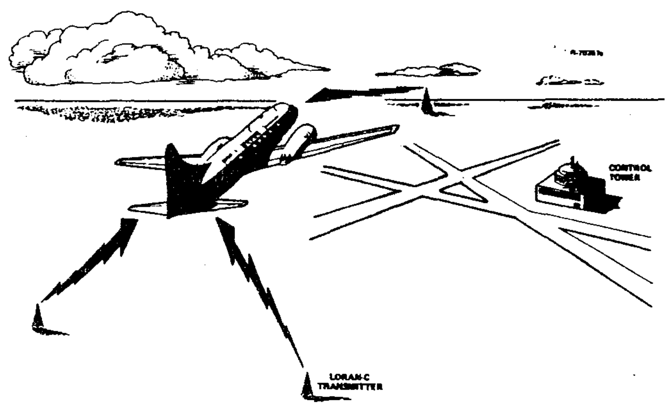


Figure 1 Loran-C: A Candidate Aircraft Navigation System

As indicated in Table 1, the requirements are more stringent for non-precision approach than for enroute and terminal flight phases. Flight test results (Refs. 3 and 4) and marine applications experience suggest strongly that enroute and terminal accuracy requirements can be met with uncompensated Loran-C. However, the non-precision approach accuracy requirement (300 m rms, along-track and cross-track) is more severe than the accuracy typically associated with uncompensated Loran-C (460 m or 0.25 nm, rms). Indeed, flight test results have shown that non-precision approach requirements are met in some regions, but not others (Refs. 3 and 4). For the above reasons, the FAATC tests are specialized to non-precision approach.

Test Objectives

The FAATC tests concentrate on the major Loran-C error source: uncertainty in the Time

TABLE 1
AIRBORNE EQUIPMENT ERROR REQUIREMENTS

FLIGHT PHASE	RMS ALONG-TRACK/ CROSS-TRACK ERROR (m)
Enroute	1400
Terminal	1000
Non-Precision Approach	300

Difference (TD)-to-position coordinate conversion. This error source arises because the propagation velocity of the Loran-C groundwave is uncertain, especially on land paths. It is convenient to divide the coordinate conversion errors into two components:

- Grid instability -- temporal TD variations at a fixed location
- Grid warpage -- off-nominal spatial TD variations at a fixed time.

Grid instability and warpage govern repeatable and absolute accuracy, respectively. Both types of errors impact aircraft navigation accuracy; both types are measured in the FAATC tests.

To isolate coordinate conversion errors, it is necessary to revisit data collection sites and to dwell at sites for extended time periods. These requirements dictate a ground-based test program. Loran-C error sources whose magnitudes depend strongly on the airborne environment are not assessed in these tests. Such error sources include aircraft dynamics and Flight Technical Errors and, to some extent, noise and interference.

Several propagation-related tests have been performed since the advent of the Loran-C system. A literature review of these tests has been conducted, to provide a benchmark for comparison to the current FAATC tests. The literature review is summarized in a companion technical paper (Ref. 5).

FAATC test instrumentation, test scenarios, and preliminary test results are discussed herein. Detailed test plans are contained in Ref. 6.

INSTRUMENTATION

Test Overview

Temporal grid instability is measured by two fixed-site Loran-C monitors. TDs and related monitor receiver outputs are recorded every 15 min during the test year (from May 1981 to May 1982).

Spatial grid warpage is assessed by the mobile FAATC Test Van. Approximately 25 sites are visited by the Test Van around each of five airports. The Test Van dwells at each site for a minimum of 30 min. The Loran-C data from different sites at an airport are necessarily collected at different times. Therefore, a temporary Loran-C monitor is established at the airport during Test Van operations. The monitor data enable short-term temporal effects to be removed from the measured warpage. The Test Van returns to each airport as often as possible during the test year, to measure the seasonal repeatability of the warpage.

Fixed-Site Monitor

An automatic Loran-C receiver, the Micrologic ML-220, is used at each fixed-site because the monitor must operate virtually unattended. The receiver is capable of tracking five Loran-C stations in the same chain. The following parameters are outputs of the receiver: date, time of day, Signal-to-Noise Ratio (SNR), Envelope-to-Cycle Difference (ECD), receiver mode, and blink status. All parameters are recorded on cassette tape, using an MFE 25000 buffered terminal, digital recorder. Occupying a cube approximately 18 inches on a side, the total instrumentation package is convenient to locate at Flight Service Station facilities. A battery backup is provided for the Micrologic ML-220 receiver so that short-term commercial power outages do not affect the internal day clock.

Flight Service Station personnel are required to perform two functions. First, the date/time tags must be checked daily. Second, the cassette tape must be reversed or changed weekly, and completed tapes mailed to FAATC.

Test Van

The FAATC Test Van is a GMC Magna Van, modified to house the electronic equipment suite. Special attention is given to reducing locally-generated interference, such as ignition noise.

The self-contained 110/220 VAC generator is located in a steel enclosure, isolated from the Test Van interior by marine-class Radio Frequency Interference (RFI) shielding. Power enters the Test Van interior through screen-room line filters, which reduce conducted interference. An extension cord is included for connection to commercial power, as a backup to the generator. An uninterruptable power supply is installed to provide continuous uniform power to the electronic equipment. Stable voltage and frequency are thus maintained under varying generator loads. In the event of total generator failure, battery power is available for 10 min. This is enough time to correct the problem, complete the test, or conduct a normal equipment shutdown.

Test Van instrumentation is divided into three categories:

- Loran-C receiver system
- Spectrum analyzer system
- Calculator system.

The systems are shown in simplified block diagram form in Fig. 2 and are discussed in subsequent paragraphs.

The Loran-C receiver is the Austron 5000, the automatic precision receiver used by the U.S. Coast Guard to monitor and control the chains. The whip antenna is mounted vertically on the Test Van roof and removed during transit. Signals enter through a passive coupler and a notch filter bank supplied by the U.S. Coast Guard. The notch filter bank is external to the receiver and includes 12 filters, pre-tuned to signals known to interfere with Loran-C reception in the Northeast U.S. chain. The Austron 5000 receiver operates in conjunction with a PDP-8 mini-computer, which is tied to a Texas Instruments Silent 700 terminal/recorder. The Silent 700 contains a keyboard, line printer, and digital cassette system.

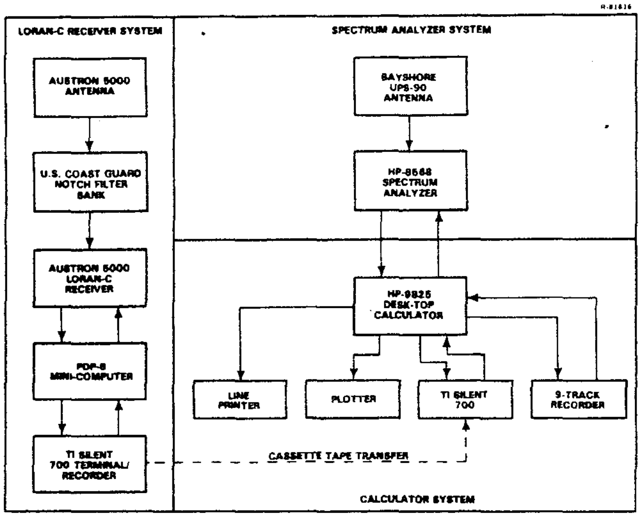


Figure 2 FAATC Test Van Equipment Suite

The cassette system is used to load the PDP-8 computer programs and record the Loran-C data. The recorded parameters are analogous to those for the Micrologic ML-220 receiver discussed above.

A Hewlett Packard HP-8568 spectrum analyzer is installed in the Test Van to detect potential RFI problems. In an ideal installation, the spectrum analyzer would be connected to the Austron 5000 antenna coupler. Because the coupler is passive, however, interfering signals would be masked by the noise floor. Selecting a point beyond the front-end amplifiers of the Austron 5000 would solve this problem, but the continual automatic gain adjustments performed by the receiver would result in spectrum fluctuations. The spectrum analyzer is instead connected to a Bayshore UPS-90 active antenna. Its short length permits the Bayshore antenna to be permanently mounted on the Test Van roof. The spectrum can thus be measured during transit, as well as during Austron 5000 operations. The HP-8568 spectrum analyzer features both front panel and remote control capabilities. The remote control feature is used to set the spectrum parameters (e.g., sweeprate) to selected values, when plotting standard spectra for each site. Remote control and plotting are conducted by the calculator system.

The calculator system consists of a Hewlett Packard HP-9825 desk-top calculator, with the following peripherals:

- Line Printer
- Plotter
- Nine-Track Tape Recorder
- TI Silent 700 Terminal.

This equipment suite enables the test engineer to evaluate the quality of the Loran-C data on site, and to record all relevant information for future analysis. Among the outputs of the calculator system are: Loran-C data plots, statistical data summaries, and hard copies of the spectrum analyzer display.

Temporary Airport Monitor

The equipment used for the temporary airport monitor is identical to that described above for the fixed-site monitor. The package, consisting of the Micrologic ML-220 receiver and MFE 25000 recorder, is installed at a sheltered airport facility during Test Van operations. The monitor is left unattended except for daily reversal or changing of the cassette tape by FAATC personnel.

TEST SCENARIO

Fixed-Site Monitor Locations

The purpose of the fixed-site monitors is to measure temporal grid instability. Fixed-site monitor locations are thus selected to maximize the observed instability, i.e., to provide a worst-case measurement. This is accomplished by selecting sites which are far removed from the System Area Monitor (SAM) in hyperbolic coordinates.

To a first-order approximation, temporal TD variations are proportional to the "Double Range Difference"

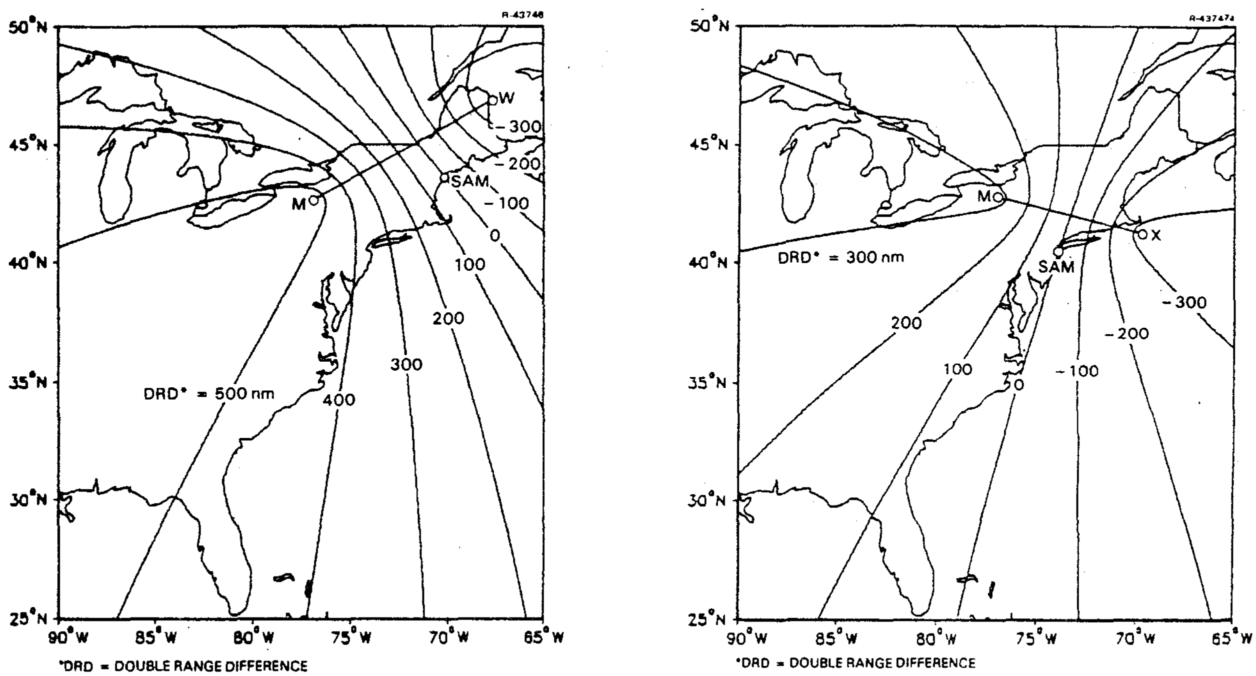
$$DRD = (R_s - R_m) - (R'_s - R'_m) \qquad (1)$$

where R_s and R_m are the ranges to the site from the secondary and master stations, respectively, and R'_s and R'_m are the corresponding ranges to the SAM (Ref. 7). DRD contours are hyperbolas, as shown for TDW and TDX for the Northeast U.S. chain in Fig. 3. Grid instability is expected to be a minimum on the contour with DRD = 0. This contour passes through the SAM: e.g., Cape Elizabeth, ME for TDW, and Sandy Hook, NJ for TDX. Instability is controlled to ± 0.1 μsec at the SAM itself.

London, KY and Buffalo, NY Flight Service Stations are selected as fixed-site monitors (see Fig. 4). DRD values for all four Northeast U.S. chain TDs are listed for these sites in Table 2. The values cover the gamut of expected instability, from best-case to worst-case. Also included in Table 2 are DRD values for Burlington, VT, where the Transportation Systems Center (TSC) measured TD instability from August 1979 to October 1980 (Ref. 3). Comparison of FAATC, TSC, and other test results is expected to contribute to a better understanding of grid instability than is currently available.

Test Van Site Locations: General

The FAATC Test Van is used to measure spatial grid warpage in the vicinity of the five airports shown in Fig. 4. Airport selection is based on signal propagation and scheduling considerations. The airports represent different geographical features:



a) TDW

b) TDX

Figure 3 Expected Dependence of TD Instability on Hyperbolic Distance to the SAM

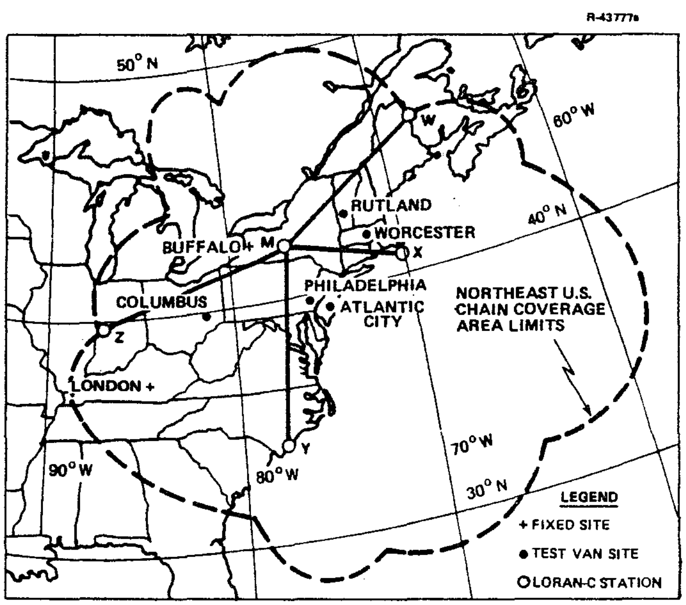


Figure 4 Test Site Locations

- Atlantic City, NJ -- sea/land interface
- Philadelphia, PA -- intense development
- Columbus, OH -- flat terrain
- Worcester, MA -- hilly terrain
- Rutland, VT -- mountainous terrain.

TABLE 2

EXPECTED RELATIVE MAGNITUDE OF GRID INSTABILITY

FIXED-SITE MONITOR LOCATION	DOUBLE RANGE DIFFERENCE (nm)			
	TDW	TDX	TDY	TDZ
London, KY (Flight Service Station)	600	200	300	200
Buffalo, NY (Flight Service Station)	500	300	200	400
Burlington, VT (TSC Tests)	100	0	200	600

The geographical features in the vicinity of the airport, rather than along the entire signal paths, are of primary interest here. Uncertain propagation velocity along the paths can be thought to result in TD biases, which are easily measured and removed if necessary. Uncertain propagation velocity in the vicinity of the airport determines the non-bias or "random" warpage component, which is difficult to measure and, therefore, of greater potential concern.

For test purposes, the "airport approach area" is defined as a circle with a 20 km radius, centered on the Airport Reference Point (ARP).

The Outer Markers for most U.S. airports are less than 20 km from the ARP. The selected airport approach area definition is a convenient, conservative standard.

The Test Van visits approximately 25 sites within each airport approach area. Sites are located as closely as possible to the following airport radial lines:

- Runway extensions
- Gradients to the hyperbolic Lines of Position (LOPs).

Sites on runway extensions permit measurement of grid warpage along current approach profiles. Sites on LOP gradients are expected to yield an estimate of worst-case warpage. The latter is important if test results are to be "extrapolated" to other airports. The above criteria typically yield, after some compromise, six data collection radials spaced approximately 60 deg apart. An attempt is made to locate sites at distances of 5, 10, 15, and 20 km from the ARP.

Sites must be accessible by the Test Van. Generally, it is not possible to locate sites on straight radials at fixed distance intervals. Locations are instead dictated by road availability. Gaps in Test Van coverage can occur due to lakes, marshes, mountains, and the ocean. An additional constraint is that sites be near survey monuments (benchmarks), where possible. Although Transit Satellite and the Global Positioning System (GPS) are being considered for site surveying, the most economic method appears to be triangulation by a survey team. Locating sites near benchmarks will minimize the cost of triangulation. Transit or GPS will be used to survey sites where triangulation is not feasible. In all cases, the survey accuracy objective is 10 m rms.

General site location areas are marked on U.S. Geological Survey (USGS) topographic maps, prior to departing for the airport. Specific locations are selected after on-site inspection by the Test Van. An example of the distribution of sites, for the Atlantic City airport approach area, is given in Fig. 5.

<u>Test Van Site Locations: Specific</u>

Every effort is made to avoid <u>local</u> reception and interference problems when selecting specific Test Van sites. The rationale is that such problems would not be experienced in the airborne environment.

The Test Van is driven to the general site location area marked on the USGS maps. A quick search is conducted on foot for the survey monument. If the monument is not found, an alternate site may be selected. The specific site location must be removed from traffic, trees, power/phone lines, and industrial equipment. Consideration is also given to winter access of the site; parking lots are ideal.

The frequency spectrum is next examined for high local noise levels and RFI. The Test Van

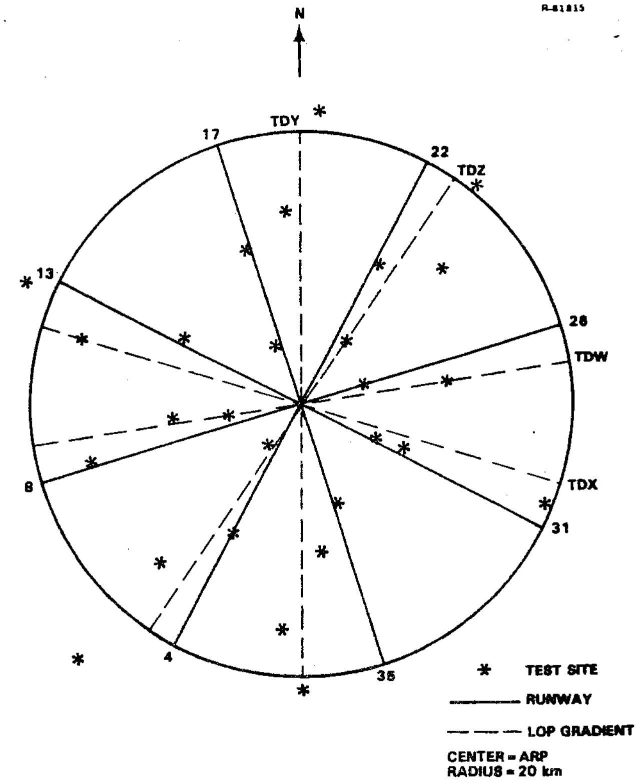


Figure 5 Atlantic City Airport Test Sites

may be moved up to 1 km from the original site, if necessary, to reduce the local effects. When an acceptable site is found, the Loran-C data are collected. If the measured TDs at the site are inconsistent with the TD bias observed at previous sites, validation checks are conducted. A nearby site may be visited to aid in the validation.

<u>Typical Test Day</u>

A typical day in the Test Van operations is outlined below:

A. Check the temporary airport monitor for proper date, time, and Loran-C cycle; insert a new cassette tape and initiate ML-220 data collection at a 1 min rate

B. Record Austron 5000 data for 15 min at a 1 min rate, with the Test Van parked next to the monitor; these data are compared to the ML-220 data for consistency

C. Proceed to the Test Van sites in sequence, following the steps below at each site:

   1. Search for the survey monument

   2. Select a specific site location

   3. Examine the frequency spectrum

   4. Determine approximate site coordinates from the USGS map

   5. Compute predicted TDs for the site using the approximate coordinates and a simple model

6. Start the Austron 5000 receiver and wait until it is locked on to all five station signals; the predicted TDs may be used here to aid the receiver

7. Commence 30 min of data collection at a 1 min rate

8. Plot a standard series of frequency spectra

9. Mark the site by a spike or paint

10. Sketch the site in relation to permanent structures

D. After visiting the last Test Van site for the day, return to the airport and collect 15 min more of ML-220/Austron-5000 comparison data

E. Plot the TD data for each Test Van site and the monitor; tabulate TD, SNR, and ECD summary statistics

F. If the data does not satisfy certain consistency checks, it may be necessary to return to one or more of the sites on subsequent days.

It takes two to three weeks to cover one airport. The five airports were each completed one time during the period from May 1981 to October 1981. Return visits at a reduced scale are planned for the winter months.

PRELIMINARY RESULTS

Grid Warpage Data Base

Preliminary FAATC test results are presented in this section. The results pertain to grid warpage; grid instability results are not yet available. Further analysis is planned which may modify the results slightly, but the basic conclusions are not expected to change.

The data base consists of Test Van data collected at the five airports. The total number of sites for each airport is given in Table 3. A three-step editing procedure is adopted. First, the receiver mode indicator is checked for normal signal tracking. Most of the data edited in this manner are associated with low SNR for the Caribou (W) signal at Philadelphia and Columbus. Second, the measured TD is compared to a predicted TD, to detect cycle slips. Little data is edited in this manner, because of the effort made in the field to prevent cycle slippage. Finally, to detect outliers, the measured TD is compared to a ± 0.1 μsec tolerance band centered on the site-averaged TD. Typically, this last operation results in editing of less than 5% of the TD samples.

The editing procedure is implemented in an automated Loran-C Data Management System. Edited data are flagged, rather than deleted from the data base, making it possible to focus on the "bad" data if desired.

TABLE 3

TEST VAN DATA INVENTORY

AIRPORT	NUMBER OF SITES
Atlantic City	28
Philadelphia	18
Columbus	29
Worcester	31
Rutland	20

Site Coordinates

Only the Test Van sites at Atlantic City have been surveyed to date. The Atlantic City site coordinates were obtained by triangulation, with a quoted error of less than 10 m rms. For preliminary analysis purposes, site coordinates for the other four airports are obtained from USGS topographic maps. Based on the resolution of these maps and discussions with USGS personnel, the map coordinates are expected to be accurate to 100 m rms. Comparisons to the AC-90-45A requirement (300 m rms) can, therefore, be made with confidence. The results herein will be refined when surveyed coordinates become available.

Data Analysis Approach

The grid warpage data analysis approach is outlined in Fig. 6. TD residuals are first computed as the differences between the measured TDs and those predicted by a baseline coordinate-conversion model. The baseline model accounts for the published emission delay and for signal propagation in a standard atmosphere (refractive index = 1.000338). It is the simplest model implemented in receivers, and yields what is referred to as "uncompensated" Loran-C. The analysis methodology is repeated for more complex models.

TD residuals for the selected Loran-C station triad are next transformed to north and east position errors. This transformation accounts for the site/station geometry. The north and east position errors are then resolved into along-track and cross-track navigation errors. This is accomplished by associating each Test Van site with an

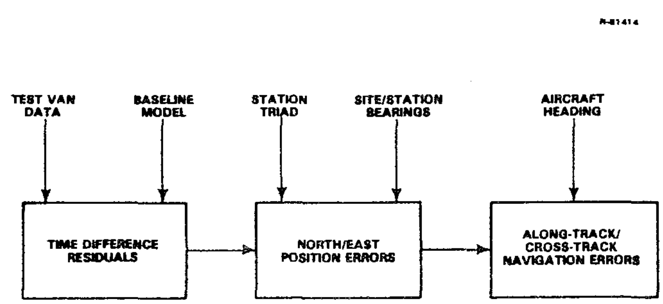


Figure 6 Grid Warpage Data Analysis Approach

airport radial and equating the radial with an aircraft approach. Navigation errors so computed only include coordinate conversion errors. Error contributions due to aircraft dynamics and piloting are not measured in the tests.

Dominance of Loran-C Bias

Selected test results for Atlantic City are presented first, to illustrate a property common to all five airports: dominance of the Loran-C bias. The results in this section pertain to uncompensated Loran-C.

A useful description of grid warpage is obtained by plotting the TD residuals against range difference, i.e., the site-to-secondary range minus site-to-master range. Such plots are presented for Atlantic City TDX and TDY residuals in Fig. 7. Each plot symbol is the 30-min mean for one site. The dominant warpage component is typically a bias, as is the case for TDX. The bias is negligible for TDY at Atlantic City, i.e., the "random" warpage component dominates in this case.

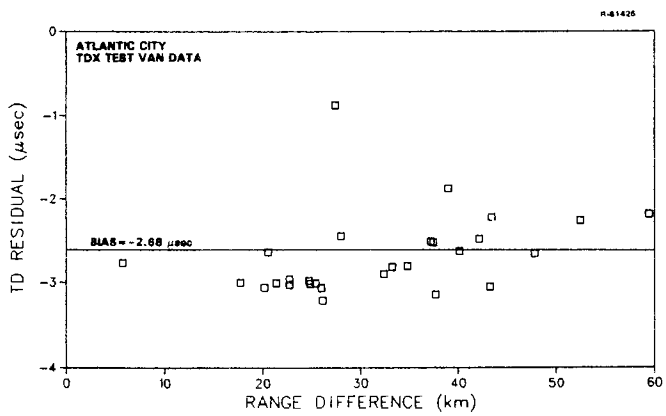
Seneca/Nantucket/Carolina Beach (MXY) is the primary station triad for Atlantic City, based on geometry and SNR considerations. When a position fix is computed from TDX and TDY, the resulting error is approximately 700 m in the westerly direction. This is illustrated by plotting the Loran-C errors as vectors on a background map of the airport approach area (see Fig. 8). The "tail" of each vector is positioned at a test site; the vector indicates the magnitude and direction of the Loran-C error. The vectors and airport map are scaled differently for clarity. The consistency of the vectors for different sites indicates that the bias dominates.

Along-track and cross-track navigation errors for Atlantic City are plotted against aircraft heading in Fig. 9. The relationships would be sinusoidal for a pure bias. For example, the along-track error is nearly zero for north/south headings (0 deg/180 deg), because flight is perpendicular to the westerly bias. In contrast, along-track error is a maximum for east/west headings (90 deg/270 deg). The relationship for cross-track error is analogous, but shifted 90 deg.

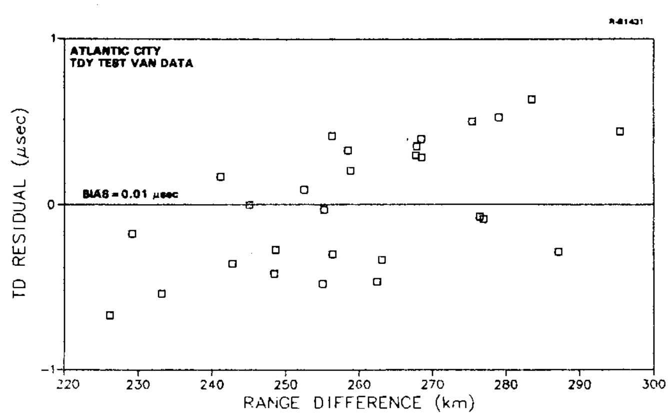
Comparison to AC-90-45A Requirements

Position error vector maps are presented in Fig. 10 for the other four airports, again for uncompensated Loran-C. The maps apply to the primary triad: MXY for Philadelphia, MYZ for Columbus, and MWX for Worcester and Rutland. The biases for Atlantic City and Philadelphia are similar in magnitude and direction -- an intuitive result, given the proximity of these airports. However, airport proximity does not guarantee similar biases. This is illustrated by the biases for Worcester (600 m) and Rutland (300 m), which are only 200 km apart. A few of the vectors in Fig. 10 do not fit the bias patterns. These are explained by errors in the coordinates of sites which are not easily pinpointed on the USGS maps.

Along-track and cross-track errors must be less than 300 m rms to satisfy the AC-90-45A



a) TDX



b) TDY

Figure 7 TD Residuals for Atlantic City for Uncompensated Loran-C

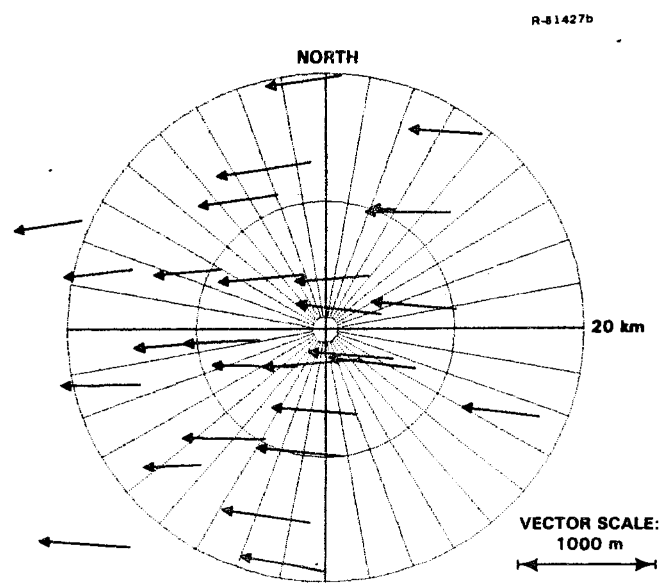
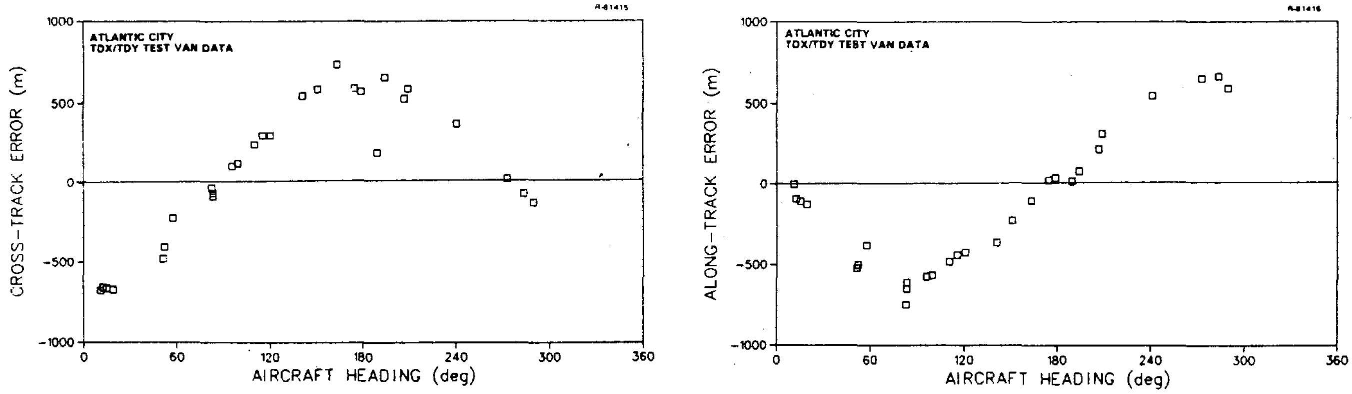


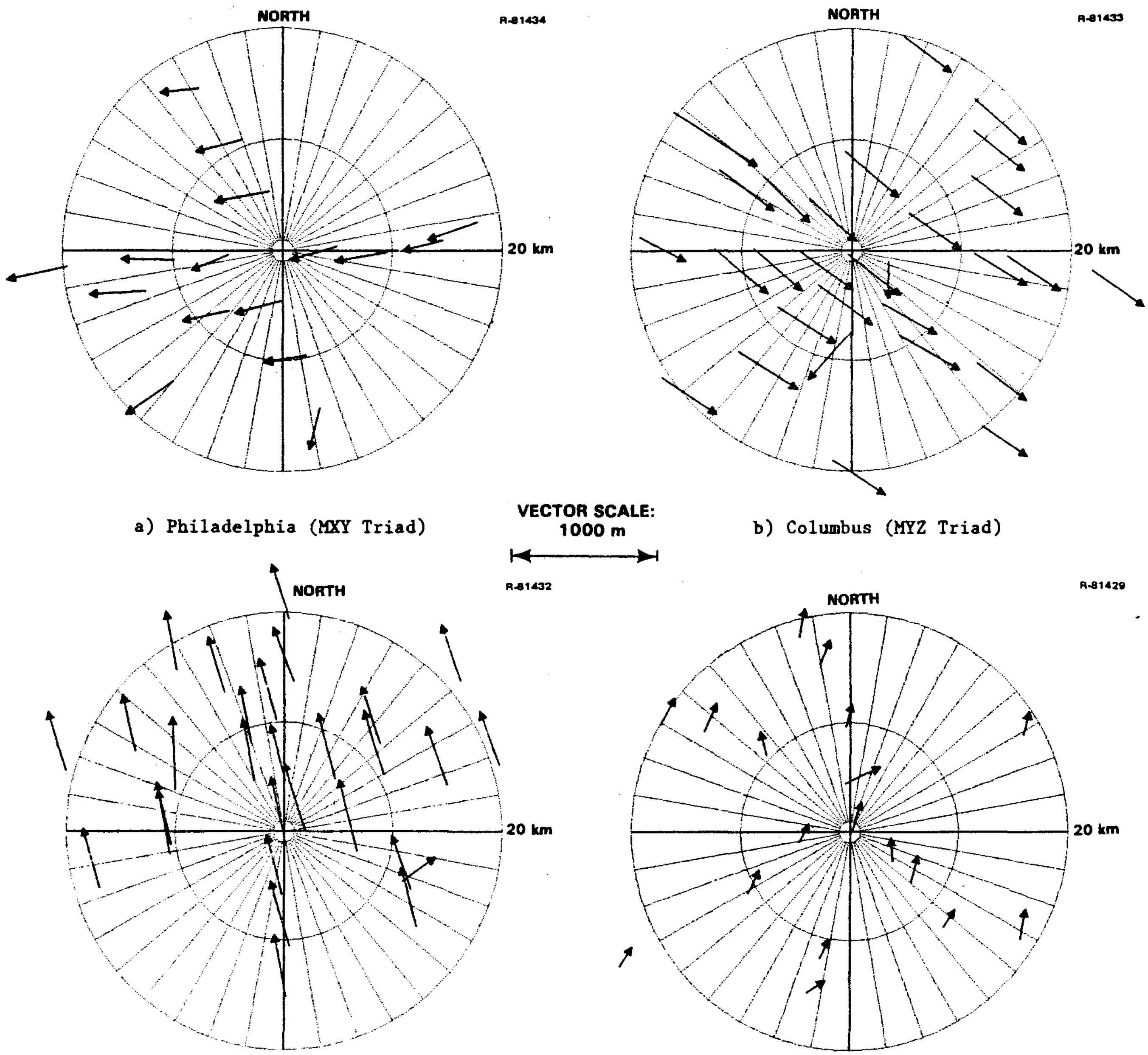
Figure 8 Uncompensated Loran-C Errors for Atlantic City for MXY Triad



a) Along-Track

b) Cross-Track

Figure 9 Uncompensated Navigation Errors for Atlantic City for MXY Triad



a) Philadelphia (MXY Triad)

b) Columbus (MYZ Triad)

c) Worcester (MWX Triad)

d) Rutland (MWX Triad)

Figure 10 Uncompensated Loran-C Errors for Primary Triad requirement. The error averaging implied by the "rms" is performed over the entire aircraft approach path. For bias errors, the rms error is the bias itself. Along-track errors and/or cross-track errors exceed 300 m for all runway headings at the Atlantic City, Philadelphia, Columbus, and Worcester airports. Errors for the Atlantic City runways, for example, are as large as 700 m (see Table 4). Rutland is the only airport tested where the AC-90-45A requirement is met. All Rutland runways satisfy the requirement (see Table 5). This result is consistent with Loran-C flight tests conducted by TSC in Vermont (Ref. 3). The fact that the AC-90-45A requirement is only met at one of the five airports tested illustrates an important point: Loran-C system accuracy is not uniform throughout the chain coverage area.

Advantage of Bias Removal

The Loran-C bias can be measured by locating a receiver at a known airport location. Bias corrections could be furnished to the airborne receiver in the form of a table. If the bias varies with time, the table may have to be updated periodically, e.g., seasonally. If the table is updated continuously over a telemetry link, the result is differential Loran-C.

TABLE 4

UNCOMPENSATED LORAN-C ERRORS FOR ATLANTIC CITY RUNWAYS

RUNWAY	ALONG-TRACK ERROR (m)	CROSS-TRACK ERROR (m)
4	-300	-500
8	-700	0
13	-500	+400
17	-100	+700
22	+300	+500
26	+500	+200
31	+500	-300
35	+100	-700

TABLE 5

UNCOMPENSATED LORAN-C ERRORS FOR RUTLAND RUNWAYS

RUNWAY	ALONG-TRACK ERROR (m)	CROSS-TRACK ERROR (m)
1	+200	+100
13	-100	-300
19	-200	0
31	+100	+200

The advantage of removing the bias by measurement/correction is shown in Fig. 11 for the primary triad. The rms cross-track error is plotted for two cases: 1) where the bias is uncompensated; and 2) with the bias removed. Here, the averaging implied by the "rms" is over all headings (0 deg to 360 deg). The choice of "rms cross-track error" as a statistic is motivated by the desire to

- Assign a single performance index to each airport
- Factor in all headings, not just runways
- Average out large errors only observed at a few sites.

The rms cross-track error tends to approximate the maximum cross-track error (over all headings) which would remain after deleting "odd" data. The index can be compared directly to the AC-90-45A requirement, with appropriate caveats.

The results in Fig. 11 indicate that the AC-90-45A requirement is met at all five airports, if the bias is removed by measurement. If the bia is stable, the necessary measurements could be obtained during certification of Loran-C approaches. Therefore, bias measurement appears to be a feasible method of compensating Loran-C to satisfy non-precision approach accuracy requirements.

Alternative Triads

Flight safety margins will likely dictate that AC-90-45A requirements must be satisfied for at least two triads. If the primary triad is not operational because of a station failure, an alternative triad could then be used in its place. Only triads which include the master station are considered here. Additional station combinations are made possible by master-independent receivers.

Figure 12 shows rms cross-track errors for the six master-dependent triads, for uncompensated Loran-C. The AC-90-45A requirement for non-precision approach is not met for multiple triads at any of the five airports. The MWY triad satisfies the AC-90-45A requirement for Worcester, even though the primary triad (MWX) does not satisfy the requirement. This demonstrates that grid warpage can negate good geometry. Also note that the primary triad is the only acceptable triad at Rutland.

Although the FAATC tests concentrate on non-precision approach, it is interesting to compare the results in Fig. 12 to terminal and enroute accuracy requirements (1000 m and 1400 m rms, respectively). Not surprisingly, uncompensated Loran-C satisfies these requirements for two or more triads at all five airports.

Loran-C performance for alternative triads, for the case where the bias is removed, is shown in Fig. 13. Three or more triads at each airport satisfy the non-precision approach requirement in this case. Therefore, bias removal not only brings the primary triad within AC-90-45A requirements, but also provides needed redundancy.

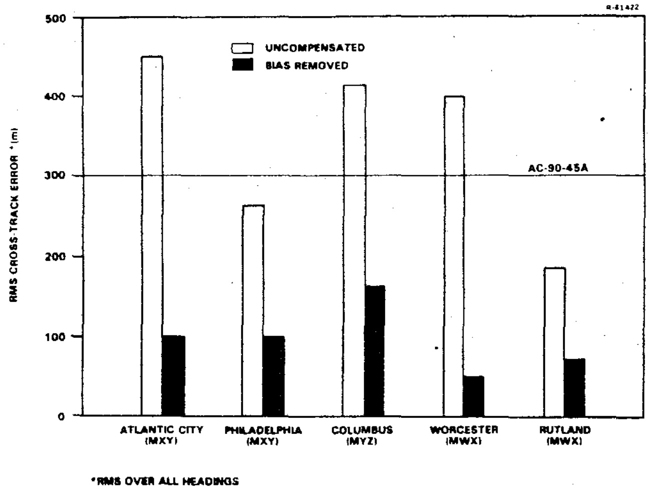


Figure 11 Advantage of Bias Removal

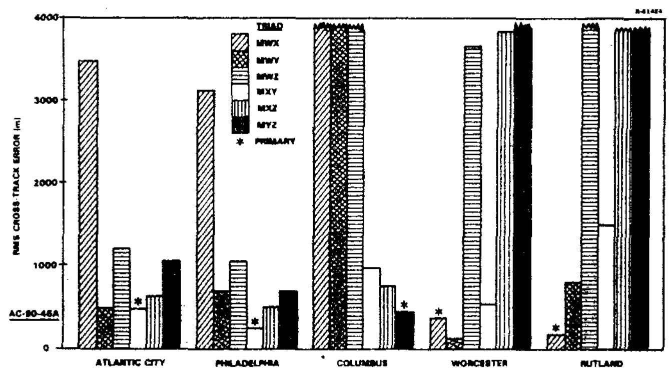


Figure 12 Comparison of Alternative Triads: Uncompensated Loran-C

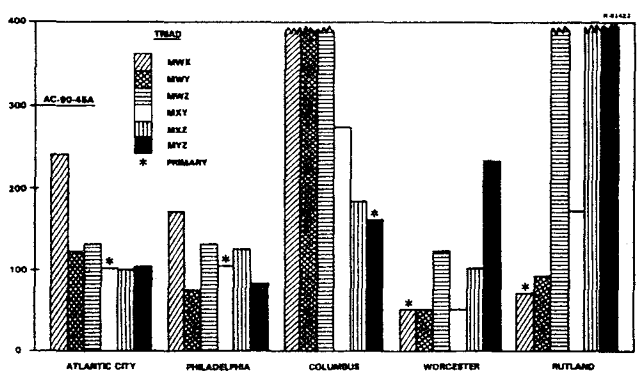


Figure 13 Comparison of Alternative Triads: Bias Removed

Coordinate Conversion Models

The baseline coordinate conversion model assumed for uncompensated Loran-C can be refined to reduce the bias. The objective is to eliminate the need for bias measurement by placing an increased burden on the airborne receiver software.

Candidate coordinate conversion models are described in Table 6. Recall that the baseline model assumes a standard atmosphere, the Earth's presence being ignored. The sea model assumes that the paths are all sea water, while the land model assumes they are all average land with a conductivity of 0.003 mho/m. The sea and land models are simple extensions of the baseline model, involving nonlinear functions of range. The nonlinear functions can be represented by polynomials, but are often implemented as linear approximations.

The mixed model is based on a path approximation consisting of segments of all sea water and all average land. Millington's method is used to compute the signal propagation delay along the mixed path (Ref. 8). Receiver implementation of the mixed model would require storage of the digitized coastline.

Loran-C chart production is conducted by the Defense Mapping Agency (DMA) Hydrographic/Topographic Center. The DMA model employs Millington's method on a five-level conductivity map. Implementation in a receiver would require storage of the digitized map. Although currently implemented in very few receivers, coordinate conversion models based on conductivity maps are not a serious burden on microprocessor storage capacity.

Each coordinate conversion model is evaluated using the data analysis approach outlined previously in Fig. 6. The number of triads which satisfy the AC-90-45A requirement is given in Table 7, for each model and each airport. The mixed model is the only model evaluated which results in more than one acceptable triad at every airport. The poor performance of the DMA model at Columbus and Rutland may be a result of DMA calibrating their conductivity map with Coastal Confluence Zone data. The DMA model may out-perform the mixed model at these airports, if a theoretical conductivity map is instead used.

Despite the apparent excellent performance of the mixed model, examination of the TD residuals reveals that none of the coordinate conversion

TABLE 6

CANDIDATE COORDINATE CONVERSION MODELS

MODEL	ASSUMED PATH PROPERTIES	COMPLEXITY
Baseline	Standard Atmosphere; Earth's Presence Ignored	Low
Sea	All Sea Water (Conductivity = 5 mho/m)	Low
Land	All Average Land (Conductivity = 0.003 mho/m)	Low
Mixed	Segments of All Sea Water and All Average Land; Millington's Method Used	Medium
DMA	Segments Defined by Five-Level DMA Conductivity Map; Millington's Method Used	High

TABLE 7

COORDINATE CONVERSION MODEL PERFORMANCE

AIRPORT	NUMBER OF ACCEPTABLE TRIADS*				
	BASELINE	SEA	LAND	MIXED	DMA
Atlantic City	0	1	3	5	5
Philadelphia	1	3	4	6	5
Columbus	0	3	1	3	1
Worcester	1	3	3	3	3
Rutland	1	1	3	3	1

*Based on comparison of rms cross-track error to AC-90-45A requirement.

models is a consistent predictor. The models would likely have to be validated at every airport, an effort equivalent to measuring the bias at every airport. Nevertheless, it is still possible that a validated model may be more attractive to implement in a receiver than a table of biases.

CONCLUSIONS

The FAATC ground test program described herein will provide a definitive assessment of the impact of Loran-C grid instability and warpage on non-precision approach aircraft navigation accuracy. The following conclusions are drawn from preliminary analysis of the grid warpage data:

1) The dominant grid warpage component is the Loran-C bias

2) AC-90-45A requirements are not met by uncompensated Loran-C at four of the five airports tested

3) AC-90-45A requirements are met for three or more triads at all five airports, if the Loran-C bias is measured and removed

4) A coordinate conversion model accounting for land/sea path segments satisfies AC-90-45A for three or more triads at all five airports.

Therefore, preliminary results indicate that grid warpage errors can be reduced to acceptable levels for non-precision approach, by bias measurement or mixed-path modeling. An assessment of grid instability and an update of the grid warpage results will be available at the conclusion of the tests.

ACKNOWLEDGMENT

This work is sponsored by the FAA Systems Research and Development Service, under Contract No. DTFA01-81-C-10031. The contract monitor is Mr. George Quinn. Three employees of The Analytic Sciences Corporation have been instrumental in the effort: Mr. Ronald S. Warren, program manager; Mr. Edward A. Schoen, prior project leader; and Mr. Peter G. Clark, software analyst. Three FAATC technicians have contributed to various aspects of test operations: Howard Meeks, Thomas Wisser, and William Yost. The cooperation of Mr. Bud Swartwood of DMA in furnishing their TD model predictions is also appreciated.

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DETERMINATION OF LORAN OVERLAND PHASE SHIFT MEASUREMENTS

Alan H. Phillips
Sperry
Systems Management
Great Neck, NY 11020

ABSTRACT

The Loran signal, in propagating over a mixed land and sea-water path, experiences a greater phase shift than it would experience in propagation over an all-water path. This added "overland phase shift" must be compensated for or it will result in errors in the Loran computed position. At present, compensation is made by use of overland phase shift charts calculated by the Defense Mapping Agency (DMA) from best available data.

One of the tasks in the Improved Accuracy Program is the validation of the Loran error model. In order to accomplish this, measurements were made of overland phase shifts off the coast of Southern Italy to determine the accuracy of the DMA charts. These measurements were conducted with the assistance of the U.S. Coast Guard and DMA, and are unique in terms of the realized measurement accuracy and data density. In some cases, considerable discrepancies were found between measurements and the existing charts.

Measurements were also made of the relationship between Loran signal phase and bearing from the transmitting antenna. (Previous measurements had raised suspicions that phase was dependent on bearing.) Phase was found to have little or no dependence on bearing.

Alan Phillips

An additional byproduct of the measurement program was the assessment of the accuracy of the Loran network calibration. This assessment revealed a significant error in the X secondary station emission delay in the Mediterranean net.

BIOGRAPHICAL SKETCH

Alan H. Phillips received a BS degree in Physics from Illinois Institute of Technology in 1949, and a MS degree in Physics from the University of Illinois in 1950. He joined Sperry Gyroscope Company in 1953 to work on CYTAC, forerunner to Loran-C. He was involved with development of the first transistorized Loran-C receiver, and with the earliest digital Loran-C receiver. Mr. Phillips holds three patents and has written technical articles for "Electronics, Electronics Design, Sperry Engineering Review," and for the "Sylvania Technologist."

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by

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Abstract

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Theory of Measurement

Measured Loran arrival times must be corrected for secondary phase shift before computation of position. This is done in two steps in Sperry Systems Management's (SSM) position fix program. The position fix algorithm first calculates a secondary phase shift, assuming an all sea-water path, and corrects the arrival times. An additional correction is inserted by the operator based on charts or tables issued by the Defense Mapping Agency (DMA). SSM calls this additional correction the "Overland Phase Shift;" the U.S. Coast Guard refers to it as the "Additional Secondary Factor;" DMA refers to it as the "Rho-Rho Phase Correction." The correction can amount to more than a microsecond, and must be accurately known if an accurate position fix is to be determined.

DMA calculates the correction using Pressey's Method* based on ground conductivities furnished by the U.S. Coast Guard. The U.S. Coast Guard deduces these conductivities from time differences measured by a mobile monitor receiver at surveyed land positions.

SSM, under contract** to the U.S. Navy Strategic Systems Projects Office, and with the cooperation of the Coast Guard and DMA, conducted tests off the Southern Italian peninsula to test the validity of the present overland phase correction. Data were collected at sea at a very high density and with extremely accurate positioning equipment. This allows predictions of overland correction without requiring extrapolation from data collected ashore. This technique allows a much more accurate determination of overland correction than using only the land-based data. The ship, AG-153, followed the tracks shown in Figure 1. Measurement was made of Loran arrival time, and the ship's position was determined simultaneously by the Autotape. Autotape is a microwave range-range system having a position fixing accuracy of 1-2 meters.

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*Pressey's method is used to calculate secondary phase shift over a path having varying ground conductivity. It is analogous to Millington's method (which is used to calculate the attenuation of a signal over a path of varying ground conductivity). In it, the phase shift of each segment is first calcualted using classical theory and the total phase shift evaluated by summing them. The transmitter and receiver are then interchanged and the total phase shift, again, is summed. The true phase shift is the arithmetic mean of these two total phase shifts.

**Strategic Systems Project Office. Contract N00030-80-C-0072 to Sperry Corporation.

The Loran receiver used a Hewlett Packard cesium frequency standard as the timing reference. The overland phase shift was determined from the following equations.

$$MAT - CAT = OLP + CSE \qquad (1)$$

MAT is measured arrival time

CAT is computed arrival time, assuming all-water path

OLP is overland phase shift

CSE is cesium standard timing error

The cesium standard timing error is expressible by the following equation:

$$CSE = a + b\ (t - t_o) \qquad (2)$$

t is time

t_o is a reference time

a and b are constants determined by measuring the Loran arrival time at two different times over an all-water path.

Autotape System Description

The Autotape system consists of an interrogator and receiver on board the ship, and two responders at carefully surveyed sites. The time delay between the interrogating signal and the response is proportional to the range to the responder. Range measurements to two responders are sufficient to determine the ship's position. Figure 1 shows the location of the responder sites. The accuracy of the site survey was on the order of a few meters.

Before the tests a reconnaissance was made of the area to select the sites. The first sites selected, Mont Alto (6400 ft. high) and Mont Pecoraro (4700 ft. high) were unsatisfactory. Mont Alto (Figure 2) had 8 feet of snow at the end of March; similar conditions were expected at the end of October. Mt. Pecoraro turned out to be a series of minor peaks, none of which had a clear view of both sides of the peninsula.

Consequently, four sites (Charlie, Bravo, Foxtrot, and Echo in Figure 1) were selected; two for operations off the east coast and two for operations off the west coast.

Before this main test, a preliminary test had been made in July 1978 to determine whether Autotape reception would be adequate and to determine the locations of null zones. The Autotape responders were set up at the proposed sites, and a small boat was run through the planned test areas. Autotape reception proved to be adequate. During the main test the responder sites were manned around the clock.

Shipboard Installation

A BRN-5 Loran receiver measured the arrival times once per minute, and these were recorded digitally. Three cesium standards were installed onboard the ship. If the on-line standard had changed frequency, it would have been detected, and could have been compensated for. Autotape ranges were recorded once per second.

Conduct of Test

The test, off the Italian Coast, was conducted October 24-30, 1978. It was conducted 24 hours per day during this period.

The responders had 60° beamwidth. It was therefore necessary to rotate the responder antennas occasionally in order to maximize the return signals. The interrogator on the ship had a meter indicating the strength of the return from the responder. The ship was in constant communication with the responders.

The Autotape signals occasionally disappeared for reasons not completely understood. One case of the signal drop-out was interference between the signal reflected from the water and the direct signal. The normal Autotape antenna was an omnidirectional antenna at the top of one of the masts of the ship. A directional antenna and a second omnidirectional antenna were installed at deck level. One of these sometimes produced a useable signal when the higher antenna would not.

"Sunny Italy" was not a very apt description of the autotape sites in late October. Weather conditions were unfavorable. Freezing rain was encountered at times, which increased the difficulty of manning the responders. Fortunately, it was necessary to man only two of the four responders at any one time.

A small area off the east coast was within range of two Autotape stations, and had all water paths to both the Master and Lampedusa signals. This provided an accurate measurement of station emission delay. For some of the data of this test, a site on top of Mont Alto (highest point in southern Italy) was used. However, Autotape data from the lower site (see map) turned out to be better. (Before running the test there had been a question of whether the lower site would be within range.)

There was no Autotape coverage in the vicinity of the Straits of Messina (mountains blocked the signal from "Foxtrot"), consequently there is a 40° sector missing in the Master overland phase shift.

A power outage occurred prior to the third passage of the Straits. The cesium standard timing error (a in Equation 2) therefore had to be redetermined, and no tie-in between data taken before and after the power outage was possible. There was sufficient data, however, to determine the overland phase shift accurately. The cesium standard did not lose power since a backup battery was automatically switched in; its frequency was unaffected.

Results: Off Italian Coast

Figure 3 is a plot of measured overland phase shift and DMA charted values. Overland phase shift is plotted against bearing angle. For these tests, overland phase shift had very little dependence on anything except bearing angle. Note the large discrepancy between measured and charted overland phase shift. Figure 4 is a similar plot of overland phase shift for the Lampedusa station over Sicily. Agreement between measured and charted values, in this case, is better.

The quality of the data collected was good, but not as good as expected considering the excellent signal-to-noise ratio. A portion of the random error is believed to be due to random phase shifts in the transmitters. In any case, enough data was taken to reduce the random errors by averaging. From the scatter of the individual points of the Figure 3 plot it was concluded that the accuracy of overland phase shift determination was on the order of 10 nanoseconds.

The value of overland phase shift depends, to some extent, on what is assumed for the secondary phase shift of the all-water path. The secondary phase for the all-water path was calculated in accordance with NBS Report 573. Since the salt water paths were short, any error due to deviation from NBS Report 573 is not great.

These measurements can be used to determine overland phase shifts at other points in the service area (i.e., the overland phase shift for all points on a radial from the transmitter can be determined from data taken at one point using Pressey's method). Different ground conductives are assumed, and Pressey's method is used to calculate the resulting overland phase shift. By trial and error, a ground conductivity is found which leads to the observed overland phase shift. This conductivity is used to determine the secondary phase shift for all points on the radial. As an alternative to Pressey's method, the integral equation method* can be used.

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*The integral equation method [1, 2] is a means of computing the secondary phase shift for signal propagation over irregular terrain, knowing the "electromagnet impedence" of the terrain. By trial and error, the "Impedence" can be found which yields the observed secondary phase shift.

Analysis of the all-water path measurements indicated an emission delay of 12755.61 μsec, 0.35 μsec less than the published value. The published value was based on baseline extension measurement of coding delay. The emission delay is equal to the delay on the baseline extension plus the calculated propagation time along the master-slave baseline. Since the baseline includes 132 miles of mountainous terrain, the calculated baseline propagation time was not very reliable. The emission delay was thus not very reliable.

A second determination of emission delay was made during the later test around Lampedusa (called the X station). This confirmed the above numbers.

Results: Around Lampedusa

The purpose of the Lampedusa tests was to see if the transmitting antenna caused a directionally dependent phase shift. Previous data, taken in the Mediterranean, had shown anomalous phase shifts which might have been explained by such an antenna effect.

The test required only a single Autotape responder close to the Loran transmitting antenna. Simultaneous measurements were taken of Autotape range and Loran arrival time as the ship circumnavigated Lampedusa. A variation in the difference between the computed and measured propagation time would indicate the postulated antenna effect.

Since it was necessary to displace the Autotape responder from the Loran antenna, the Autotape range was not exactly equal to the range to the Loran antenna. Knowing the approximate ship's position, it was possible to correct the Autotape range measurement (see Figure 5). Variation in difference between measured and computed arrival times were small, and most of it was explainable by variations in the overland path over the small island. No significant variation in antenna phase with direction was observed.

It was possible to make a second determination of X emission delay. This was done as follows. The time of arrival was measured in the vicinity of the X station. Knowing the distance from the station, the emission time (with respect to the receiver's cesium standard) was determined. The Master time of arrival had previously been determined when in the vicinity of the Master station. Knowing the distance from the Master station at that time, the Master emission time was determined. The difference between these emission times was the X emission delay. (This difference was also corrected for the known drift of the Loran receiver's cesium standard.) The X emission delay determined in this way agreed with the emission delay previously determined within 0.01 μsec.

Conclusions

Measurements have been made of Overland Phase Shifts in the Mediterranean. These measurements show that the charted Master Overland Phase Shift has considerable error. The charted X secondary station Overland Phase Shift agrees fairly well with measurements. Overland phase shift charts could be improved if use were made of these measurements.

The Mediterranean X emission delay was measured and found to be 0.35 sec less than the published value.

Measurements were made of the variations of signal phase with direction from the Lampedusa transmitting antenna, and it was concluded that transmitting antennas do not cause a directionally dependent phase shift.

Acknowledgement

The success of these tests is due in no small part to the untiring efforts of Mr. Earl Matchett of SSM who managed the Autotape responder installation and conducted Autotape operations.

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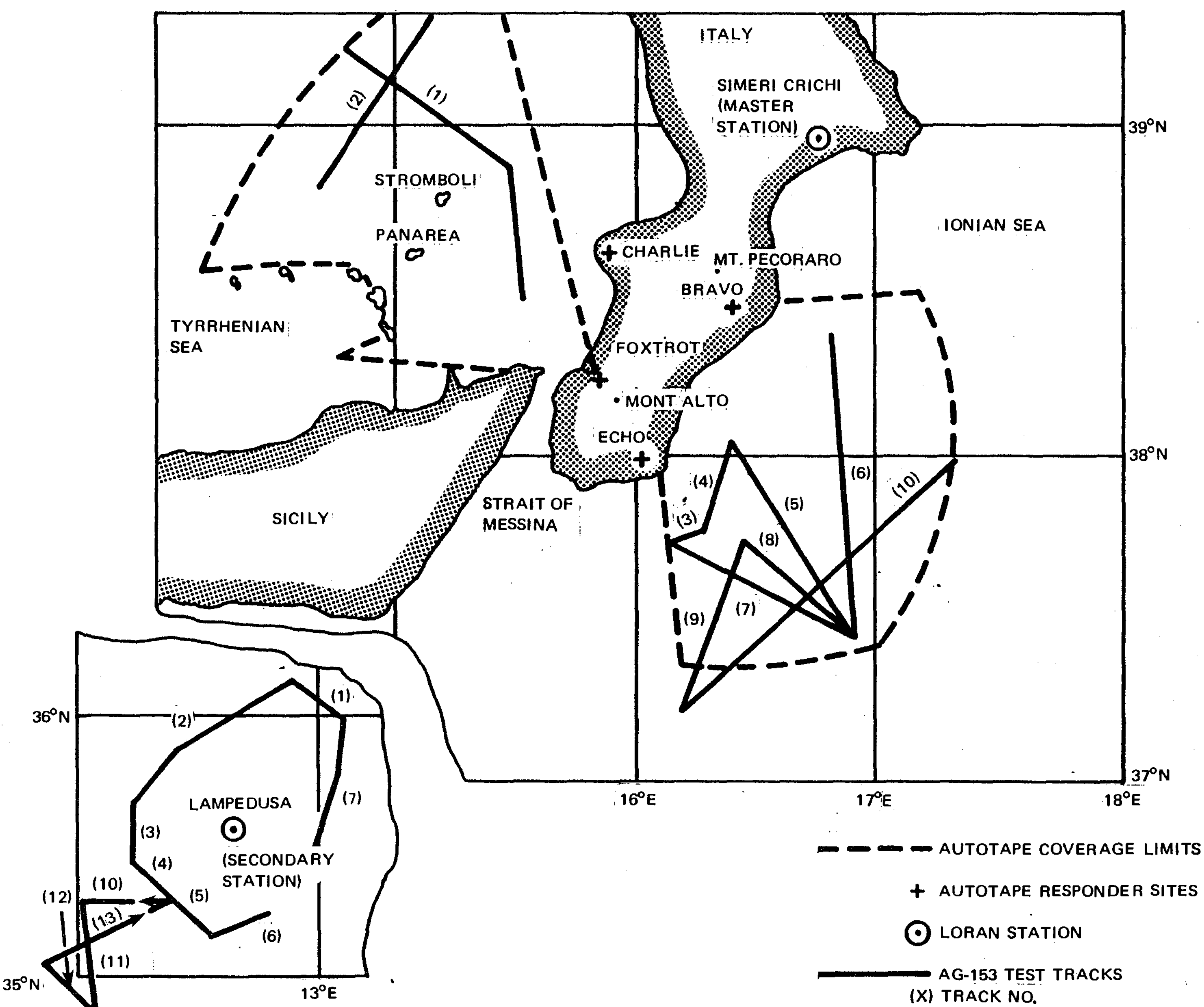

Figure 1. Loran Secondary Phase Correction Tests

Figure 2. Photographs at Summit of Mont Alto

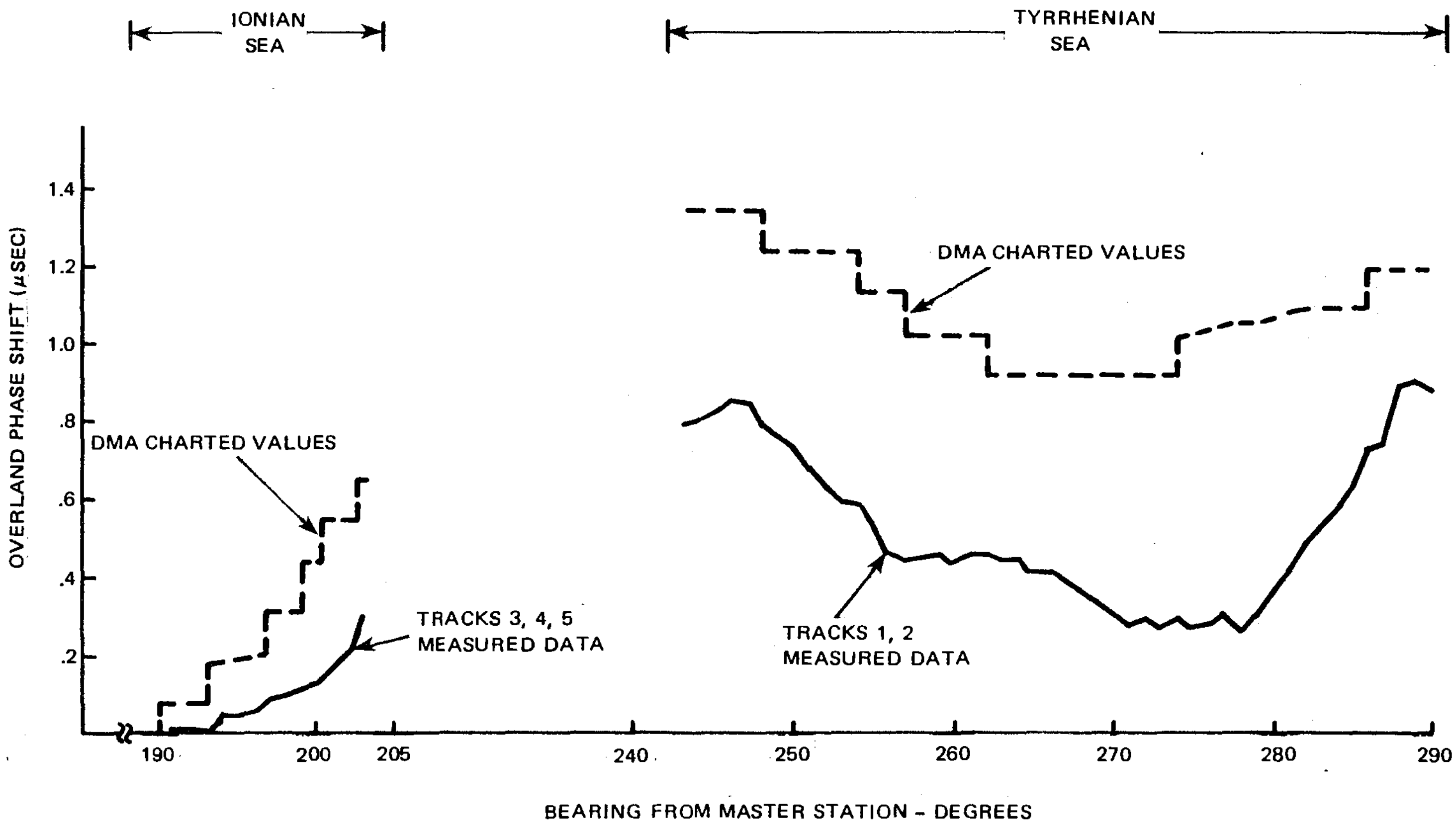

Figure 3. Master Station Overland Phase Shift

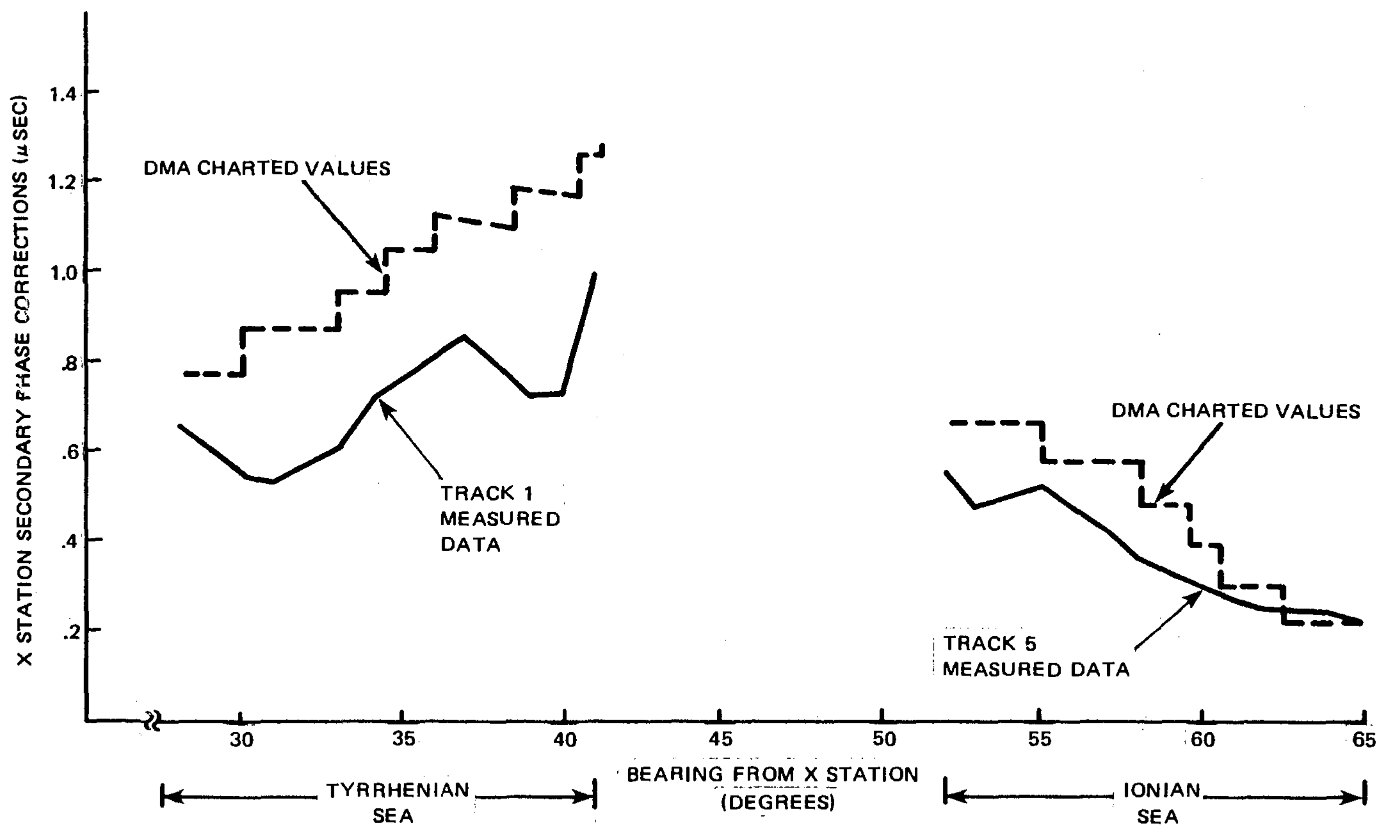

Figure 4. Lampedusa (X) Station Overland Phase Shift

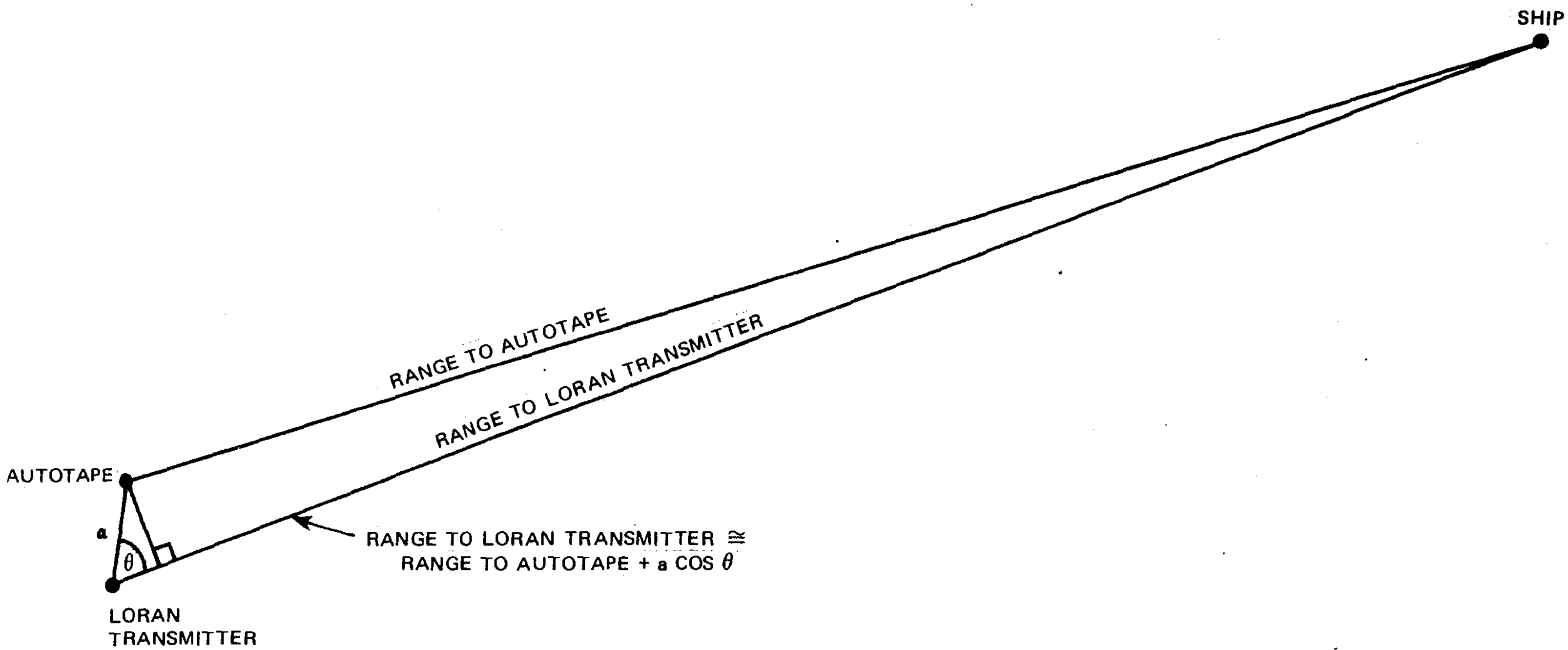

Figure 5. Autotape Range Measurement

LITERATURE REVIEW OF LORAN-C GRID STABILITY AND WARPAGE TESTS

P. M. Creamer and L. M. DePalma
The Analytic Sciences Corporation
One Jacob Way
Reading, Massachusetts 01867

ABSTRACT

The Federal Aviation Administration (FAA) is conducting Loran-C tests to assess the impact of Time Difference (TD) grid instability and warpage on aircraft navigation accuracy. In support of this effort, a literature review was conducted to summarize previous tests dealing with temporal and spatial propagation issues. The literature review is presented in a slide format. Two slides are given for each Loran-C test: first, a summary of the test scenario, including site locations and sampling rates, and second, the reviewers' interpretation of the most important results. Stability results are generally summarized in a TD time series plot, while warpage results are given by a TD contour map. The material is not intended to provide an exhaustive summary of each test, but serves as a convenient reference to past work and a stimulus for future research. By analyzing current test results in the context of past results, inconsistencies can be addressed and a more unified stability/warpage "picture" will emerge. (Supported under Contract No. DTFA01-81-C-10031.)

BIOGRAPHICAL SKETCHES

(See first paper in this session)

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INTRODUCTION

The Federal Aviation Administration (FAA) is conducting Loran-C tests to provide a decision data base for execution of the Federal Radionavigation Plan (Ref. 1). The tests are designed to measure the Loran-C navigation errors associated with signal propagation uncertainties (Ref. 2). A literature review of past Loran-C propagation tests has been performed in conjunction with the FAA tests. The past test results provide a baseline for comparison to the current FAA test results and for isolation of possible inconsistencies. The literature review is a convenient summary for others planning Loran-C tests or using Loran-C for high-accuracy applications. It is a necessary step in development of a unified "picture" of propagation errors.

Loran-C system accuracy is limited by the accuracy of the Time Difference (TD)-to-position coordinate conversion, which is in turn limited by propagation uncertainties. Propagation errors are comprised of two components:

- Grid instability -- temporal TD variations at a fixed location
- Grid warpage -- spatial TD variations at a fixed time.

Grid instability governs repeatable accuracy, while grid warpage governs absolute accuracy. User compensation of instability and warpage is needed to realize the maximum potential of the Loran-C system. The need for compensation has become more evident with the increased accuracy requirements imposed by applications such as harbor navigation and land vehicle routing.

Temporal grid instability includes the seasonal TD cycle, which is driven by atmospheric temperature/humidity cycles and snowfall accumulation. Additional contributors, diurnal and short-term instability, are caused by "random" phenomena such as weather-front passage. Spatial grid warpage includes the TD bias commonly encountered in local regions. Additional components of grid warpage are scale factor error (i.e., local signal propagation velocity error) and the anomalies attributed to mountains, coastlines, bridges, etc.

The literature review is presented in a slide format. The first section provides the motivation for the review. The second and third sections are devoted to temporal and spatial tests, respectively. Two slides are presented for each of the 16 tests: the first outlines the test scenario, and the second presents the reviewers' interpretation of key test results. The review is not intended to be exhaustive; the literature cited in the last section of slides should be consulted for additional information.

ACKNOWLEDGEMENT

This work was sponsored by the Federal Aviation Administration under Contract No. DTFA01-81-C-10031. The contract monitor was Mr. George Quinn of the FAA Systems Research and Development Service.

REFERENCES

1. "Federal Radionavigation Plan," U.S. Departments of Defense and Transportation, Technical Report DOD-NO.4650.4-P/DOT-TSC-RSPA-80-16, July 1980.

2. DePalma, L.M., Creamer, P.M., and Erikson, R.H., "Loran-C Grid Stability and Warpage Tests for Aircraft Navigation Accuracy Assessment," Proc. of Tenth Annual Technical Symposium of the Wild Goose Association (San Diego, CA), October 1981.

PRESENTATION OVERVIEW

- LITERATURE REVIEW MOTIVATION
- TEMPORAL LORAN-C TESTS
- SPATIAL LORAN-C TESTS
- SUMMARY
- REFERENCES

LITERATURE REVIEW MOTIVATION

LORAN-C: A HIGH-ACCURACY SYSTEM

R78222

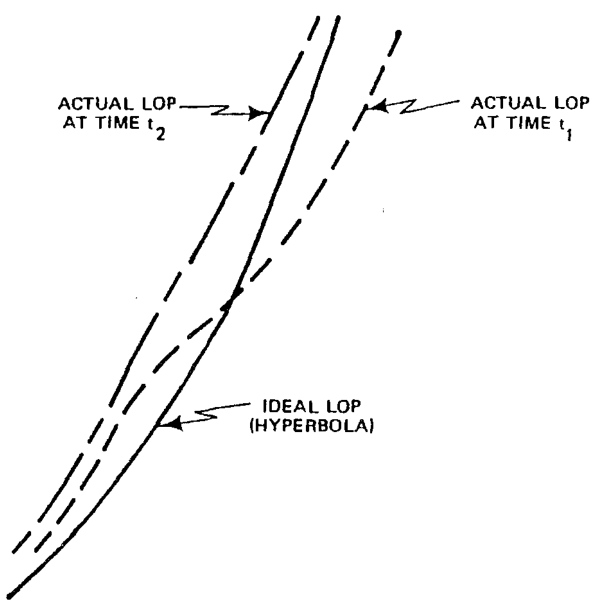
- ACCURACY REQUIREMENTS ARE INCREASING
- PROPAGATION UNCERTAINTIES LIMIT COORDINATE CONVERSION ACCURACY
- COMPENSATION MAY BE REQUIRED

USER GROUP	APPLICATION
AVIATION	AIRPORT APPROACH
MARINE	HARBOR NAVIGATION
TERRESTRIAL	VEHICLE MONITORING

TASC

PROPAGATION-RELATED LORAN-C ERRORS

TEMPORAL/SPATIAL TD GRID ERRORS

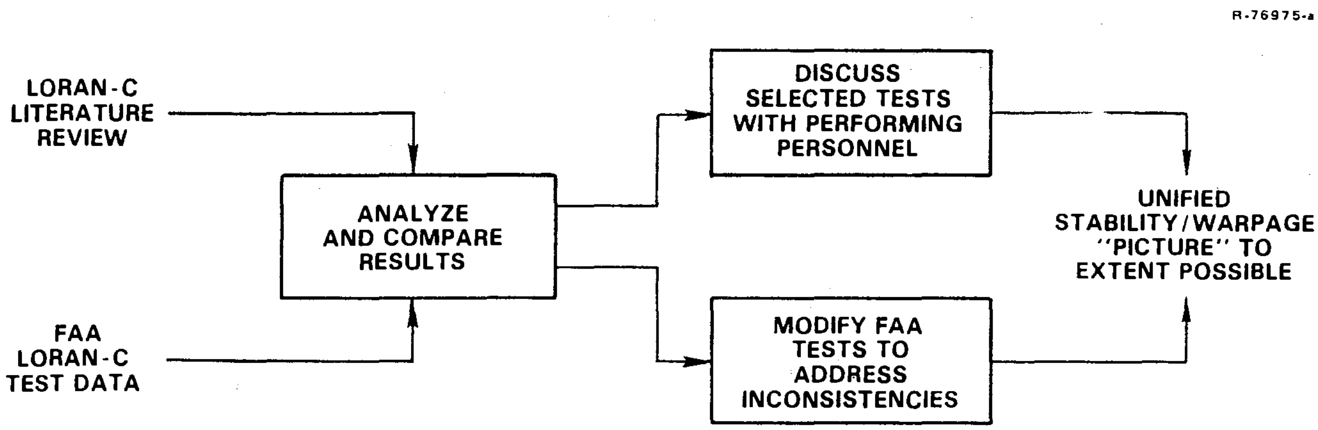


R-78186

ERROR COMPONENT	ISSUE
TEMPORAL INSTABILITY	REPEATABLE ACCURACY
SPATIAL WARPAGE	ABSOLUTE ACCURACY

TASC

LITERATURE REVIEW UTILITY DURING FAA LORAN-C TESTS



TASC

LITERATURE REVIEW BY-PRODUCTS FOR LORAN-C COMMUNITY

R78223

- SCOPE OF TESTING DURING LAST DECADE
- CONCISE SUMMARY OF TEST SCENARIOS
- EXAMPLES OF KEY TEST RESULTS
- IMPORTANCE OF PROPAGATION ERRORS
- DIALOGUE AMONG PERFORMING ORGANIZATIONS
- FURTHER RESEARCH REQUIREMENTS
- BIBLIOGRAPHY

TASC

TEMPORAL LORAN-C TESTS

TASC

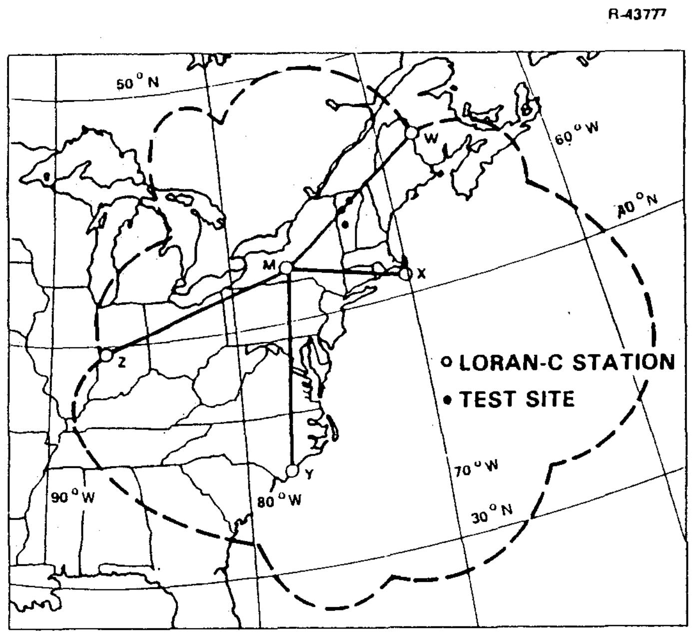
OVERVIEW OF TEMPORAL TESTS

R-70658

SPONSORING/PERFORMING ORGANIZATIONS	COMPLETION DATE	LORAN-C CHAIN	SITE LOCATIONS	NUMBER OF SITES	TEST DURATION
FAA/TSC	1980	NORTHEAST U.S.	VERMONT	3	14 mo
U.S. COAST GUARD/TASC	1980	ST. MARYS RIVER	NORTHERN MICHIGAN	3	1 yr
CANADIAN HYDROGRAPHIC SERVICE/ KAMAN TEMPO	1978	NORTHEAST U.S.	GREAT LAKES REGION	3	3 wk
U.S. COAST GUARD/KAMAN TEMPO	1978	U.S. WEST COAST	CALIFORNIA AND NEVADA	4	10 mo
U.S. COAST GUARD/MAGNAVOX	1977	U.S. EAST COAST	INDIANA, OHIO, AND WASHINGTON, D.C.	3	3 mo
U.S. COAST GUARD/INTERNAV	1973	U.S. EAST COAST	ALONG DELAWARE RIVER	8	2 mo
U.S. NAVY/SPERRY SYSTEMS MANAGEMENT	1971	U.S. EAST COAST	LORAN-C TRANSMITTERS	3	1 yr

FAA/TSC 1980 TEST SCENARIO

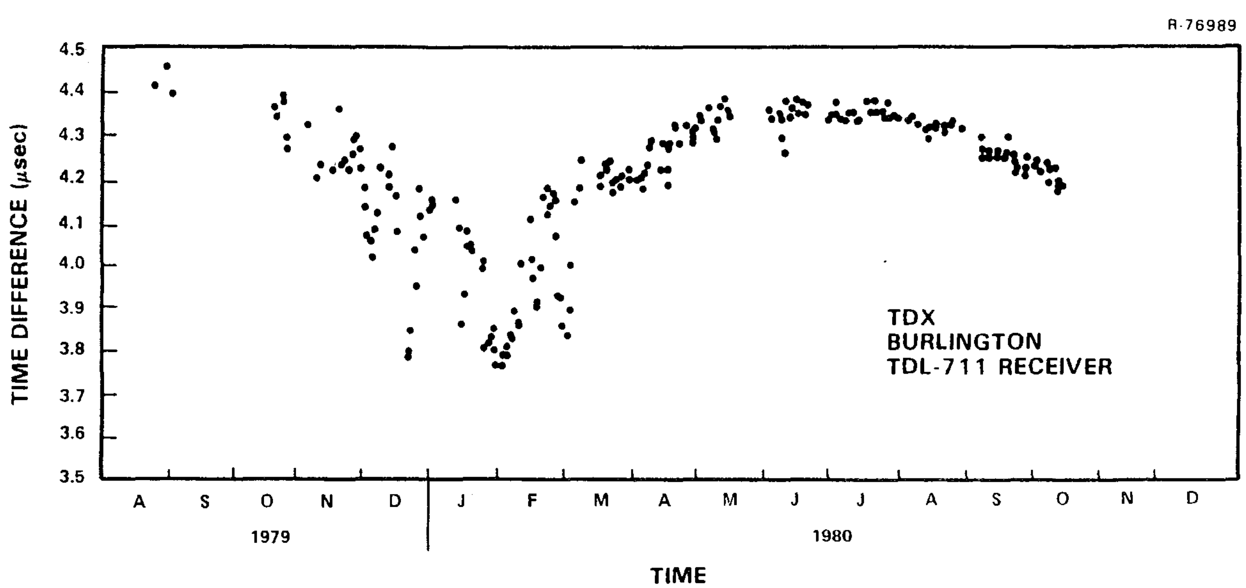
APPLICATION:	CIVIL AIRCRAFT NAVIGATION
MOTIVATION:	SEASONAL/DIURNAL VARIATIONS IN TD GRID BIAS
CHAIN:	NORTHEAST U.S.
MEASUREMENTS:	TDW, TDX, TDY
SITES:	3
LOCATION:	BURLINGTON, NEWPORT, AND RUTLAND, VERMONT
INTERVAL:	3 hr
DURATION:	AUG 1979-OCT 1980
QUALITY:	0.1 μsec



TASC
THE ANALYTIC SCIENCES CORPORATION

FAA/TSC 1980 TEST RESULTS

SEASONAL TD VARIATIONS IN VERMONT ARE
<0.8 μsec p-p AND LARGEST IN WINTER



TASC
THE ANALYTIC SCIENCES CORPORATION

U.S. COAST GUARD/TASC
1980 TEST SCENARIO

APPLICATION: ORE CARRIER NAVIGATION OF ST. MARYS RIVER

MOTIVATION: CONFIRMATION OF MONTH-TO-MONTH TD VARIATIONS

CHAIN: ST. MARYS RIVER (MODIFIED)

MEASUREMENTS: TDX, TDY, TDZ

SITES: 3 + SAM

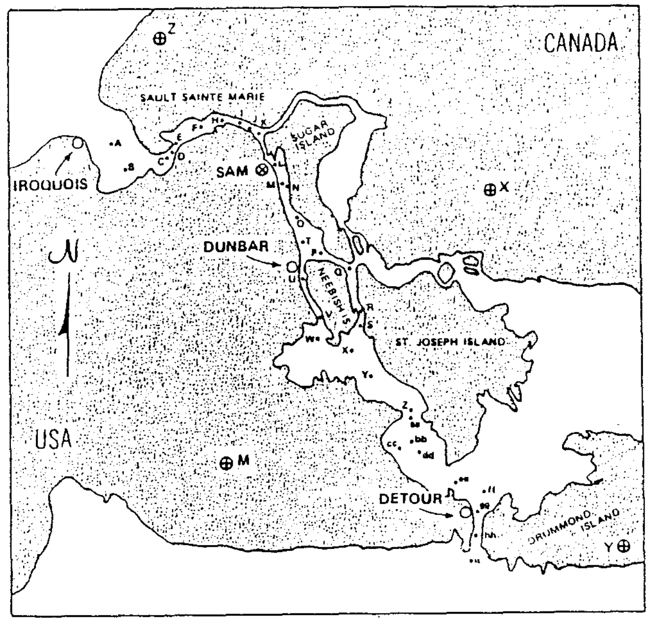
LOCATION: NORTHERN MICHIGAN

INTERVAL: 15 min

DURATION: MAY 1979 TO MAY 1980

QUALITY: 0.02 μsec

R 32744

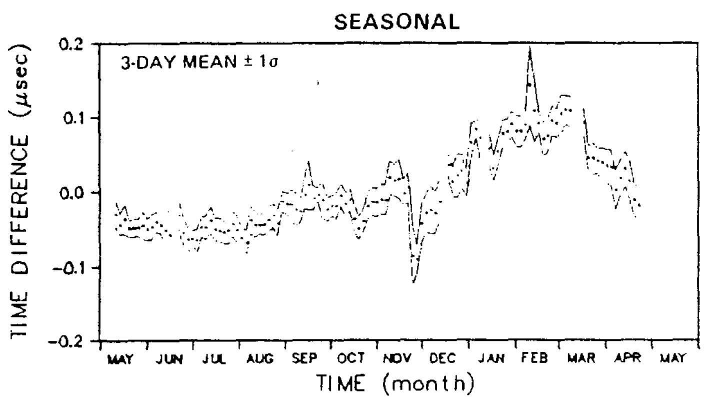


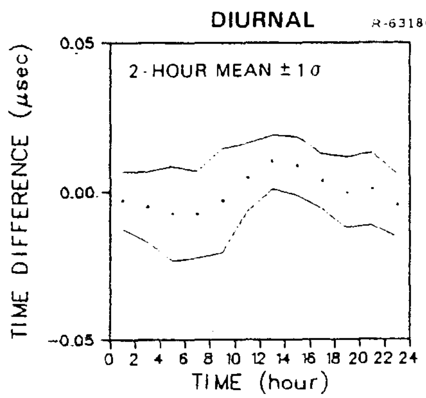
TASC

U.S. COAST GUARD/TASC
1980 TEST RESULTS

SEASONAL TD VARIATIONS IN ST. MARYS RIVER CHAIN ARE <0.4 μsec p-p AND LARGEST IN WINTER DIURNAL TD VARIATIONS ARE <0.04 μsec p-p

R-63180



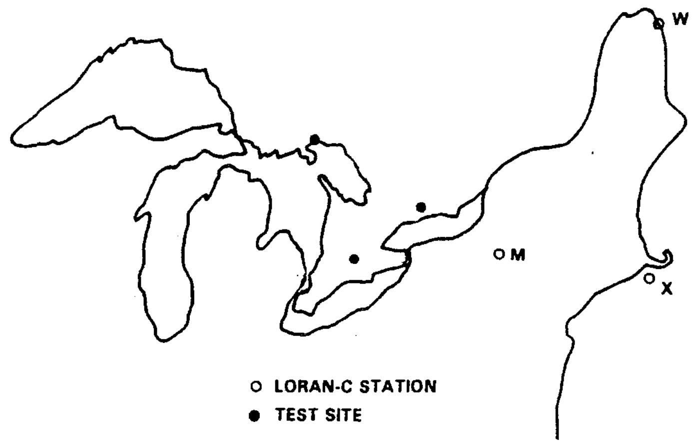


TASC

CANADA/KAMAN TEMPO 1978 TEST SCENARIO

APPLICATION:	GREAT LAKES NAVIGATION
MOTIVATION:	WEATHER FRONT EFFECTS AND RELATION TO CHAIN CONTROL
CHAIN:	NORTHEAST U.S.
MEASUREMENTS:	TDW, TDX
SITES:	3
LOCATION:	GREAT LAKES REGION
INTERVAL:	100 sec
DURATION:	3 weeks
QUALITY:	0.02 μsec

R-76980



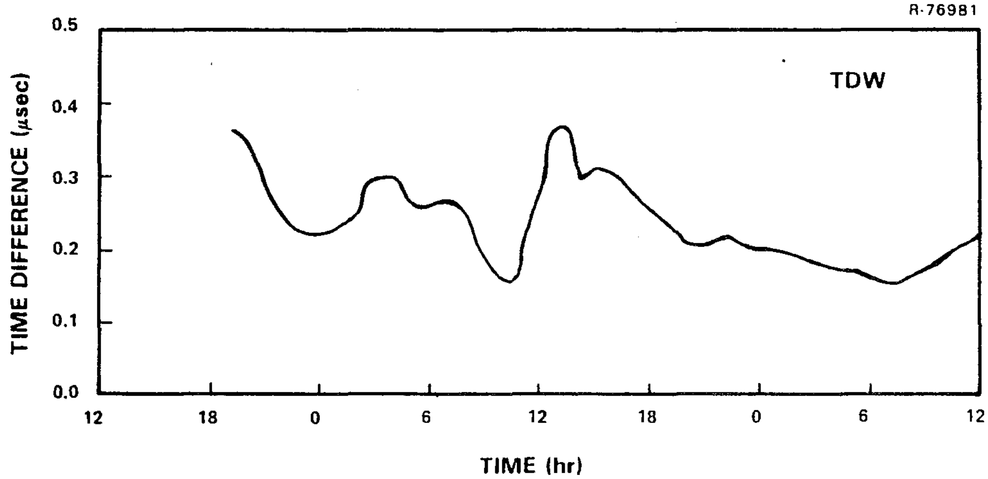
TASC

CANADA/KAMAN TEMPO 1978 TEST RESULTS

TD VARIATIONS IN REGION ARE 0.3 μsec p-p OVER TWO DAYS

WEATHER FRONTS INTRODUCE <0.05 μsec TD VARIATION

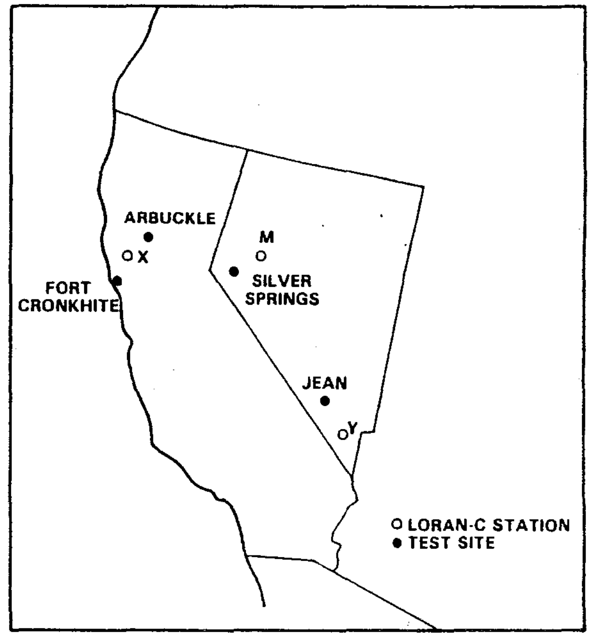
R-76981



TASC

U.S. COAST GUARD/KAMAN TEMPO 1978 TEST SCENARIO

APPLICATION:	HARBOR NAVIGATION
MOTIVATION:	DIFFERENTIAL LORAN-C REQUIREMENTS
CHAIN:	U.S. WEST COAST
MEASUREMENTS:	TDX, TDY
SITES:	4
LOCATION:	NEAR STATIONS M, X, Y
INTERVAL:	100 sec
DURATION:	AUG 1977-MAY 1978
QUALITY:	0.02 μsec

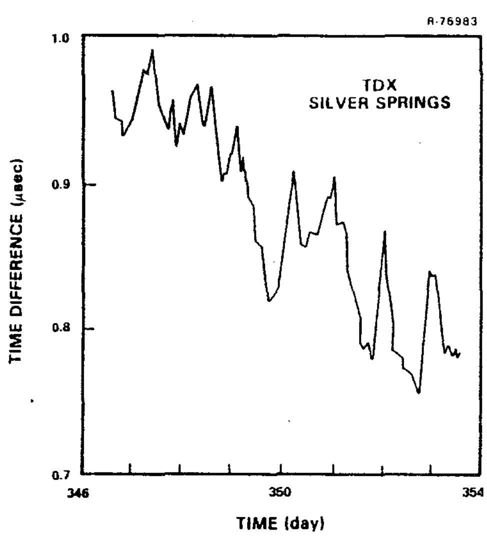


TASC

U.S. COAST GUARD/KAMAN TEMPO 1978 TEST RESULTS

SEASONAL TD VARIATIONS ARE <0.06 μsec p-p AT FORT CRONKHITE (NEAR SAM)

WEEKLY TD VARIATIONS ARE <0.3 μsec p-p AT SILVER SPRINGS

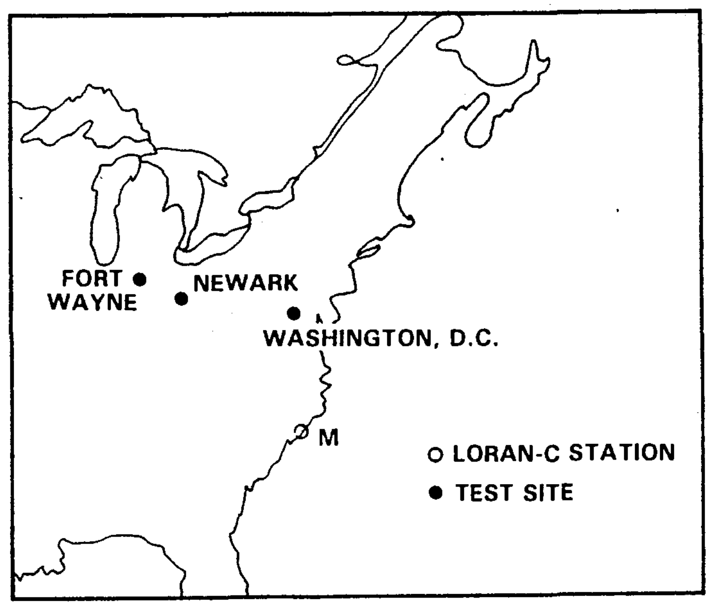


TASC

U.S. COAST GUARD/MAGNAVOX
1977 TEST SCENARIO

APPLICATION:	LORAN-C SYSTEM SUPPORT
MOTIVATION:	CAUSE OF DIURNAL TD VARIATIONS
CHAIN:	U.S. EAST COAST
MEASUREMENTS:	TOAM
SITES:	3
LOCATION:	FORT WAYNE, IN NEWARK, OH WASHINGTON, DC
INTERVAL:	15 min
DURATION:	SEVERAL-DAY PERIODS IN FEB-APR 1977
QUALITY:	0.02 μsec

R-76984



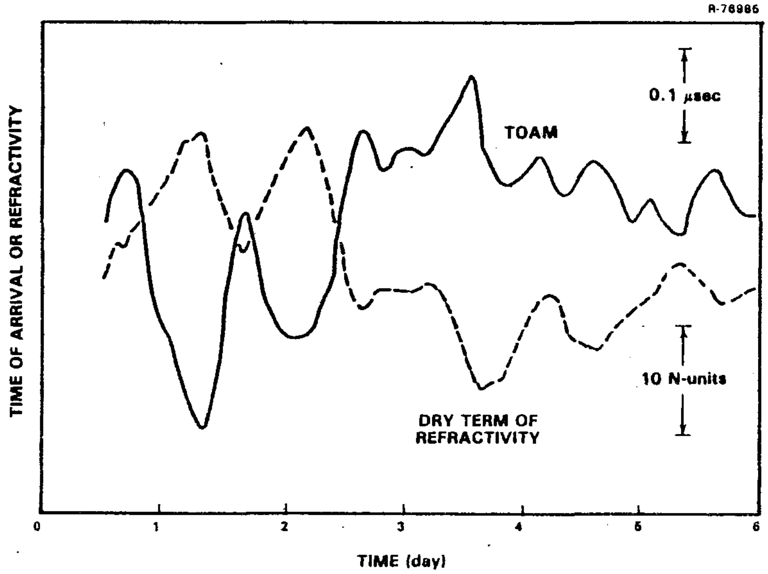
TASC

U.S. COAST GUARD/MAGNAVOX
1977 TEST RESULTS

DIURNAL TD VARIATIONS ARE INDUCED BY VERTICAL LAPSE RATE VARIATIONS

WEEKLY TD VARIATIONS ARE <0.3 μsec p-p

R-76986



TASC

U.S. COAST GUARD/INTERNAV
1973 TEST SCENARIO

APPLICATION: HARBOR NAVIGATION

MOTIVATION: DIFFERENTIAL LORAN-C EVALUATION

CHAIN: U.S. EAST COAST

MEASUREMENTS: TDY, TDZ

SITES: 2 FIXED
6 MOBILE

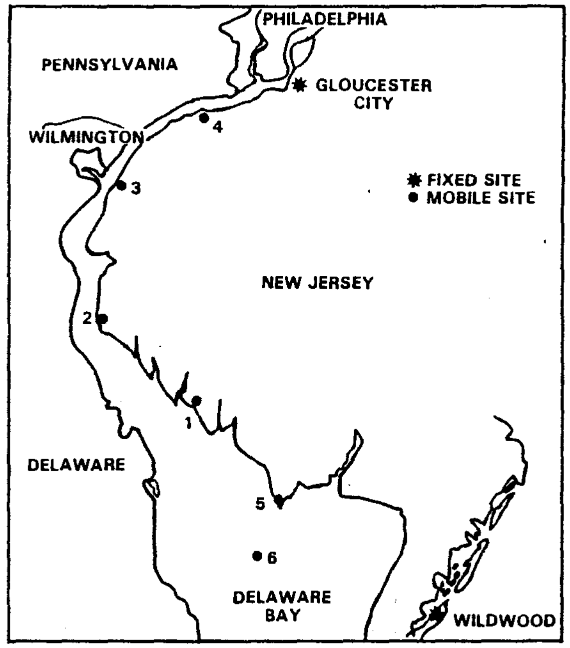
LOCATION: ALONG DELAWARE RIVER

INTERVAL: 100 sec

DURATION: JUL-AUG 1973

QUALITY: 0.02 μsec

R-76986



TASC

U.S. COAST GUARD/INTERNAV
1973 TEST RESULTS

BIAS CORRECTION IS APPLICABLE AT LEAST WITHIN 100 km OF MONITOR

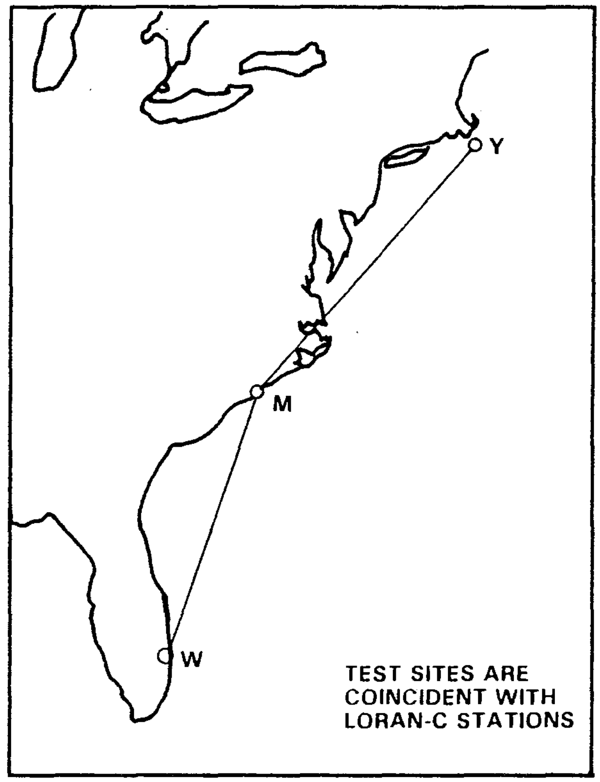
SCENARIO	UPDATE INTERVAL	RMS TD ERROR (nsec) FOR WEEK: 1	2	3	4	5	6
GLOUCESTER TDZ CORRECTED BY WILDWOOD TDZ (SEPARATION ≈100 km)	100 sec	28	21	20	20	19	18
	15 min	29	23	23	22	34	18
	2 hr	33	27	33	28	41	24
	6 hr	34	35	36	35	41	23
	24 hr	49	35	54	35	48	31
GLOUCESTER UNCORRECTED	NO UPDATES	46	36	62	32	41	38

TASC

U.S. NAVY/SPERRY 1971 TEST SCENARIO

APPLICATION:	STRATEGIC SUBMARINE NAVIGATION
MOTIVATION:	POTENTIAL IMPROVEMENT AFFORDED BY PROPAGATION CORRECTIONS
CHAIN:	U.S. EAST COAST
MEASUREMENTS:	TDW, TDY
SITES:	3
LOCATION:	STATIONS M, W, Y
INTERVAL:	15 min
DURATION:	OCT 1967-SEPT 1968
QUALITY:	0.01 μsec

R-76987



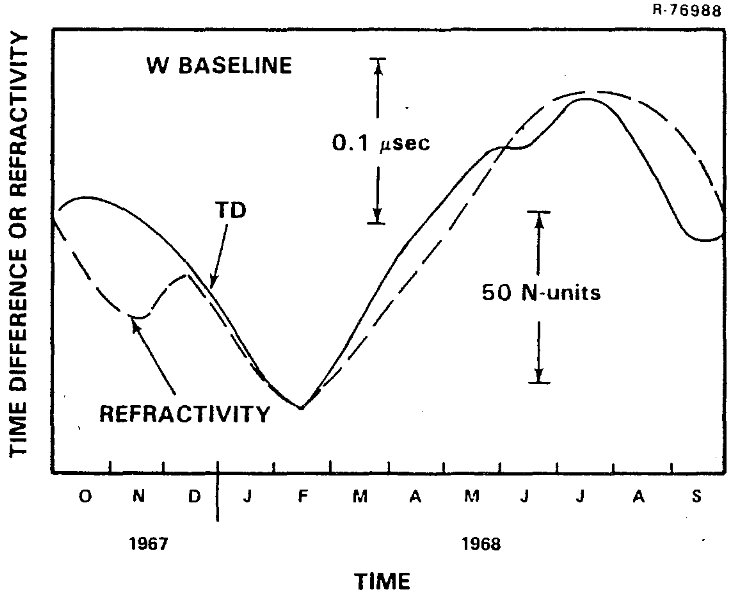
TASC

U.S. NAVY/SPERRY 1971 TEST RESULTS

SEASONAL TD VARIATIONS ARE HIGHLY CORRELATED WITH REFRACTIVITY

WEATHER FRONTS INDUCE TD VARIATIONS

R-76988



TASC

SPATIAL LORAN-C TESTS

TASC

OVERVIEW OF SPATIAL TESTS

SPONSORING/PERFORMING ORGANIZATIONS	COMPLETION DATE	LORAN-C CHAIN	SITE LOCATIONS	NUMBER OF SITES	COVERAGE (km)
U.S. COAST GUARD/TASC	1979	U.S. WEST COAST	PACIFIC COAST	27 LAND 23 SEA	1500
U.S. AIR FORCE/MITRE	1979	SOUTHEAST U.S.	EGLIN AFB, FLORIDA	126	80×140
U.S. COAST GUARD/TASC	1978	ST. MARYS RIVER	NORTHERN MICHIGAN	25	120
CANADIAN HYDROGRAPHIC SERVICE/ KAMAN TEMPO	1978	NORTHEAST U.S.	GREAT LAKES REGION	10	1000
U.S. COAST GUARD/KAMAN TEMPO	1978	U.S. WEST COAST	CALIFORNIA AND NEVADA	8 ON RADIAL 14 IN HARBOR	800 40
CANADIAN HYDROGRAPHIC SERVICE/SAME	1977	CANADIAN WEST COAST	VANCOUVER ISLAND REGION (OFFSHORE)	200	1000
U.S. ARMY/SAME	1975	U.S. EAST COAST	CENTRAL NEW JERSEY	61	100×100
U.S. ARMY/SAME	1973	U.S. EAST COAST	MONTAUK POINT ON LONG ISLAND	54	3×8
COMMERCE DEPT./SAME	1972	U.S. EAST COAST	CLEMSON, SOUTH CAROLINA	74	100×100

TASC

U.S. COAST GUARD/TASC
1979 TEST SCENARIO

APPLICATION: COASTAL CONFLUENCE ZONE NAVIGATION

MOTIVATION: LORAN-C CHART ERRORS

CHAIN: U.S. WEST COAST

MEASUREMENTS: TDW, TDX, TDY

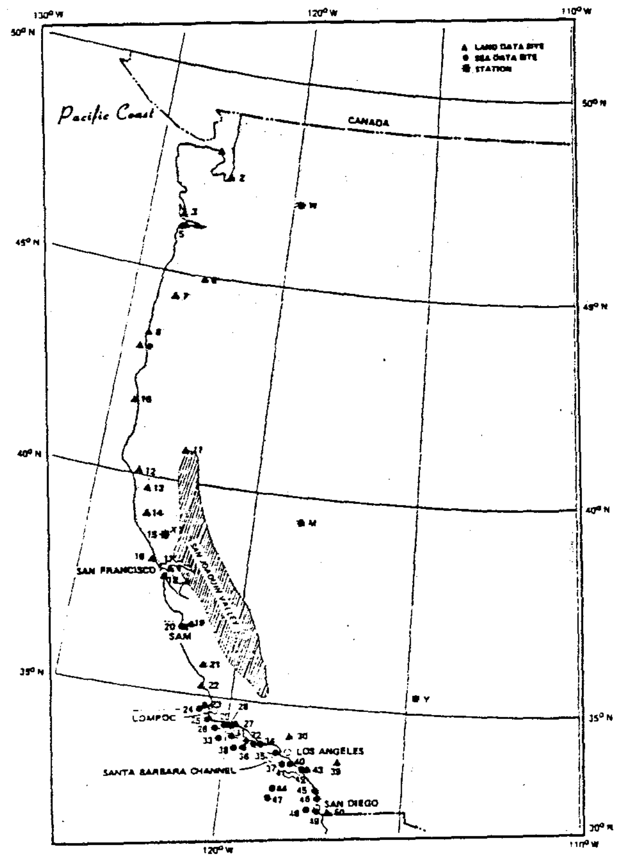
SITES: 27 ON LAND
23 AT SEA

LOCATION: PACIFIC COAST

SPACING: 20-100 km

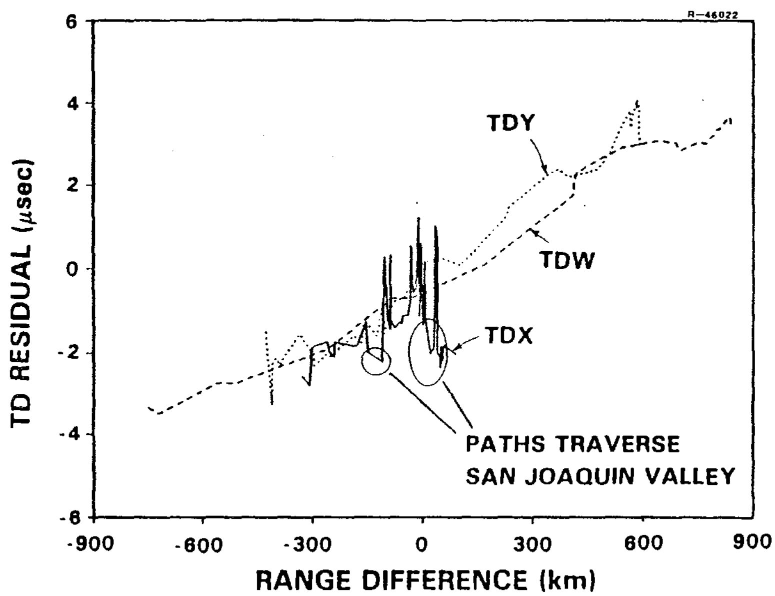
COVERAGE: 1500 km

QUALITY: 0.1 - 0.2 μsec



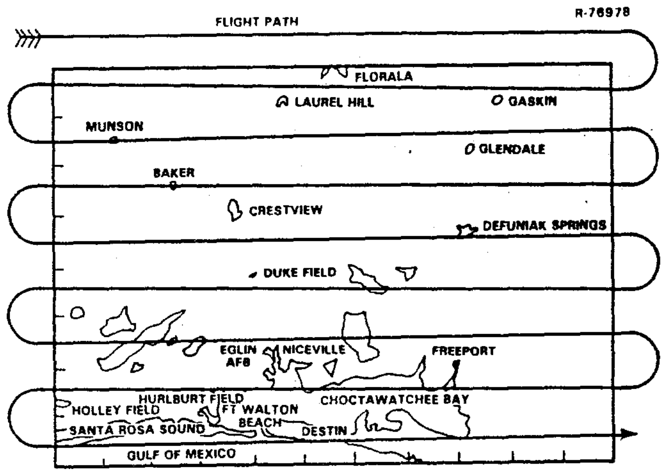
U.S. COAST GUARD/TASC
1979 TEST RESULTS

SAN JOAQUIN VALLEY INTRODUCES
1-2 μsec TDX ANOMALY



U.S. AIR FORCE/MITRE 1979 TEST SCENARIO

APPLICATION:	AIRCRAFT NAVIGATION USING AN/ARN-101 RECEIVER
MOTIVATION:	GRID WARPAGE CAUSED BY LAND PATHS
CHAIN:	SOUTHEAST U.S.
MEASUREMENTS:	TDW, TDY
SITES:	126
LOCATION:	EGLIN AFB, FLORIDA
SPACING:	10 km
COVERAGE:	80 km × 140 km
QUALITY:	0.1-0.2 μsec

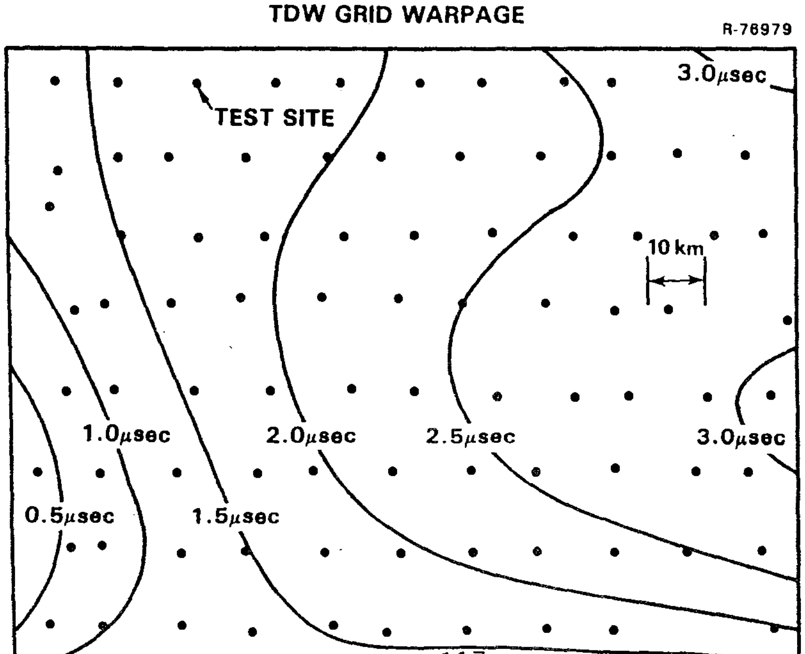


U.S. AIR FORCE/MITRE 1979 TEST RESULTS

LARGE-AREA WARPAGE CANNOT BE MODELED AS BIAS

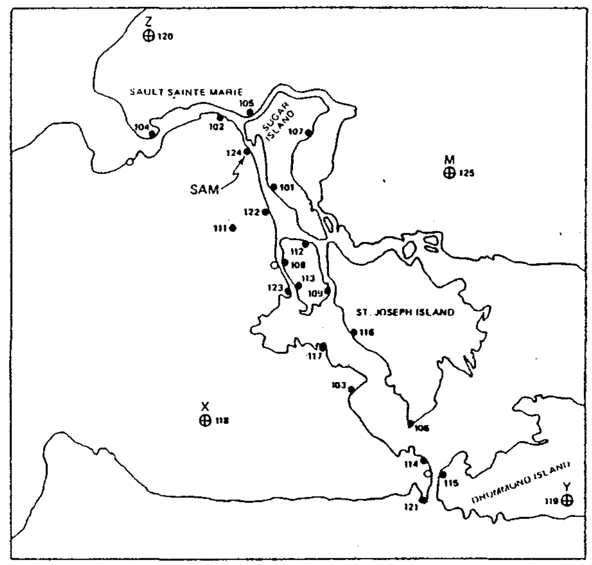
WARPAGE IS NEARLY INDEPENDENT OF ALTITUDE BELOW 13,000 ft

TDW GRID WARPAGE



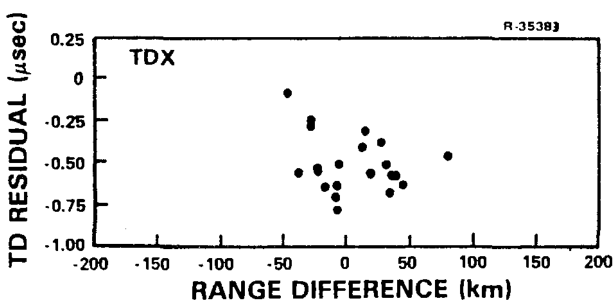
U.S. COAST GUARD/TASC
1978 TEST SCENARIO

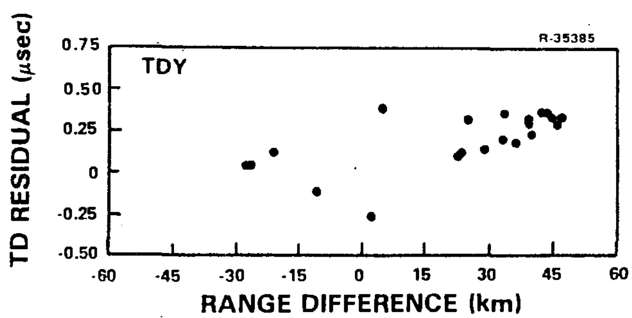
APPLICATION:	ORE CARRIER NAVIGATION OF ST. MARYS RIVER
MOTIVATION:	CHAIN CALIBRATION
CHAIN:	ST. MARYS RIVER (ORIGINAL)
MEASUREMENTS:	TDX, TDY, TDZ
SITES:	25
LOCATION:	NORTHERN MICHIGAN
SPACING:	4 km
COVERAGE:	120 km
QUALITY:	0.02 μsec

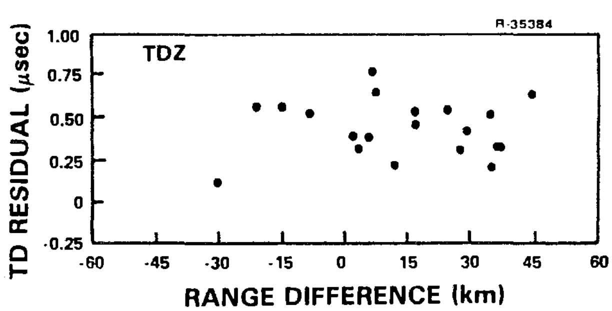


U.S. COAST GUARD/TASC
1978 TEST RESULTS

CONDUCTIVITY IS NON-UNIFORM IN 70 km × 130 km COVERAGE AREA







CANADA/KAMAN TEMPO 1978 TEST SCENARIO

R-76990

APPLICATION: GREAT LAKES NAVIGATION

MOTIVATION: CONDUCTIVITY MAP IMPROVEMENT

CHAIN: NORTHEAST U.S.

MEASUREMENTS: TOAM, TOAW

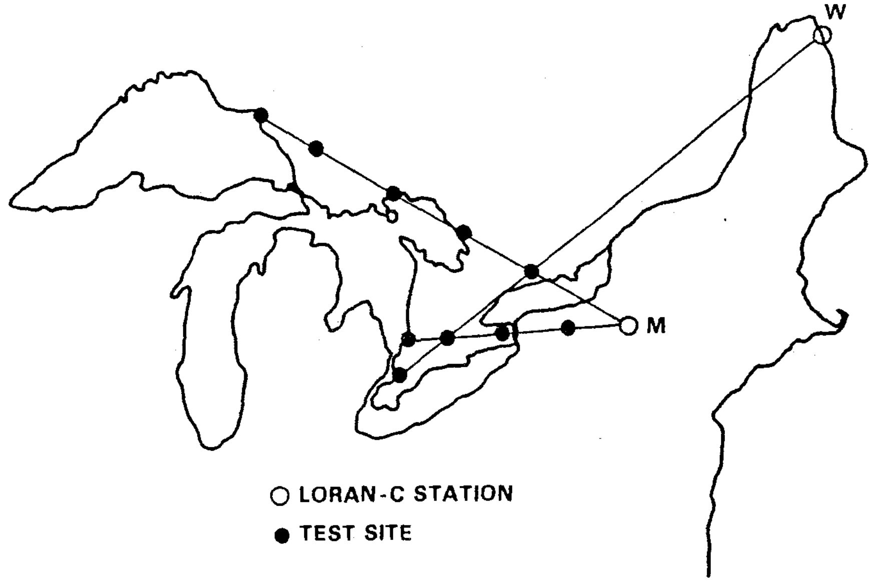
SITES: 10 ALONG RADIALS

LOCATION: GREAT LAKES REGION

SPACING: 200 km

COVERAGE: 1000 km

QUALITY: 0.1 - 0.2 μsec



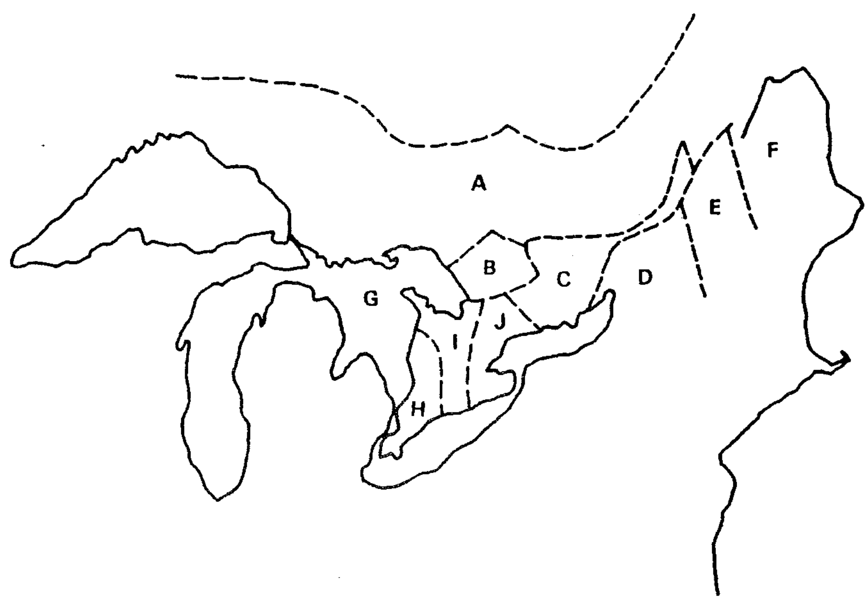
TASC

CANADA/KAMAN TEMPO 1978 TEST RESULTS

CONDUCTIVITY MAP IS INCORRECT BY FACTOR OF 2-10 IN CERTAIN REGIONS

R-78991

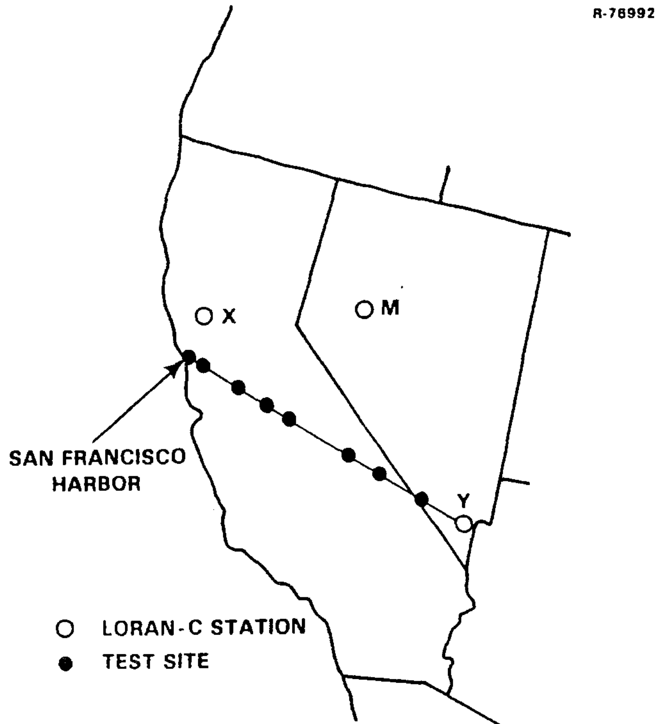
REGION	CONDUCTIVITY (mmho/m)	
	MAP	DATA
A	2	2-4
B	1	1
C	4	1
D	10	7
E	6	4
F	1	1
G	10	1-4
H	6	10-20
I	4	15-40
J	6	10



TASC

U.S. COAST GUARD/KAMAN TEMPO 1978 TEST SCENARIO

APPLICATION:	HARBOR NAVIGATION
MOTIVATION:	GRID PREDICTION MODEL EVALUATION
CHAIN:	U.S. WEST COAST
MEASUREMENTS:	TOAY ALONG RADIAL TDX AND TDY IN HARBOR
SITES:	8 ALONG RADIAL 14 IN HARBOR
LOCATION:	CALIFORNIA AND NEVADA
SPACING:	100 km ALONG RADIAL 4 km IN HARBOR
COVERAGE:	800 km ALONG RADIAL 40 km IN HARBOR
QUALITY:	0.1-0.2 μsec

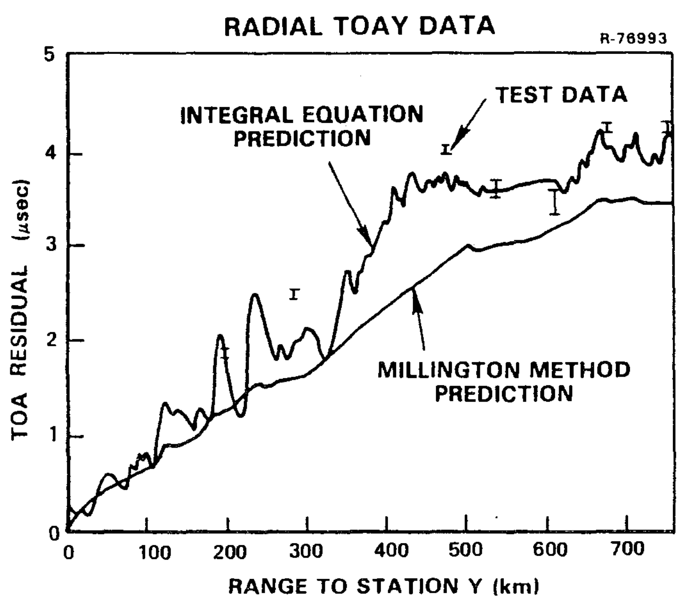


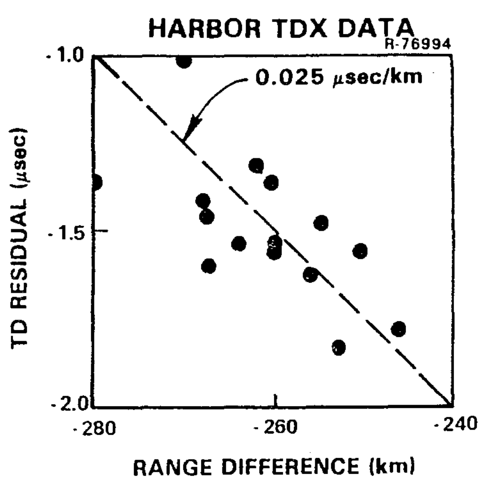
TASC

U.S. COAST GUARD/KAMAN TEMPO 1978 TEST RESULTS

ACCURATE PREDICTION REQUIRES BOTH TERRAIN AND CONDUCTIVITY DATA

TD RESIDUAL CHANGES RAPIDLY AT LAND/SEA INTERFACE

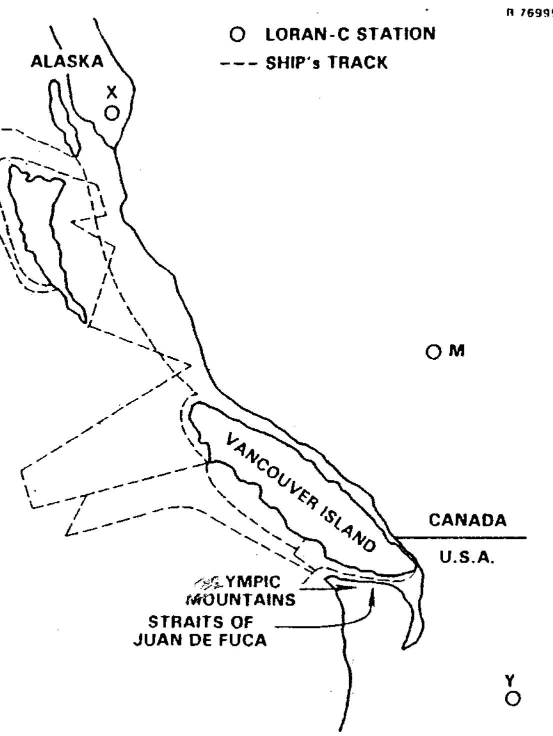




TASC

CANADIAN HYDROGRAPHIC SERVICE
1977 TEST SCENARIO

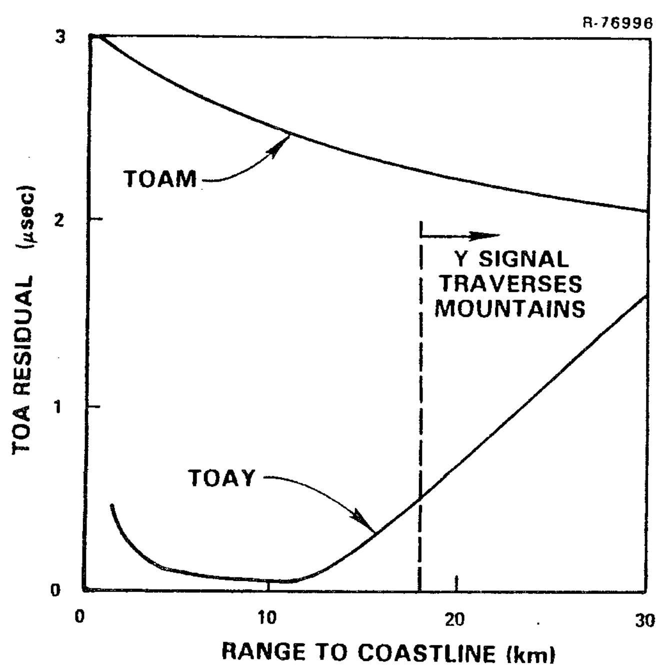
APPLICATION:	COASTAL CONFLUENCE ZONE NAVIGATION
MOTIVATION:	CHAIN CALIBRATION
CHAIN:	CANADIAN WEST COAST
MEASUREMENTS:	TOAM, TOAX, TOAY
SITES:	200 OFF SHORE CONTINUOUS NEAR STRAITS
LOCATION:	VANCOUVER ISLAND REGION
SPACING:	30 km OFF SHORE CONTINUOUS NEAR STRAITS
COVERAGE:	1000 km
QUALITY:	0.5 μsec OFF SHORE 0.1 μsec NEAR STRAITS



TASC

CANADIAN HYDROGRAPHIC SERVICE
1977 TEST RESULTS

EFFECTS OF LAND/SEA INTERFACE AND MOUNTAINS ARE EXHIBITED CLEARLY BY DATA



TASC

U.S. ARMY 1975 TEST SCENARIO

R-76997

APPLICATION: TERRESTRIAL NAVIGATION USING ARMY MANPACK RECEIVER

MOTIVATION: COORDINATE CONVERSION MODEL DEVELOPMENT

CHAIN: U.S. EAST COAST

MEASUREMENTS: TDY, TDZ

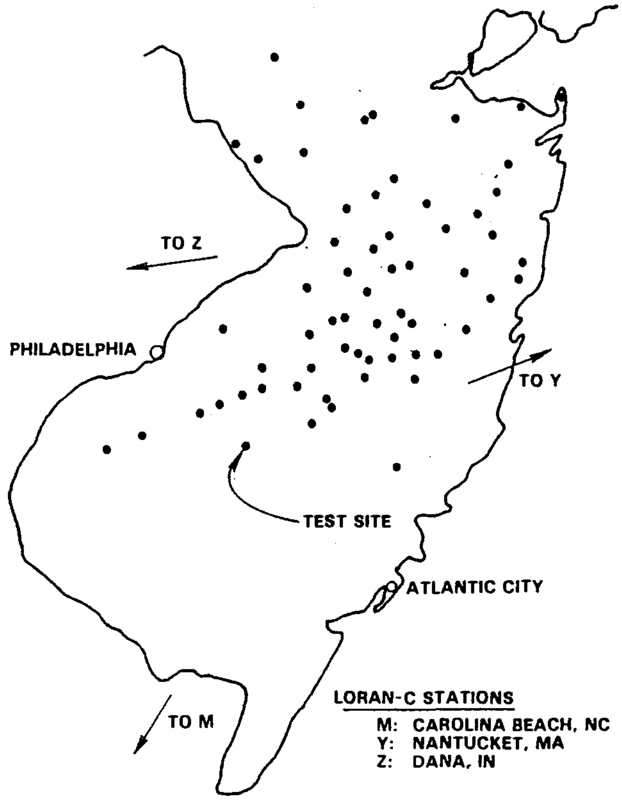
SITES: 61

LOCATION: CENTRAL NEW JERSEY

SPACING: 10 km

COVERAGE: 100 km × 100 km

QUALITY: 0.2 μsec

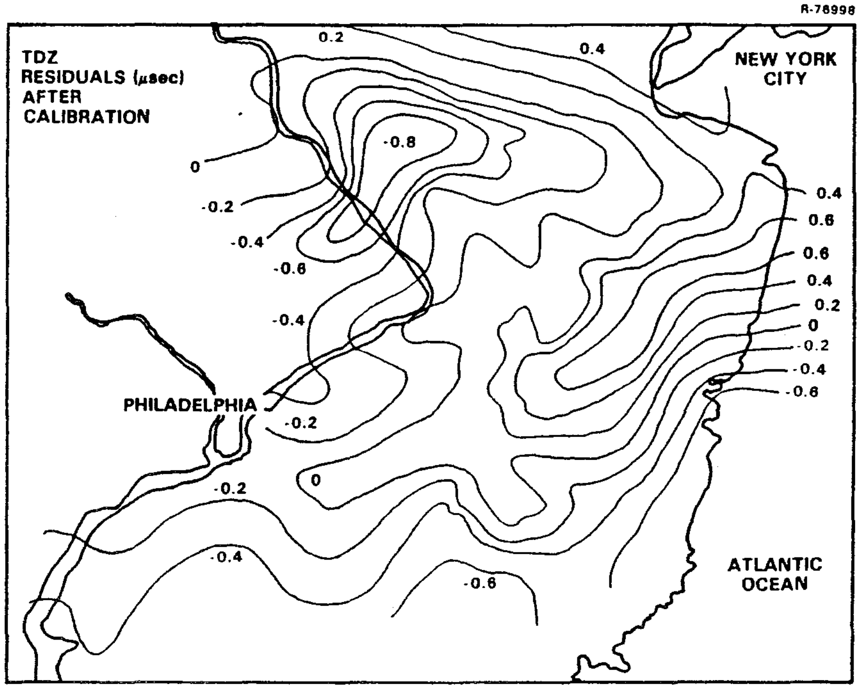


TASC

U.S. ARMY 1975 TEST RESULTS

TD RESIDUALS AFTER LARGE-AREA CALIBRATION OF LINEAR MODEL ARE 0.3 μsec rms

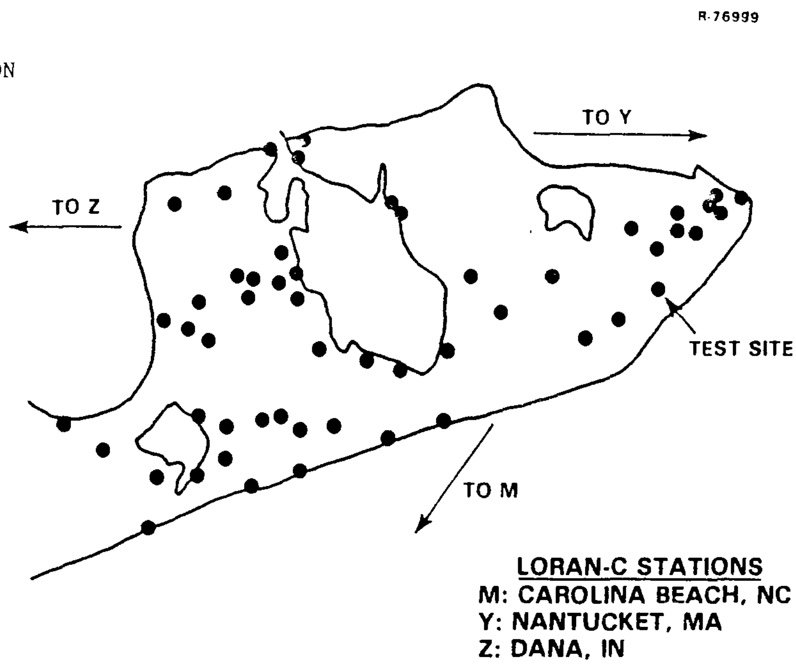
R-76998



TASC

U.S. ARMY 1973 TEST SCENARIO

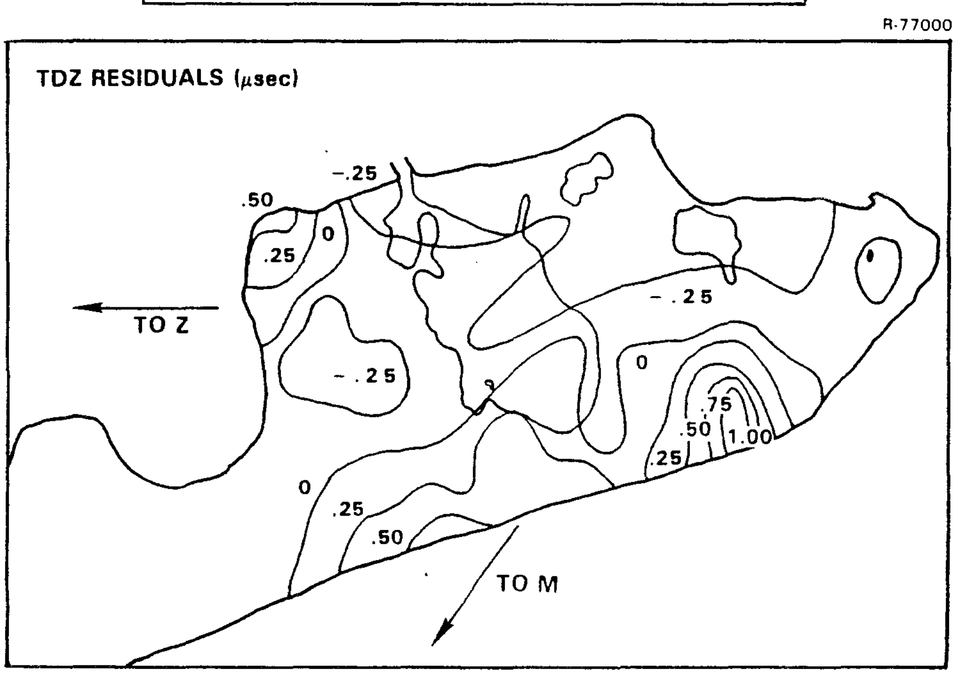
APPLICATION:	TERRESTRIAL NAVIGATION USING ARMY MANPACK RECEIVER
MOTIVATION:	COASTLINE-INDUCED ANOMALIES
CHAIN:	U.S. EAST COAST
MEASUREMENTS:	TDY, TDZ
SITES:	54
LOCATION:	MONTAUK POINT ON LONG ISLAND
SPACING:	0.5 km
COVERAGE:	3 km × 8 km
QUALITY:	0.1 μsec



TASC

U.S. ARMY 1973 TEST RESULTS

TD ANOMALY IS OBSERVED AT SEA/LAND INTERFACE

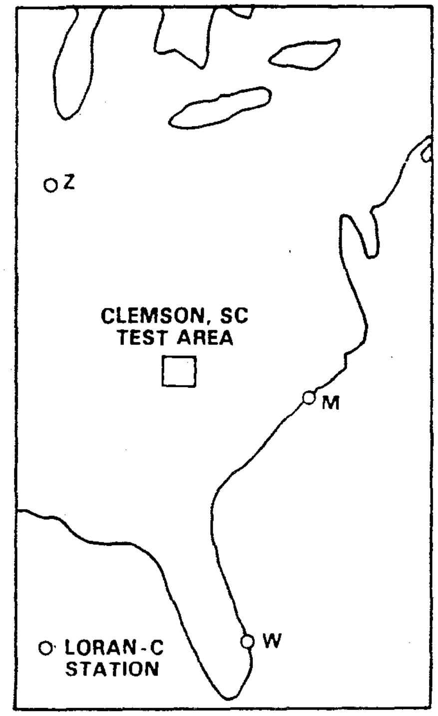


TASC

COMMERCE DEPARTMENT
1972 TEST SCENARIO

R-77001

APPLICATION:	BASIC PROPAGATION RESEARCH
MOTIVATION:	LOCAL GRID WARPAGE
CHAIN:	U.S. EAST COAST
MEASUREMENTS:	TDW, TDZ
SITES:	74
LOCATION:	CLEMSON, SC
SPACING:	5 km
COVERAGE:	100 km × 100 km
QUALITY:	0.1 μsec



TASC

COMMERCE DEPARTMENT
1972 TEST RESULTS

MEASURED SCALE FACTORS FOR INLAND SITES ARE CONSISTENT WITH THEORY

SIGNAL PATH	SCALE FACTOR (μsec/km)
CAPE FEAR TO CLEMSON (ALL LAND)	0.0050
JUPITER TO CLEMSON (MIXED LAND/SEA)	0.0036
DANA TO CLEMSON (ALL LAND)	0.0048
THEORETICAL FOR CONDUCTIVITY OF 0.003 mho/m (ALL LAND)	0.0051
THEORETICAL FOR CONDUCTIVITY OF 5.0 mho/m (ALL SEA)	0.0023

SUMMARY

R78224

ERROR COMPONENT	CATEGORY	TYPICAL RESULTS
TEMPORAL INSTABILITY	SEASONAL	• DISTINCT CYCLE • < 1 μsec
	DIURNAL	• NO CONSISTENT CYCLE • < 0.2 μsec
	SHORT-TERM WEATHER FRONT EFFECTS	• NOT WELL UNDERSTOOD • < 0.1 μsec
SPATIAL WARPAGE	BIAS	• DIFFICULT TO PREDICT • < 3 μsec
	LOCAL SCALE FACTOR	• PREDICTABLE EXCEPT NEAR COASTLINE • < 0.005 μsec/km
	ANOMALIES CAUSED BY COASTLINE AND MOUNTAINS	• REQUIRE MEASUREMENT • <1 μsec

TASC

REFERENCES GUIDE

TEMPORAL TESTS

SPONSORING/PERFORMING ORGANIZATIONS	COMPLETION DATE	REF.
FAA/TSC	1980	1
U.S. COAST GUARD/TASC	1980	2
CANADIAN HYDROGRAPHIC SERVICE/ KAMAN TEMPO	1978	3
U.S. COAST GUARD/KAMAN TEMPO	1978	4
U.S. COAST GUARD/MAGNAVOX	1977	5
U.S. COAST GUARD/INTERNAV	1973	6
U.S. NAVY/SPERRY SYSTEMS MANAGEMENT	1971	7

SPATIAL TESTS

SPONSORING/PERFORMING ORGANIZATIONS	COMPLETION DATE	REF.
U.S. COAST GUARD/TASC	1979	8
U.S. AIR FORCE/MITRE	1979	9
U.S. COAST GUARD/TASC	1978	10
CANADIAN HYDROGRAPHIC SERVICE/ KAMAN TEMPO	1978	11
U.S. COAST GUARD/KAMAN TEMPO	1978	12
CANADIAN HYDROGRAPHIC SERVICE/SAME	1977	13
U.S. ARMY/SAME	1975	14
U.S. ARMY/SAME	1973	15
COMMERCE DEPT./SAME	1972	16

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1. Mackenzie, F.D., "Flight Evaluation of Loran-C in the State of Vermont," Transportation Systems Center, Draft Report, July 1981.

2. DePalma, L.M., Creamer, P.M., and Anderson, E., "Quantification of St. Marys River Loran-C Time Difference Grid Instability," Proc. of Ninth Annual Technical Symposium of the Wild Goose Association (Boston, MA), October 1980.

3. Illgen, J.D., Mason, T., and Gambill, B., Jr., "Loran-C Propagation and Equipment Timing Fluctuations and Conductivity Estimates Observed in the Great Lakes Region," Proc. of Eighth Annual Technical Symposium of the Wild Goose Association (Williamsburg, VA), October 1979.

4. Gambill, B., and Schwartz, K., "Loran-C Signal Analysis Propagation Model Evaluation," Kaman TEMPO, Report No. CG-D-20-80, July 1979.

5. Dean, W.N., "Diurnal Variations in Loran-C Ground Wave Propagation," Magnavox Government and Industrial Electronics Co., Unpublished Report, 1978.

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6. Goddard, R.B., "Differential Loran-C Time Stability Study," U.S. Coast Guard, Report No. DOT-CG-31146-A, November 1973.

7. "Final Report on Loran-C Propagation Study," Sperry Systems Management Division, Report No. CJ-2232-1892, April 1971.

8. Gupta, R.R., and Anderson, E., "Application of Semi-Empirical TD Grid Calibration to the West Coast Loran-C Chain," Proc. of Eighth Annual Technical Symposium of the Wild Goose Association (Williamsburg, VA), October 1979.

9. Marchand, M.A., Kennedy, J.L., and Kellett, L.A., "Loran Warpage Coefficients Generation Program (WARP)," Hanscom Air Force Base, Technical Report ESD-TR-81-116(III), February 1981.

10. Warren, R.S., Gupta, R.R., and Shubbuck, T.J., "Design and Calibration of a Grid Prediction Algorithm for the St. Marys River Loran-C Chain," Proc. of Seventh Annual Technical Symposium of the Wild Goose Association (New Orleans, LA), October 1978.

REFERENCES (Cont.)

11. See Reference 3.

12. See Reference 4.

13. Mortimer, A.R., Eaton, R.M., and Gray, D.H., "Calibration of the West Canadian Loran-C Chain," Canadian Aeronautics and Space Journal, Vol. 24, No. 3, May/June 1978. pp. 129-136.

14. Pearce, D.C., and Walker, J.W., "Ground Effects on Loran-C Signals," Proc. of the Sixth Annual Precise Time and Time Interval Applications and Planning Meetting (Washington, D.C.), December 1974.

15. Anderson, C.W., III, Pearce, D.C., and Walker, J.W., "Coastline Induced Loran-C Anomalies," U.S. Army Electronics Command, Report No. ECOM-4075, February 1973.

16. Doherty, R.H., "A Loran-C Grid Calibration and Prediction Method," Institute for Telecommunication Sciences, Report No. OT/TRER 25, February 1972.

TASC

SESSION 4

TEST AND EVALUATION

Session Chairman: Commander J. Alexander, 11th Coast Guard District

A LORAN-C/ACCUFIX EVALUATION IN THE CANADIAN ARCTIC

M. McAloney
Internav Ltd.
Sydney, Nova Scotia

R. M. Eaton
Canadian Hydrographic Service
Dartmouth, Nova Scotia

B. Waldock
Canada Center for Inland Waters
Burlington, Ontario

A. Mortimer
Canadian Hydrographic Service
Sidney, British Columbia

ABSTRACT

Two sets of tests were made in the Beaufort Sea area under summer and winter weather conditions to define propagation characteristics for Loran-C. Further qualitative measurements were made to demonstrate range and cycle identification capabilities of the system under Arctic conditions. Data analysis provided the effective conductivities for propagation over permafrost, sea ice, and varying Arctic terrain. Special attention was paid to problems associated with Accufix operation in high northern latitudes.

BIOGRAPHICAL SKETCHES

M. McAloney - Mr. McAloney graduated in 1978 from the University of Brunswick with a BSEE before joining Internav as a development engineer. He was project engineer for the Internav 112 Loran-C receiver, and has considerable experience with troubleshooting Loran problems in the field.

R. M. Eaton - Mr. Eaton is Head of the Navigation Group at the Bedford Institute of Oceanography. He has considerable experience in Loran-C calibration and propagation measurements in Canada, and has worked extensively in the Arctic. He is the author of several papers on the calibration of Loran-C for charting and its application to surveying. He has a BS in Physics from Dalhousie University.

B. Waldock - Mr. Waldock is an electronics technologist with the Canadian Hydrographic Service in Burlington, Ontario. He has eighteen years experience in the communications field specializing in positioning systems. During the past five years he has been involved in Loran-C/Accufix installation and operational problems as well as antenna configuration tests.

A. Mortimer - Mr. Mortimer is a hydrographer with the Canadian Hydrographic Service in Sidney, B.C. In addition to survey work in the Canadian Arctic, he has conducted Loran-C charting calibrations for the Canadian West Coast Chain. He has a BS in Mathematics from the University of Victoria, and is a Master Mariner and Canada Lands Surveyor.

M. McAloney

A. Mortimer

INTRODUCTION

The Canadian Arctic has in recent years, been the scene of intensive resource exploration activity. Some of this exploratory work is about to bear fruit. Natural gas production and shipment is planned from the Central Arctic Islands in the mid-eighties. Ore shipments from the Central Arctic should start in 1983. In the Western Arctic, petroleum exploration has been in progress since the mid-sixties. Drill ships were brought into the Beaufort Sea in 1976 by Dome Petroleum Ltd. Imperial Oil continued their drilling program using islands built in up to 10 metres of water. Gulf Canada Ltd. will be resuming their exploration program offshore next year.

The oil production potential of the Beaufort Sea has proven to be sufficiently encouraging for the companies, principally Dome, to consider shipping oil out by sea at some date after 1986. Such shipments would mean deep draught tanker traffic through the Northwest Passage. Positioning is not the major problem for the navigator in the Northwest Passage. Ice is, of course, the navigator's main concern. Through much of the Northwest Passage the water is deep and radar fixes are frequently available. However in the Beaufort Sea the continental shelf extends one hundred miles offshore. The seabed in this area is scattered with pingo-like features (Ref. 1) that rise to within nine metres of the sea's surface, (a pingo is an ice-cored conical hill). In addition, the coast in this area is low and presents a limited radar-target, and the lack of elevation minimizes the range of Racon beacons. A corridor for deep-draught shipping through the Beaufort Sea pingo area is presently being surveyed. The corridor is ten miles wide, and runs along the coast about twenty-five miles offshore. The route taken by the corridor passes outside the twenty metre depth contour but inshore from the densest pingo swarms. See Figure 1.

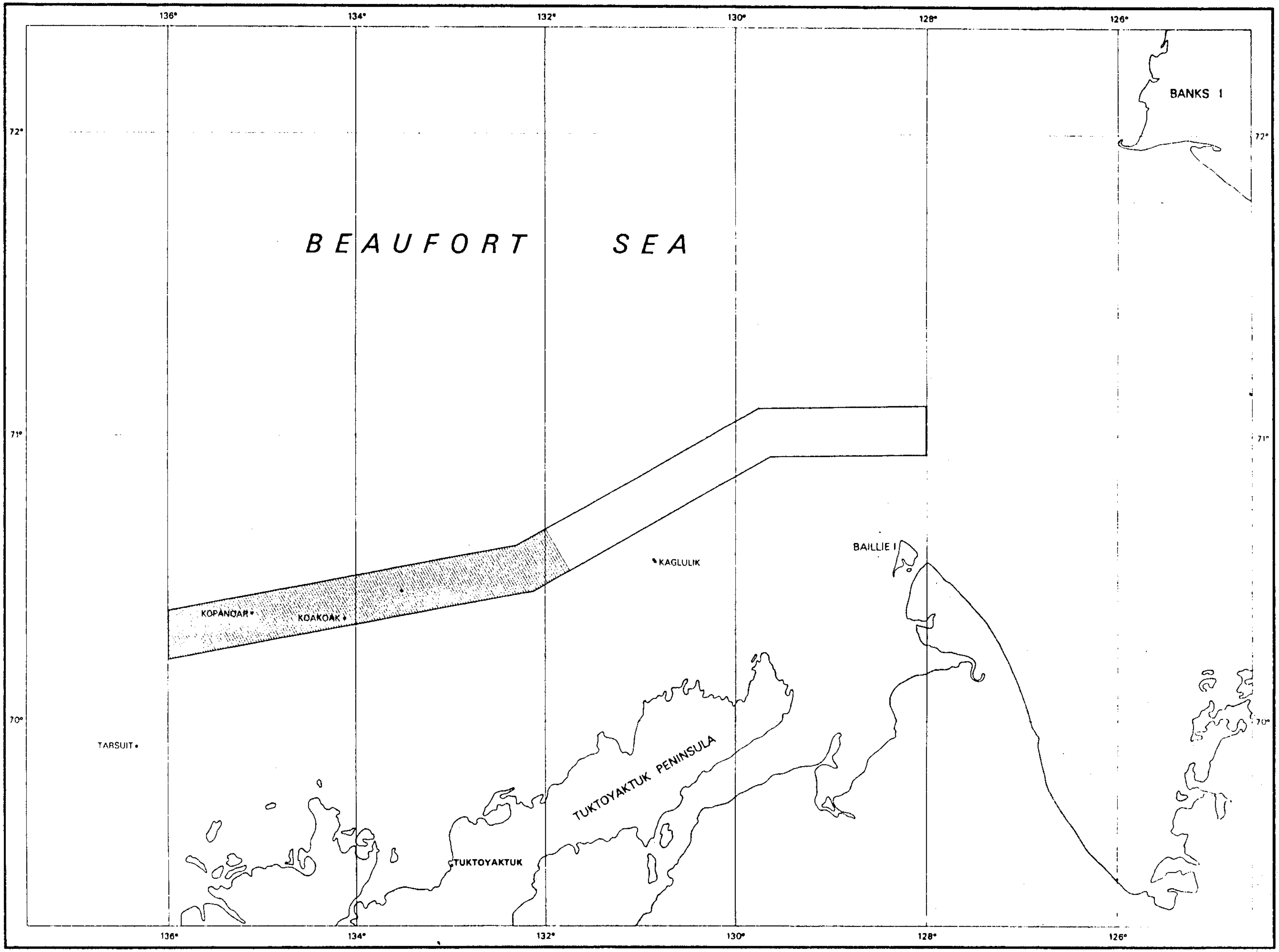
136°
134°
132°
130°
128°
126°
72°
71°
70°
BANKS I
BEAUFORT SEA
KOPANOAR
KOAKOAK
KAGLULIK
BAILLIE I
TARSUIT
TUKTOYAKTUK PENINSULA
TUKTOYAKTUK

Figure 1

It is apparent that any shipping using the area will require good positioning. Loran-C/Accufix is a candidate system that could be used in the Beaufort Sea and perhaps elsewhere in the Canadian Arctic. As well as providing positioning for deep draught shipping such a system would be available for rig supply vessels, for offshore helicopter work, for some oil industry and government survey work, and for government regulatory and services work. Main chain Loran-C is available in the Western Arctic, but only the Master of the Gulf of Alaska chain can be received reliably on ground wave. The geometry of the fixes from both the Gulf of Alaska and Bering Sea chains is very weak. Other electronic positioning systems are in use in the Beaufort Sea. Although more accurate than Loran-C these systems do not provide the reliable long range coverage and ease of operation for the navigator. Two medium frequency ARGO chains were operational in the area this summer but the range is limited, especially at night, due to skywave interference. About twenty Syledis stations were also working this summer in the Beaufort, but this system also has limited range and the characteristics of UHF propagation for positioning are not well known.

THE TESTS

Loran-C operations are well established in the Greenland Sea north of the Arctic Circle but in this area overland and over ice transmission paths do not limit the chains operational effectiveness. There were therefore a number of questions concerning the operational capabilities and propagation characteristics of a potential Accufix chain in the Arctic that required to be answered. We needed to know about:

1. Antenna configurations, transmitter operations and site selection for Accufix;

2. Propagation of the Loran-C/Accufix pulse over permafrost, varying conditions of sea ice, and over glacial deposits with interstitial ice overlaying bedrock; also about the effect of skywave interference from the lower Arctic ionosphere;
3. The maximum range of reliable reception, signal stability, third cycle identification capabilities using the Loran-C/Accufix transmissions and commercial receivers;
4. Seasonal variations in the three preceding questions. Therefore it was necessary to make the tests under late summer (maximum thaw) and under spring (freeze-up) conditions.

The tests were designed to attempt to answer the above questions in the following manner.

1. Antennas

Two 150 feet triangular lattice towers belonging to the Polar Continental Shelf Project, a Canadian Government research agency, were available for use in the Beaufort Sea area. These antennas had been in use with Decca transmitters for several years and were well "aged". The ground at the two sites presented an interesting contrast. At Atkinson Pt., where the Master transmitter was set up (see Figure 2) the terrain is flat and marshy, with one metre of active zone over permafrost. The active zone in permafrost regions is the surface layer above the permanently frozen ground that freezes in winter and thaws in summer. It usually consists of waterlogged peat mixed with sand, gravel or clay. At Duck Hawk Bluff on Banks I., where the secondary transmitter was sited, the ground is typical of the Arctic Islands with glacial veneer over bedrock.

The stations were operated by personnel from Marinav Corporation, Ottawa. Only the two transmitters were used providing one time difference

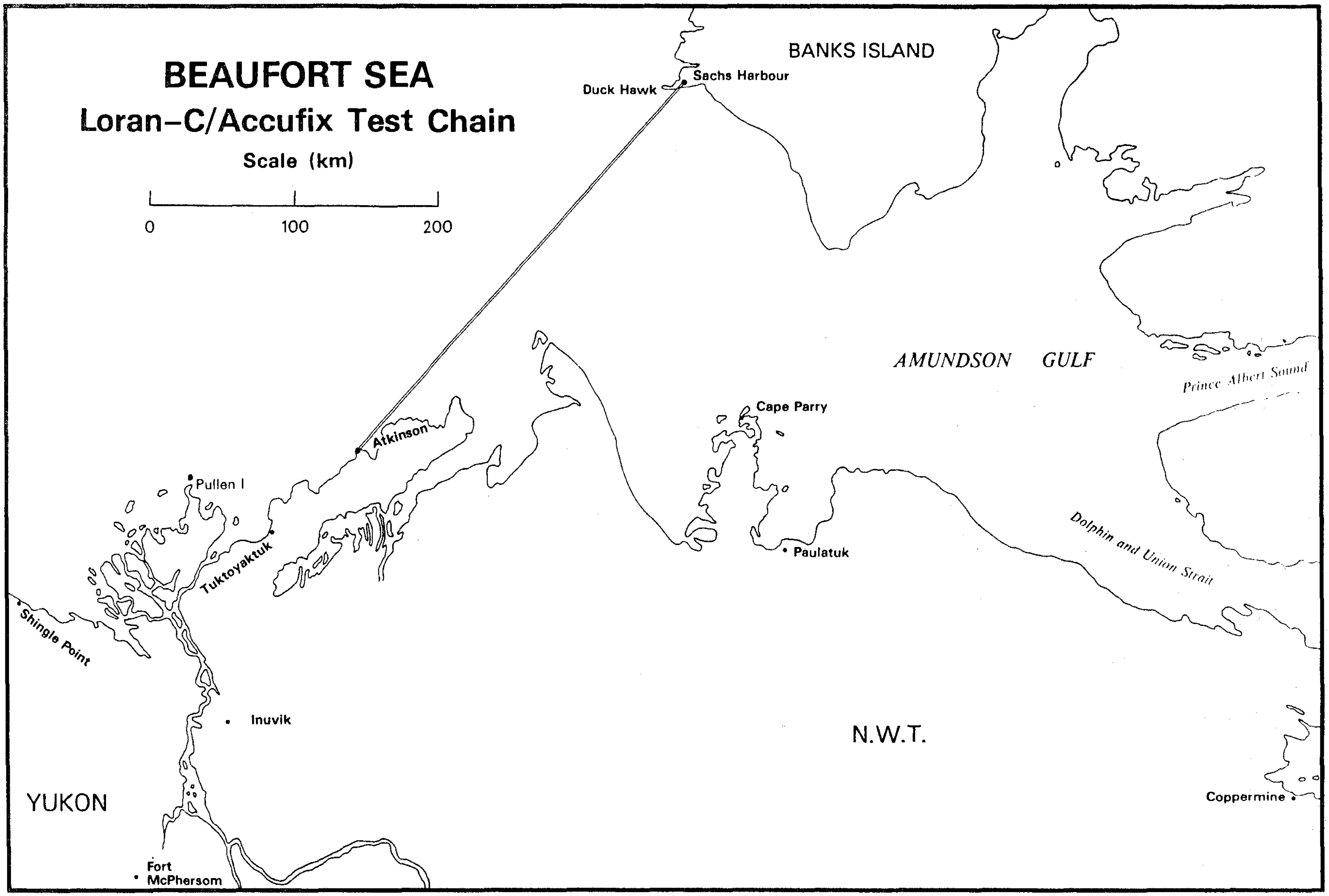
BEAUFORT SEA
Loran–C/Accufix Test Chain
Scale (km)
0
100
200
BANKS ISLAND
Sachs Harbour
Duck Hawk
AMUNDSON GULF
Prince Albert Sound
Cape Parry
Atkinson
Pullen I
Tuktoyaktuk
Paulatuk
Dolphin and Union Strait
Shingle Point
Inuvik
N.W.T.
YUKON
Coppermine
Fort McPhersom

Figure 2

(T.D.). The timing at the transmitter was provided by cesium frequency standards, but local phase adjustments were not made. Consequently T.D.'s drifted at the rate of the cesium clocks. To define this drift, and to allow for it in the data analysis, monitor receivers were set up at Tuktoyaktuk and at Pullen I. (in the fall test only). Of course, the transmitter station receivers were also used to define the clock drift. At the transmitters, the pulse rise time and peak power were also logged and correlated with environmental effects such as hoar frost and ground freezing.

Local variations in ground conductivity at the transmitter sites were also of interest. The ground plane at the transmitters consisted of one hundred 150 feet long copper wire radials, tied with a peripheral wire. At the secondary the ground proved to be so poor that for the spring tests the ground mat was lengthened using fifteen 500 feet long radials extending 650 feet from the tower. A noticeable improvement in pulse shape was achieved as well as some increase in peak power. The master transmitter tower proved to be adequately grounded in the active zone of the Mackenzie Delta permafrost. Another problem expected at the transmitter sites was icing on the tower. We had had recent experience of heavy icing on a short-lived tower on the Labrador Coast. Fortunately, icing does not appear to be a major problem in the Western Arctic. We experienced heavy frosting on the towers in both September and April. Nothing structurally disasterous occurred, however the frost did cause the Accufix automatic tuning to reach its limits.

At the start of the fall tests the guys on the master antenna were changed from steel to Kevlar (see Ref. 4). Kevlar is a brand name for a non-conductive artificial fibre rope. It is relatively strong for its diameter and weight. We were unable to change the top guys but the use of Kevlar did produce a small increase in signal strength. A change of +1 db was observed at Tuktoyaktuk, 80 kilometers away

2. Propagation

One of the main objectives of the tests was to estimate the effective conductivity of 100 Kilohertz (KHz) transmissions over the principal types of Arctic terrain. Passive ranging techniques that are used in southern Canada (Ref. 2) for phase lag measurements were not applicable in the Arctic because of logistics problems. Therefore time difference measurements were used to estimate phase lags. This procedure required some interpolation.

A. The transmitter baseline and the transmission paths to the monitor at Pullen I. were over water or water and ice. We were confident that we had a good estimate of phase lags over water and fair knowledge of low frequency propagation over ice (Ref. 3). Therefore having measured the emission delay, by both direct measurement on crossing the baseline extension with a helicopter-borne receiver, and by interpolation from the T.D. observed at the Pullen I. monitor receiver, the test chains coding delay was established. The use of the helicopter-borne receiver, an Internav 123 with aircraft firmware, allowed us to positively establish the chain emission delay for the spring tests.

B. With the chain parameters, clock drift and over sea phase lags known, we were able to estimate overland phase lags and corresponding conductivities from observations at several places in the Western Arctic. A mobile monitor party travelled to C. Parry, Paulatuk, Shingle Pt., Inuvik and Fort MacPherson during both the fall and spring tests. See Figure 3. All these sites were occupied for about 48 hours. T.D. measurements were also made at Coppermine in the spring. The positions of the test sites

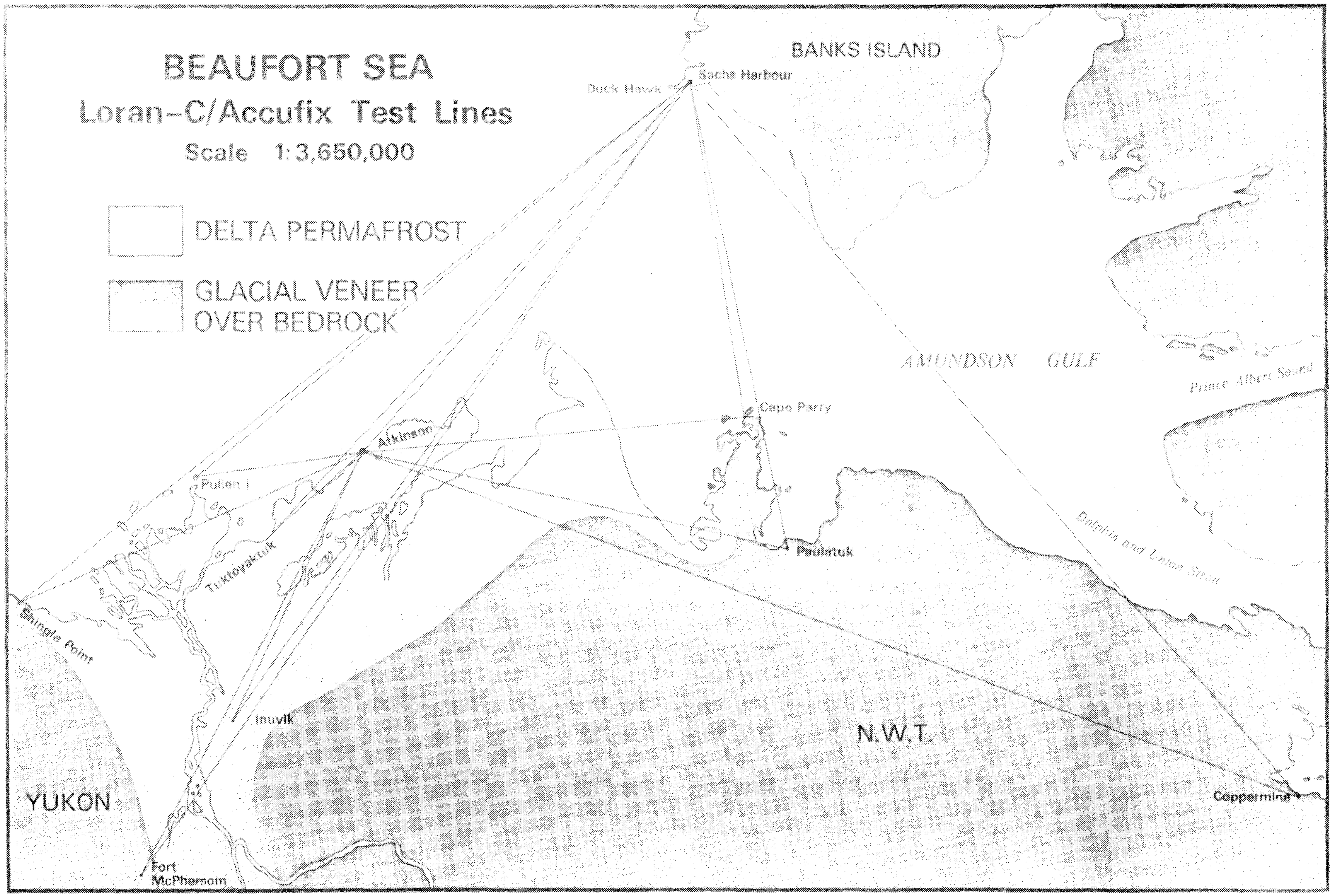
BEAUFORT SEA
Loran-C/Accufix Test Lines
Scale 1:3,650,000
DELTA PERMAFROST
GLACIAL VENEER
OVER BEDROCK
BANKS ISLAND
Duck Hawk
Sachs Harbour
AMUNDSON GULF
Prince Albert Sound
Cape Parry
Atkinson
Pullen I
Tuktoyaktuk
Paulatuk
Dolphin and Union Strait
Shingle Point
Inuvik
N.W.T.
YUKON
Coppermine
Fort
McPhersom

Figure 3

were measured using doppler satellite measurements with an accuracy in the order of ±10 metres.

Table 1

Chain and Test Site Parameters

Master Lat.	69-56-02.891	Secondary Lat.	71-58-04.650
Lon.	131-25-56.804	Lon.	125-36-41.701
Baseline length	310.382 kms	G.R.I.	49300 μsecs
	Fall		Spring
Coding Delay	10866.4 μsecs		10873.9 μsecs
Baseline Phase Lag	0.82 μsecs (sea-ice)		1.22 μsecs (sea-water)
Baseline Conductivity	2.6 mhos/metre		0.08 mhos/metre

Monitor Sites	Distance to Transmitters (Kms) Master	Secondary
Cape Parry	258.329	203.991
Paulatuk	293.102	297.404
Shingle Pt.	253.733	549.532
Inuvik	198.673	505.166
Fort MacPherson	314.162	620.903
Coppermine	694.833	611.269
Tuktoyaktuk	83.135	392.753
Pullen I.	115.210	403.165

3. System Capabilities

In addition to phase lag measurements, the data collected at the monitor sites was also used to show the chains signal stability and potential accuracy. Cycle selection tests were made at each site. As a receiver's ability to choose the correct cycle is generally at least 10db less sensitive than its ability to track the signal, these tests provided a good indication of the maximum range for reliable acquisition. Signal strength measurements were also made using an Internav 303 receiver, an S.S.4 signal strength meter and a loop antenna. At each monitor site an identical ground plane was laid out for both the signal strength and for the phase measurements.

4. Seasonal Variations

An important aspect of the tests was to attempt to define any seasonal changes affecting transmitter operation, accuracies or other requirements of a potential chain. The upper layer (active zone) of the permafrost in the Western Arctic thaws out in summer to depths of between one and two metres. So changes in conductivity, affecting both the transmitters and the propagation paths, were possible.

The sea ice in the Beaufort Sea retreats in summer, sometimes as far north as a line from Banks I. to the Alaska border (see Fig. 2). In winter, leads lie between the shore fast ice and first year ice and the polar pack further offshore. Therefore, considerable changes in the characteristics of the over water segments of the propagation paths were also possible. In addition, to our major interest in measuring any seasonal change in phase lags, we also looked for changes in signal stability and in cycle identification capabilities.

DATA ANALYSIS

The data collected during the two tests was analyzed by Internav Ltd., who also participated in the field work. Two reports cover the analysis (see Refs. 5 and 6).

Comments on Monitor Sites

Although the ambient atmospheric noise is generally low throughout the Western Arctic, local man-made noise caused considerable problems. Each site represented a challenge to select a place with shelter and access to a power supply, but without interference from powerlines or reflecting buildings or esoteric ground systems for A.C. power. So each field site had its individual quirks some of which warrant comment. A local anomaly in time difference readings was observed at Cape Parry Dewline site. It amounted to a four microsecond difference between observed and computed time difference. This anomaly was found to be localized by making additional satisfactory, measurements at a site two kilometres away, but we have no explanation for this shift.

Strong local man-made noise was experienced at Tuktoyaktuk, at Pullen Island Monitor site and at Fort MacPherson. Noise due to precipitation static, even from blowing snow, did not present a problem at the field sites, but this source of noise can still be expected to give the sea-going user the same problems he has to cope with in lower latitudes.

Clock Drift

All time differences observed at the field monitor sites had to be adjusted for the drift of the cesium frequency standards controlling transmitters. The drift rate was assumed to be linear and was based on continuous T.D. observations at the chain monitor either on Pullen I. (in the fall) or at Tuktoyaktuk (in the spring). After compensation for clock drift the observed T.D.s from the field monitor sites were averaged for the period of observation at each site.

Signal Stability

To assess the received signal stability at each monitor site the T.D. data was edited through 300 nanosecond window. Table 2 shows both the population standard deviation, which can be used to demonstrate the chains short term stability, and the standard deviation of the mean, which is helpful in quantifying the errors in our phase lag measurements.

Table 2

Short Term Signal Stability (Nanoseconds)

	Population Stnd. Dev.		Stnd. Dev. of the Means	
	Fall	Spring	Fall	Spring
C. Parry Dewline	44	8	2	1
C. Parry Strip	-	37	-	5
Paulatuk	23	133	1	10
Shingle Pt.	14	48	1	2
Inuvik	20	36	1	2
Ft. MacPherson	36	28	6	2
Pullen I.	68	-	6	-
Coppermine	-	247	-	-

The use of the 300 nanosecond window was mainly an aid in data processing to eliminate lost signals and other blunders. The standard deviations shown above can be directly related to distance from the transmitters and to local noise. Coppermine had the greatest instability and was the farthest site from the transmitters. At Paulatuk where the second largest standard deviations occurred, the instability can be attributed to low line voltages, which can cause small phase errors. The excellent results at the remainder of the sites were due to their moderate distances from the transmitters and/or low local noise levels.

Phase Lag Calculations

Having positioned each monitor site using up to 30 fixes accummulated on a JMR4 satellite receiver, the distances to the transmitters were computed. The land and sea segment lengths for each path were then scaled from topographic maps. With this information phase lag calculations were made using Millington's method (Ref. 7). T.D. values were calculated using:

$$TD = CD + (BLTT + PL_b) + (STT + PL_s) - (MTT + PL_m) \quad (1)$$

where
TD = time difference
CD = coding delay
BLTT = baseline travel time
PL_b = baseline phase lag
STT = secondary travel time
PL_s = secondary phase lag
MTT = master travel time
PL_m = master phase lag

The emission delay (coding delay pulse baseline travel time) was established:

A. For the fall tests, using T.D. observations at the Pullen I. monitor and conductivity of 2.6 mhos/metre, and

B. For the spring tests, using baseline extension crossing data obtained with a helicopter-borne receiver and a sea-ice conductivity of 0.08 mhos/metre. For the land paths on the baseline extensions a conductivity of 3 millimhos/metre (mmho/metre) was used.

To estimate the actual conductivities along the land paths an iterative process was used. For the first estimate a reasonable conductivity was selected and the phase lags were computed using Brunav's polynomial approximations (see Ref. 8). Our estimate of the conductivity was then refined and the process repeated until a good agreement was achieved between the observed and calculated data. The "best fit" obtained was 1.4 mmhos/metre for the fall tests (see Table 3) and 3 mmhos/metre for the spring tests (see Table 4).

Table 3

Phase Lags - Fall Tests

(At 1.4 mmhos/metre conductivity overland and 2.6 mhos/metre conductivity over water)

Site	PL_m	PL_s	T.D. (Calc.)	T.D. (Obs.)	Residual
Paulatuk	2.55	0.98	11915.28	11915.65	0.39
Shingle Pt.	1.41	1.50	12889.28	12889.49	0.19
Inuvik	2.43	3.00	12925.58	12925.16	-0.42
Ft. MacPherson	3.39	3.75	12926.14	12925.87	-0.27
Pullen I.	0.45	1.07	12863.75	12863.55	-0.20

Table 4

Phase Lags - Spring Tests

(At 3 mmhos/metre conductivity overland and 0.08 mhos/metre conductivity over water)

Site	PL_m	PL_s	T.D. (Calc.)	T.D. (Obs.)	Residual
Cape Parry Strip	1.78	1.04	11728.37	11728.42	0.05
Paulatuk	2.26	1.47	11923.93	11923.58	-0.35
Shingle Pt.	1.54	2.34	12897.92	11897.68	-0.24
Inuvik	1.96	3.02	12993.78	12933.49	-0.29
Ft. MacPherson	2.75	3.71	12934.53	12934.32	-0.21
Tuktoyaktuk	0.73	2.00	12944.21	12944.07	-0.14
Pullen I.	0.64	1.76	12871.96	12872.04	+0.08
Coppermine	5.70	3.39	11629.05	11628.38	-0.67

The four sites, Shingle Pt., Inuvik, Tuktoyaktuk and Fort MacPherson, where delta terrain dominates along the land path, have only a 0.15 μsec spread for the spring tests. The largest residual is for Coppermine where the transmission path from master crosses upland terrain. The "best fit" conductivities for each site during the spring tests is given in Table 5.

Table 5

Conductivities - Spring Tests
(assuming 0.08 mhos/metre over sea ice)

Site	T.D. (Calc.)	T.D. (Obs.)	Land Conductivity (mmho/metre)
Cape Parry	11728.42	11728.41	3.0
Paulatuk	11923.58	11923.58	1.6
Shingle Pt.	12897.68	12897.68	2.0
Inuvik	12933.50	12933.49	0.7
Tuktoyaktuk	12944.08	12944.07	0.75
Fort MacPherson	12934.31	12934.32	1.25
Coppermine	11628.74	11628.38	0.5

The discrepancy between the measured and calculated T.D.s at Coppermine is due to the insensitivity of the model for the relationship between phase lag and conductivity for this range and terrain.

All assumptions about conductivity depend heavily on the chain constants. For example an increase of 0.2 μsec in the coding delay would show up in the end analysis as a change of 1.5 to 2 mmho/metre in conductivity. Therefore, given the uncertainties in the coding delay it can be stated that 3 mmhos/metre is a fair estimate for the conductivity of 100 KHz transmissions over arctic terrains but the actual conductivity may lie between 0.5 and 5 mmhos/metre.

A comparison showing the change of observed T.D.s at the sites between the fall and spring test is given in Table 6. All T.D.s have been reduced, using the Pullen I. remote site (1 km from any noise or obstructions) as the reference point.

Table 6

Seasonal Change in Time Differences
(referred in Pullen I. remote site)

	Fall 1980	Spring 1980	Difference
Cape Parry	11716.90	11717.05	+0.15
Paulatuk	11915.65	11915.30	-0.35
Shingle Pt.	12889.47	12889.40	-0.07
Inuvik	12925.16	12925.21	+0.05
Ft. MacPherson	12925.87	12926.04	+0.17
Pullen Monitor	12863.55	12863.76	+0.21
Pullen Remote	12863.70	12863.70	Held constant
Tuktoyaktuk	12935.96	12935.79	-0.17

The seasonal change is quite large and would be larger on the opposite side of the baseline bisector from the chain monitor. However, changes as large as this are seen on main-chain Loran-C, and the largest shift, at Paulatuk, is less than 100 m and so would not show at chart scale.

Signal Strength

Measurements for signal strength were made at the field sites using an Internav 303D receiver, SS4 signal strength metre and a loop antenna. As the transmitter performance was improved for the spring tests a seasonal comparison is not valid. The observed signal strengths and estimates of conductivities derived from them are listed in Table 7.

Table 7

Signal Strengths and Derived Conductivities - Spring Tests

Site	Master (in db above/1 μvolt/metre)	Secondary	Land Conductivity (in mmhos/metre)
Cape Parry	72.5	65.0	>10
Shingle Pt.	49.5	36.5	$1 < \sigma < 5$
Inuvik	49.0	32.5	$1 < \sigma < 5$
Ft. MacPherson	45.5	31.0	$1 < \sigma < 5$
Tuktoyaktuk	65.0	44.0	$1 < \sigma < 5$
Paulatuk	48.0	48.0	$1 < \sigma < 5$

The observed signal strength at Cape Parry is higher than expected, and probably another indication of the local anomaly found at this site. Using signal strengths to estimate land conductivities is less sensitive than using time differences. Errors in our observations are ±2 db. Conductivity calculations were made using the well known U.S. Coast Guard (1-EEE-4/63) graph of field intensity, conductivity and distance. The conductivities derived from our signal strength measurements do serve to confirm those made from time difference measurements.

Cycle Selection Tests

A prime qualitative test of Loran-C performance is the reliability of correct cycle selection. In the fall, three different receivers were used for these tests, 2 Internav 303s and a 204. In the spring four receivers were used, a Furuno LC200, and an Internav 303, 204 and 123. The results of the tests are tabulated in Table 9. This type of test is made simply by turning the receiver on and waiting for it to settle. The discrepancy if any, between the correct T.D. and the acquired T.D. is noted. These discrepancies in units ±10 μsecs are given in Table 8.

Table 8

Cycle Selection Tests

	No. of Tests	Percentages Correct	-10	+10	No. of Tests	Percentages Correct	-10	+10
Cape Parry Dewline	28	100	0	0	74	91	0	0
" " Strip	-	-	-	-	88	100	0	0
Paulatuk	28	100	0	0	70	100	0	0
Shingle Pt.	62	100	0	0	95	98	1	1
Inuvik	20	80	20	0	125	99	0	1
Ft. MacPherson	44	77	23	0	90	94	0	6
Ft. MacPherson Remote	-	-	-	-	40	100	0	0
Tuktoyaktuk	62	24	0	76	57	100	0	0
Pullen I.	-	-	-	-	16	100	0	0
Coppermine	-	-	-	-	26	92	8	0

The improvements (mainly by extending the ground mat) made at the transmitter for the spring tests are apparent from the above data. Local noise at the field sites continued to be a problem. These cycle identification tests did show that even with a high proportion of land path, reliable signal acquisition could be made at distances of 600 kms from the transmitter.

COMMENTS

In general, the Loran-C/Accufix tests were successful in meeting their objectives. They demonstrated that the system can provide good positioning for shipping, and for some aircraft operations, in the Arctic under both winter and summer conditions. Accuracies and repeatabilities similar to those given by Loran-C chains in other areas could be achieved if careful attention is paid to transmitter site selection, to chain monitor site selection, to transmitter operation and chart lattice preparation.

The following comments can be made in response to the objectives set for the tests.

1. Stable signals were received at ranges of 600 kilometres. There were no significant differences between summer and winter signal stability. Therefore a potential Accufix chain should provide a similar short-term repeatability as a conventional Loran-C chain.
2. Signals were reliably received and accurate third cycle selection was made at ranges up to 600 km. From experience gained in the first tests the pulse shape was improved for the spring tests and the signal was accurately acquired at all monitor sites except Cape Parry and Coppermine (700 km). The problem at Cape Parry is not resolved but is known to be limited to a small local area around the D.E.W. Line site. At Coppermine

the long ranges caused some cycle selection errors.

3. The 1000 watt, 150 ft transmitter configuration provided the results described in this section. Changing weather conditions during both the summer and spring tests did point to the need for continuous operator attention or for transmitter modification to minimize operator attention. Poor electrical ground conditions on Banks Island also indicated the requirement for very careful transmitter site selection.

4. Using the results of earlier C.H.S. measurements for the effective conductivity of low frequency propagation over seawater and ice in the Arctic, the conductivity over land in the Mackenzie Delta was found to be between 0.5 and 5 mmhos/metre with a best estimate at 3 mmhos/metre. A more detailed breakdown of the terrain paths may yield more specific conductivity estimates.

5. The results given in this section show that skywave interference does not present an operational problem up to ranges of 600 kms.

6. Seasonal variations were found to be less significant than supposed when planning the tests. No change was noted in the range or reliability of signal selection.

ACKNOWLEDGEMENTS

Dome Petroleum Ltd.'s substantial support for the tests is greatly appreciated. Thanks are also due to Imperial Oil Ltd. for the use of their facilities at Pullen Island. We also wish to acknowledge the assistance given the field party by people at the various communities and D.E.W. Line sites we visited. Marinav Corporation provided us with willing help and reliable transmitter operation. The Polar Continental Shelf Project provided us with logistics support.

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OPERATIONAL AND ECONOMIC BENEFITS DERIVING FROM USE OF LORAN-C RNAV

William Polhemus
Polhemus Associates, Inc.
Burlington, Vermont

ABSTRACT

For the past two years the Department of Transportation, NASA, and Vermont's Agency of Transportation have been teamed in an effort to determine the technical and operational suitability of Loran-C RNAV for use in flights where traditional VOR/DME coverage is marginal and at airports where it is uneconomic or technically difficult to install instrument landing systems.

The State of Vermont's Agency of Transportation and the FAA's Technical Center in Atlantic City were responsible for flight operations. NASA's Langley Research Center and the DOT's Transportation Systems Center were responsible for operation of ground monitor facilities, data reduction and evaluation, and reports.

Long term availability, stability, and reliability of the transmitted signals were measured at three Vermont airports using permanently installed data gathering units and more than 200 hours of instrument flight evaluation were completed. A 10 meter accuracy independent ground truth system was used to measure performance of the airborne RNAV system.

The conclusions reached by the team are summarized below in terms of measured equipment error. No compensation for grid bias is present in these data.

	A Long Track	Cross Track
Enroute	0.13 nm	0.15 nm
Terminal	0.15 nm	0.16 nm
Approach	0.16 nm	0.16 nm

Sample size for each determination is greater than 11,000 data points. Slight technical error is not included in this summary but is considered in the body of this report. The failures listed are...mean plus two standard deviations... quantities.

Availability of required Loran signals exceeded 99 percent as did reliability of the airborne navigation data. Alternate triad configurations were used on many occasions, and when calibration for grid bias was introduced, system accuracy was always within the limits for equipment error set by FAA Advisory Circular 90-45. It was concluded that the Loran-C RNAV system can meet published FAA criteria for use in the National Air Space under both VFR and IFR conditions.

BIOGRAPHICAL SKETCH

Major Polhemus is a Private Pilot, Flight Navigator, and USAF Navigator Bombardier. He was a member of the USAF B-58 crew which received the 1961 Harmon and MacKay trophies for the first supersonic crossing of the Atlantic

Ocean. He also participated in flights in the Western United States which secured six international world speed records formerly held by Russian and French aviators. He is a past President of the U.S. Institute of Navigation and a winner of its Burka and Outstanding Achievement Awards, a Fellow and Bronze Medal winner of the Royal Institute of Navigation and an Associate Fellow of the Canadian Aeronautics and Space Institute. Since 1962 he has been active in research, development, and flight evaluation of navigation equipment. Since July 1979 Bill Polhemus has been under contract to Vermont's Agency of Transportation as navigation and flight operation consultant in the furtherance of the work described in this paper.

LORAN-C RNAV: THE BEST NEAR TERM SOLUTION TO AIR OPERATIONS IN NORTH EASTERN NORTH AMERICA

Major W.L. Polhemus USAF(Ret'd)
AFCASI, FIN

The State of Vermont has been involved in a long term effort to attract industrial and service-oriented high technology businesses to the State to offset declining agricultural income and employment. These efforts have in turn led to increasing demand from Vermont travelers for improvements in air transportation by the airline, air taxi and business aircraft community.

With the exception of the international airport at Burlington, aircraft movements into and out of the State's airports are inhibited by lack of suitable terminal and approach aids at most airports. This has resulted in low airport utilization, an excessive delay history and frequent cancellations; all factors which affect the confidence of the traveling public, aircraft owner/operator economics, airline fares, and (undoubtedly) federal subsidies paid to the carriers which provide "essential air service".

Of the 48 runways and 2 waterways at the 20 'public use' facilities in the State only one runway is equipped with an ILS; two others are serviced by Localizers and a third offers an LDA approach whose minimums are 900 to 1000 feet (AGL) Decision Height and 3 miles Runway Visibility Range (hardly an IFR-class service).

In addition to the four airports equipped with Localizer capability five other airports are serviced by either VOR or NDB non-precision approaches, four of which are circling approaches, and thus have relatively high minimums. Eleven airports can be used only under VFR conditions.

The instrument departure situation is similarly restrictive in its effect on efficient and economic use of the State's airports. In most cases one must either climb-out over the airport itself, over the single nav aid servicing the airport, or must use some combination of the two procedures before the aircraft is free to depart the area.

Only one terminal in the state is equipped with radar, an IFR room, and tower personnel; thus there is no means available to expedite and or separate traffic at 95% of Vermont's airports.

The location and operational characteristics of the available navigation aids is also a source of schedule-related delays, increased fuel usage and increased operating costs. The situation at Rutland Airport, a CAB designated "essential service" facility, is presented as an example typical of a high percentage of airports

Figure 1: Burlington Runway 15, Loran Approach Through Windshield

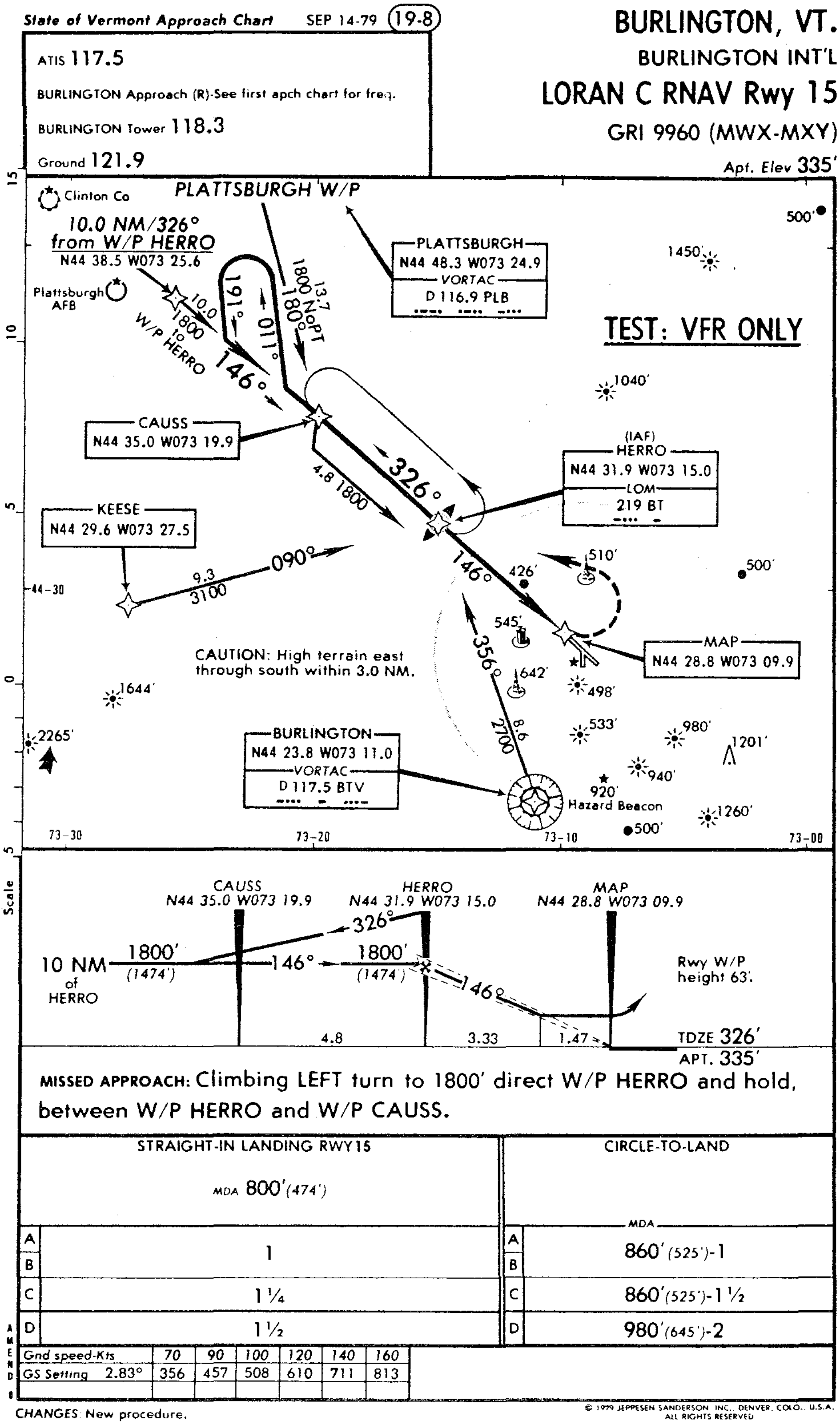

FIGURE 2 LORAN-C APPROACH TO RUNWAY 15 AT BURLINGTON INTERNATIONAL AIRPORT

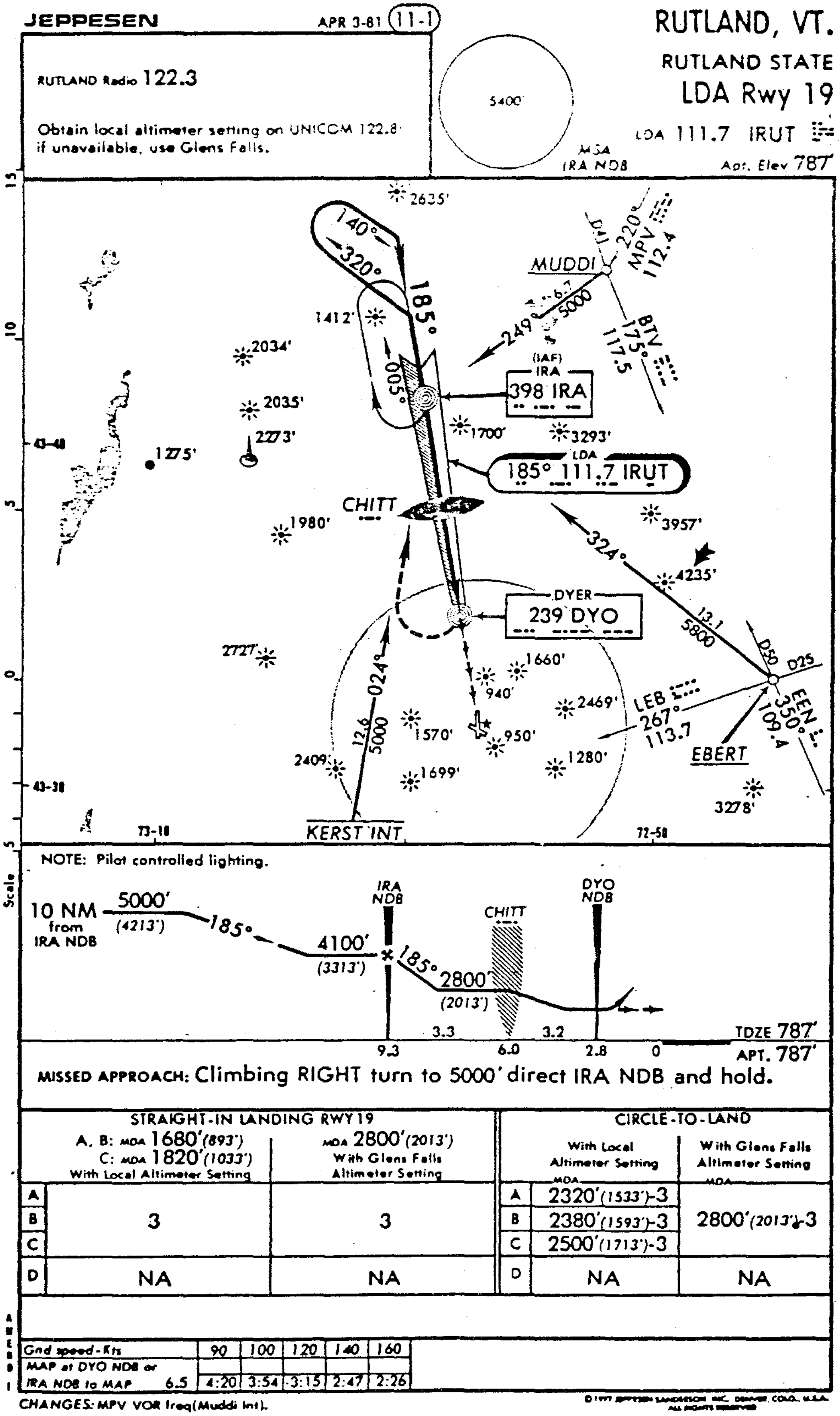

Figure 3 RUTLAND NDB/LOC APPROACH CHART

ARRIVAL AND APPROACH

around the nation. (please refer to Figure 3 a copy of a Jeppesen-Sanderson Approach Chart.)

The terminal-area navigation aid is the NDB (IRA) located 9.3 nm north of the airport. Because the airport is situated more than 30 miles from the nearest VOR facility and is surrounded by mountains reception of any VHF nav aid signal is not possible when an aircraft is below an altitude of 4000 feet.

The departure flight paths, arrival routes, holding pattern and missed approach procedure all converge on this single aid. Terminal radar and control tower assistance are not available. All inbound and outbound IFR traffic must coordinate movements through Boston Center either by land-line if on the ground, or via VHF radio communication with remotely located ATC Center personnel if airborne.

In consequence, a departing aircraft not only denies any inbound aircraft an opportunity to begin its approach once the outbound aircraft has been cleared to begin its departure sequence but also forces any arriving IFR aircraft to hold at an altitude sufficiently high to allow the outbound aircraft to reach its initial enroute altitude for its planned direction of flight and to depart the NDB. This procedure usually entails a delay of 15 minutes or more.

An inbound aircraft, cleared to make its approach by ATC, similarly blocks the airspace for a protracted period for aircraft preparing to take off as well as for the next arriving aircraft, since the block of time which is reserved must be sufficient to permit execution of the instrument approach, plus allowance for return to the NDB in the event of a Missed Approach; or, alternatively, to permit the aircraft to land, shut down engines and to notify the Center by telephone that it has cleared the airspace.

Again the delay is frequently in excess of 15 minutes. Under these ground rules it is clear that runway acceptance rate is severely limited which, in turn, adversely affects the economics of that airport's operation, schedule reliability of the servicing carrier, and fuel usage and aircraft operating costs of all Users.

There is still another factor affecting operating costs which should be recognized as one considers the potential of RNAV systems.

The location of the single navigation aid located to the north of the airport dictates that all traffic arriving from the south first proceed north of the airport to the NDB, make descent to the NNW, then return to the NDB before commencing approach. An aircraft departing to a destination in the south or east is similarly penalized . . . since it must first fly to the NDB, regardless of take-off direction, before departing on course. The instrument departure and arrival approach procedures add approximately 15 minutes air time for each case.

As it happens, the commuter air carrier which serves the Rutland Airport operates approximately 4800 flights per year into and out of this airport, all from or to the south. Thus the potential penalty in air miles due to location of the NDB at this terminal is of the order of 154,000 nm. The carrier operates the DHC-6 or Twin-Otter into this facility at an approximate DOC of $2.50 per air mile. The potential penalty is therefore $384,000 per year.

When weather, or the lack thereof, is taken into consideration only some 20% of the carrier's operation requires use of the full IFR procedure thus his penalty is reduced to about $77,000.

During our just-completed Vermont Loran-C RNAV evaluation program,feasibility of utilizing the RNAV system to provide runway-aligned (straight out) departures to the south and to the southeast . . . a procedure which would offer the commuter a savings of approximately $41,000 per year. Straight-in RNAV approaches to runways 1 and 31, see Figure 1, could further reduce this operator's costs by an estimated $36,000. Reductions in fuel usage would be of the order of 22,000 gallons per year. The total benefit equates to adding 1100 revenue-paying passengers to the carrier's manifest each year. The delay/cancellation history would likewise be improved.

We have shown that the opportunity exists to improve operating costs and fuel usage at the two other Vermont airports into which this particular carrier operates . . . the totals for the Vermont portion of its operation could be greater than $126,000 and, for its entire New England service, as much as $324,000.

These estimates were based on the assumptions that 20% of operations are made under full IFR conditions; that is, the pilot cannot cancel his IFR clearance at, say, 10 miles from airport and proceed under VFR visual flight rules; and that the ATC and FAA will accommodate the RNAV procedures. As fuel costs increase the savings will become proportionately greater (we used a price of $1.81 per gallon for jet-A in our estimates), and or if the incidence of instrument conditions were to increase, a greater benefit would be realized.

The generally mountainous terrain and relatively low utilization of Vermont State airports (as contrasted with the more populous states) makes implementation of enough VOR/DMEs and ILSs to service all airports financially unacceptable. Also the terrain adjacent to many of the runways sharply increases installation costs and in some cases makes them technically unfeasible.

Since a Loran-C or Omega User is free to assign any set of geographic coordinates as a waypoint departure or arrival fix, holding point, and in the case of Loran-C RNAV as a runway approach waypoint, without concern for topography, the scene is set for introduction of the low frequency RNAV systems.

AIRPORTS: NEW ENGLAND, DOMESTIC U.S. AND CANADA

In view of the potential which Loran-C RNAV offers to provide instrument departure and approach capabilities where none now exist and or to upgrade the capabilities of existing non-precision approaches (i.e., NDB, VOR and Circling-Only) it is worth taking a moment to place the magnitude of the need for improvements in perspective. The present status of published approaches at public-use facilities is illustrated in the table below for the six New England states plus the State of New York; tables 3 and 4 tabulate similar information for eastern Canada.

Within the section of northeastern U.S. listed in the first table there appear to be 374 airports and 63 seaplane facilities supporting 1152 landing surfaces (1026 runways and 126 waterways).[1] Of this number only 76 or 6.6% of the runways are provided a precision (ILS) approach and an additional 122 with non-precision approach capability. A whopping 954 landing surfaces (83%) cannot be used for other than VFR operations.

On a nationwide basis it has been estimated that there are more than 13,600 suitable runways not equipped for instrument approach and another 4,300-plus which offer only non-precision approach capability.

The Commuter Airline Association of America, 1980 Annual Report, "Decade of Decision", emphasized the situation facing the Commuter industry. The 290 carriers making up the U.S. Commuter industry operate into 610 airports in the 48 contiguous states, of which only 362 are equipped with ILS. While the Federal Aviation Administration plans to install another 104 systems by 1985, 213 airports serviced by scheduled airlines will continue to be without a precision approach aid as we enter 1986.

While the remarks presented thus far would seem to emphasize the situation with respect to commuter or short-haul scheduled operators, the situation is assumed to be similar for air taxi, corporate and business aircraft operators. Though their operations are less well defined and their annual operating hours per aircraft are lower the benefits from reductions in delay at departure, arrival and landing have just as relatively large economic impact.

In order to evaluate potential savings from enroute operations, as a part of the Vermont test program, a Cessna 210 was equipped with a Teledyne TDL-711 Loran-C RNAV System and operated for eight months in a series of typical charter operations. Approximately 460 hours were logged during 130 flights. No effort was made to evaluate terminal and approach operations using the 210 . . . all savings were realized from reductions in trip (enroute) distance.

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[1]Determined from current FAA-approved Sectional charts and Jeppesen-Sanderson Airway Manuals.

TABLE 1

PUBLIC USE AIRPORTS/RUNWAYS AVAILABLE IN NORTHEASTERN U.S. IN INSTRUMENT WEATHER CONDITIONS

STATE	AIRPORTS (& SEAPLANE FACILITIES)	VOR or NDB CIRCL'G-ONLY APPCHS	APTS WITH APPV'D APPCHS TO RWYS	APTS NO INSTRMT APPCH	PERCENT NO APPCH (VFR-ONLY)	RUNWAYS WATERWAYS AVAILABLE (APPROX)	NON-DUPLICATIVE APPV'D APPCHS				TOTAL RWS APPV'D INSTR. APPCH	INS
							PRECISION (ILS)	NON-PRECISION (LOC)	(VOR)	(NDB)		
MAINE	87 (21)	2	20	65	75%	208	4 (1.9%)	5	10	7	26	1
NEW HAMPSHIRE	37 (4)	2	9	26	70%	86	4 (4.6%)	3	3	0	10	
VERMONT	20 (1)	3	6	11	55%	50	2 (4%)	2	2	1	7	
MASSACHUSETTS	68 (8)	10	21	37	54%	190	14 (7.4%)	6	10	6	36	1
CONNECTICUT	38 (5)	6	6	26	68%	100	7 (7%)	0	3	2	12	
RHODE ISLAND	15 (1)	3	3	9	60%	56	3 (5.4%)	1	4	4	12	
NEW YORK	172 (23)	12	63	97	60%	462	42 (9.1%)	9	37	7	95	3
TOTALS	437 (63)	35	166	277	63%	1152	76 (6.6%)	26	69	27	198 (17.2%)	9

Fuel Savings ranged from 2 to 16 percent . . . the average being just shy of 6 percent.

This particular aircraft flys approximately 600 hours per year . . . thus the 6% savings amounted to 860 gallons of fuel and $5300 1980-81 dollars. If one assumes that the reductions are potentially typical for the air taxi industry, the 6700 U.S. aircraft in this category which consume an estimated 137 million gallons of fuel per year could be expected to save in excess of 8 million gallons and 34 million dollars. As Terminal area RNAV procedures permitting "straight-out" departures and straight-in arrivals and approaches become available these savings could be expected to increase significantly.

In our assessment of the possible benefits to be realized by the U.S. General Aviation community we have assumed that approximately 49,000 aircraft are employed by corporations and businesses, that these aircraft are flown almost 11 million hours per year and consume 237 million gallons of fuel. Direct operating costs are estimated to total 1.6 billion dollars. If we assume savings of the order of 6%, as for the air taxi fleet, it would seem that full acceptance and use of RNAV for enroute operations could produce savings of 14 million gallons and 95 million dollars. Improvements in the terminal area would further increase these benefits. Table 2 below summarizes these estimates.

Table 2. Total Annual Potential Savings

User Group	Aircraft Fleet Size	Fuel (gallons)	Direct Operating Costs
Air Taxi	6,700	8,000,000	$ 34,000,000
Commuter	1,600	40,000,000	110,000,000
Bus A/C Fleet	49,000	14,000,000	95,000,000
TOTALS	57,300	62,000,000 gallons	$239,000,000

TABLE 3

PUBLIC USE AERODROME STATUS - EASTERN CANADA

PROVINCE	Aerodromes		Avail. During Instrument Meteorological Conditions				
	Land	Water/Ice	Apts with VOR/NDB Cirling Only	Apts With Published Approaches	Apts with NO Instru. Capa.	Percent Apts VFR Only	Percent All Aerodromes VFR-Only (Water/Ice Fac.plus land facilities)
New Brunswick	12	7	1	5	6	50%	68%
Newfoundland	27	20	0	8	19	70%	83%
Nova Scotia	14	3	0	5	9	64%	71%
Ontario	110	112	11	41	58	53%	77%
Prince Edward Island	3	1	0	2	1	33%	50%
Quebec	96	67	7	31	58	60%	77%
TOTALS	262	210	19	92	151	58%	76%

Notes: (1) Tabulation does not recognize private instrument approaches

(2) Sources: Department of Energy, Mines and Resources Canada WAC Charts
DND Flight Information Publications, Low Altitude Instrument Approach Procedures
DND Flight Information Publications, IFR Supplement Canada and North Atlantic
DND Flight Information Publications, Northern Supplement

TABLE 4

PUBLIC USE RUNWAY/WATERWAY FACILITIES - EASTERN CANADA

PROVINCES	Landing Surfaces		Non-Duplicative Published Appchs					SUMMARY				
	Rwys	Water/ Ice	ILS	LOC (non-precision approach)	VOR (non-precision approach)	NDB (non-precision approach)	TACAN (non-precision approach)	Rwys Approved for Instr. Approach	Rwys NOT Instr.	% NOT Instr.	Total All Surfaces NOT Instrumented (water/ice+Rwys)	Pe
New Brunswick	32	14	5	4	0 (+1 dupl)	0 (+ 7 dupl)	3	12	20	62%	34	
Newfoundland	66	40	8	3	1	4 (+ 9 dupl)	5 (+ 2 dupl)	21	45	68%	85	
Nova Scotia	44	6	6		1	0 (+ 9 dupl)	4 (+ 4 dupl)	17	27	61%	33	
Ontario	340	224	15	8	20 (+ 4 dupl.)	15 (+ 25 dupl.)	5 (+ 11 dupl.)	61	279	82%	503	[illegible]
Prince Edward Island	10	2	1	1	0	0 (+ 3 dupl.)	3	5	5	50%	7	[illegible]
Quebec	230	134	14	13	7 (+ 8 dupl.)	12 (+ 4 dupl.)	2 (+ 5 dupl.)	56	174	76%	308	[illegible]
TOTALS	722	420	49 (6,8%)	35	29	31	22	172 (24%)	550	76%	970	[illegible]

Note: Some runways at a number of airports are instrumented for more than one kind of approach, i.e., both ILS and VOR; in this instance the less accurate non-precision approach is considered the duplicative one (dupl.).

Assuming Fox Harbor operational in the Canadian East Coast Chain, availability of the Northeast U.S. and Great Lakes chains, and a Loran-C receiver which embodies the latest state of the art in airborne RNAV signal processing characteristics, a civil operator should find reliable signals available throughout the Maritimes (except for the region north of the 55th parallel . . . 2 or 3 aerodromes), most of Quebec (approximately 27 of 163 aerodromes outside present coverage) and Ontario (an estimated 12 of 222 aerodromes outside present coverage) as candidates for use of Loran-C RNAV. Tables 3 and 4 below indicate potential benefit to Canadians from adoption of the system.

There is an estimated total of 472 aerodromes (airports and seaplane/ski-equipped facilities) providing approximately 722 runways and 420 waterways. As in the northeast U.S. fewer than 7% of the runways are equipped with ILS, virtually all Localizer approaches are Back Courses of the primary ILS system and 970 landing surfaces (85%) cannot be used for other than VFR operations.

In Canada where floatplane operations may provide the only means of transportation none of the 210 facilities offer instrument approach capability. This is a void which would appear to be admirably served by implementation of Loran-C RNAV, perhaps beginning with circling-only approaches until experience justifies upgrading to straight-in approaches.

I trust that I have established for you a basis for moving ahead forcefully with RNAV. Now let's review Vermont's reasons for its advocacy of Loran-C RNAV.

During the period beginning in October 1978 and continuing through October of this year the U.S. Department of Transportation, the National Aeronautics and Space Administration, and the Agency of Transportation of the State of Vermont have been teamed in an effort to evaluate the technical and operational suitability of Loran-C RNAV for use in areas like Vermont where traditional VOR/DME coverage is marginal and at airports where it is uneconomic or technically difficult to install ILS.

The DOT/Transportation Systems Center's Final Report[1] states that the principal objectives of the program were "to determine

[1]Flight Evaluation of Loran-C in the State of Vermont, F.D. Mackenzie DOT-TSC-RSPA Report 81-10 dtd Sept. 1981

the functional, technical and operational suitability of the low frequency radio navigation aid to meet the needs of civil aviation in the Vermont environment. A necessary element of this determination was the acquisition of independently gathered ground and airborne measurements taken over an extended period of time so as to include, to the extent possible, all expected variations in natural physical phenomena commonly experienced in air operations and likely to affect signal propagation, airborne system performance, pilot workload or interaction with the Air Traffic Control (ATC) system.

The principal measurement tasks included:

1. Acquisition of a statistically significant number of quantitative and qualitative measurements of the airborne RNAV system's behavior.

2. Validation of system accuracy through use of a very precise (10 meters, 2 drms) ground-reference system.

3. Assessment of unique operational and procedural requirements with particular interest in identification of any which could adversely affect pilot workload, acceptance by the ATC system, or flight safety.

4. Accumulation of GA pilot system-acceptance data.

5. Acquisition of Loran-C signal characteristic data at four ground facilities.

6. Compilation of an archive of meteorological data for the period of the evaluation period.

The airborne operations were planned to span a period of approximately 18 calendar months. Three separate but related flight evaluation programs were completed during the project. The first involved approximately 32 flight hours of accuracy testing by the FAA's Technical Center (FAATC) utilizing a Convair 580 aircraft equipped with the two Loran-C systems: a Teledyne Systems Company, high-price-range, TDL-424 unit and second, a TDL-711 mid-price unit, currently used for offshore operations by over 500 helicopters. Neither of these systems was instrumented to supply command guidance information to the aircraft pilot. The CV-580 flight program was under the direction of a FAATC Project Engineer who also had responsibility for reporting, separately, the results of the FAA effort.

The second flight evaluation program, conducted under the direct supervision of the TSC Program Manager, utilized a twin-Beech E-50 aircraft owned and operated by the State of Vermont. The E-50 was equipped with a single Teledyne Systems Company TDL-711 unit and was scheduled to fly approximately 100 flights (totaling 200 hours),

THE AIRCRAFT

Figure 4 : VERMONT STATE TEST AIRCRAFT

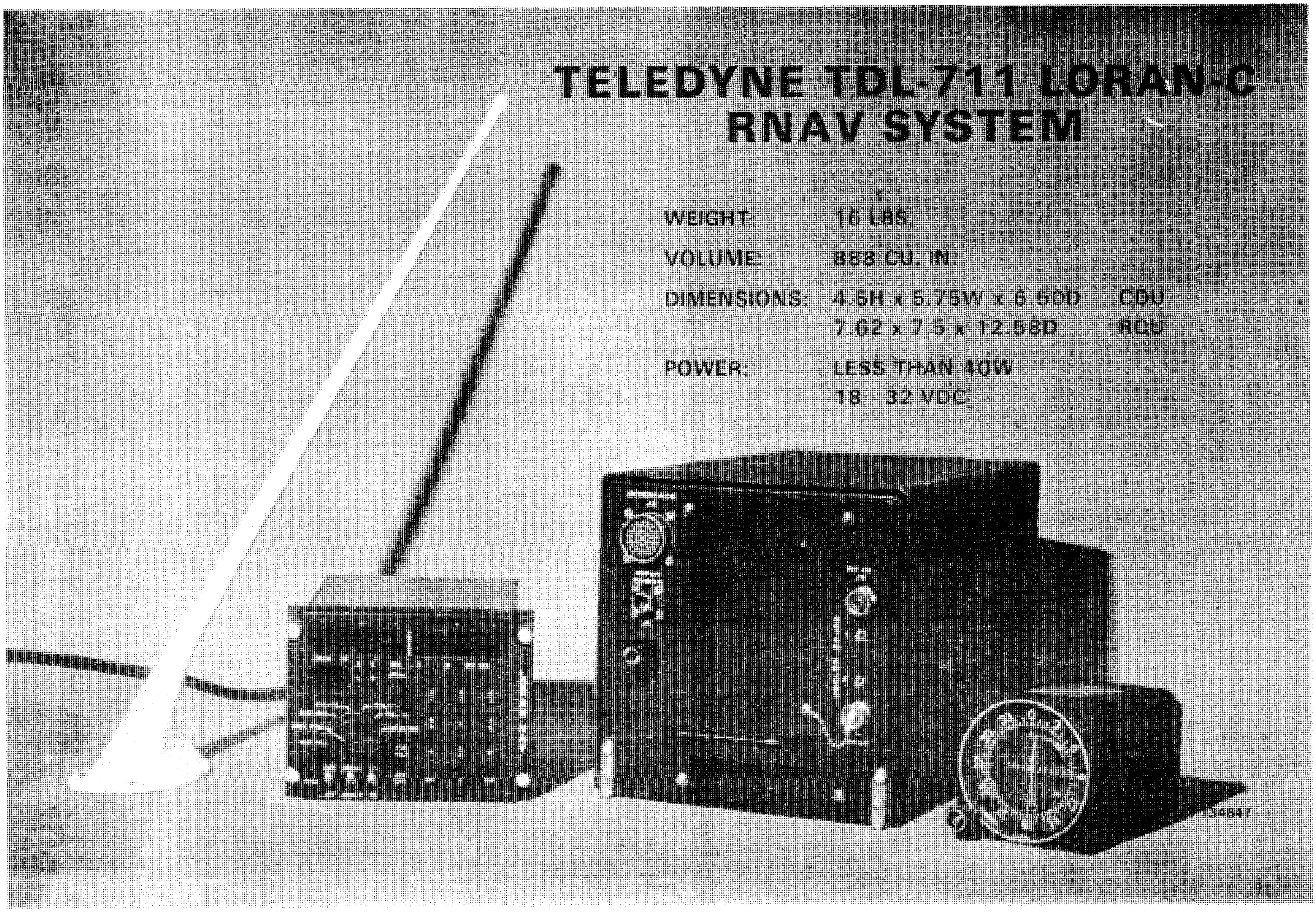

TELEDYNE TDL-711 LORAN-C
RNAV SYSTEM
WEIGHT: 16 LBS.
VOLUME: 888 CU. IN.
DIMENSIONS: 4.5H x 5.75W x 6.50D CDU
7.62 x 7.5 x 12.58D RCU
POWER: LESS THAN 40W
18 - 32 VDC
134647

Figure 5

distributed across the following activities: equipment check out, training, acquisition of performance data, development and evaluation of procedures, determination of pilot workload and system acceptance, and identification of potential ATC interface problems. The TSC/Vermont flight test team successfully completed 104 flights and 226 hours of Loran-C RNAV operation.

The Loran-C RNAV system in the E-50 was instrumented to provide command steering information to the pilot through a dedicated Course Deviation Indicator (CDI) and this configuration was regarded as the "primary mode" of operation.

The third flight evaluation activity was added to the project about halfway through the program. A Cessna 210 aircraft belonging to a local air taxi operator, The Airmaster, Inc., was equipped with a TDL-711 system. This aircraft was also equipped with a dedicated CDI on the pilot's instrument panel. The air taxi operator was requested to evaluate the system during its routine charter operations. Two of the operator's regular pilots were trained to use the equipment and were asked to keep notes on their experiences. A total of 463 hours of successful enroute Loran-C RNAV operation was acquired during the eight month period. The Loran-C RNAV flights reduced expenditures for fuel and operating costs ranging from 2 to 16 percent, with an overall average of 6 percent.

In summary, more than 750 hours of successful airborne Loran-C experience has been gained during the past three years. The project reached its conclusion with award of a Supplemental Type Certificate by the FAA to the State of Vermont in October 1981, authorizing use of Loran-C RNAV for IFR enroute operations."

The State of Vermont resources employed in the test consisted of a Twin-Beech Bonanza; hangaring facilities; operations, maintenance and technical support teams; the State Surveyor and administrative facilities.

Five airports were designated as test sites; runway threshold and airport Loran-calibration sites were carefully surveyed in; state facilities on several mountain tops were made available for installation of the NASA-supplied "Ground-Truth" triangulation system.

The airborne Loran-C RNAV system used in the test program was the Teledyne TDL-711 Loran-C Micronavigator. Outwardly it is similar to many RNAV systems on the market today. Those who have operated ARINC-class inertial and Omega Navigators, for example, will be particularly struck by its similarity of operation. The system, which weighs approximately 16 pounds, consists of an integrated control and display unit, a receiver-computer unit, an antenna with integral coupler and a course deviation indicator.

Figure 6 : CDU and CDI Installation , Cessna 210

During the last few months of the program a Texas Instruments TI 9900 system was added to the aircraft equipment.

Steering commands were presented on a conventional course deviation indicator ... and for the Vermont Project a scale factor change switch was supplied, thereby permitting the pilot to increase sensitivity of the display from one-quarter mile per dot or graduation to one-sixteenth mile (380 feet) per dot.

The Vermont, New England and New York State operations were evaluated using the Northeast Chain, GRI 9960. Four transmitters are available for fixing at any particular time when using this chain though the western transmitter at Dana was used only when the aircraft operated near or west of the Master station at Seneca. Extensive use was made of transmitter de-select, Master independent and calibration modes of operation. During flights to Illinois, Ohio, Indiana and northern Ontario the systems were operated on the Great Lakes Chain, GRI 8970.

The Ground Truth equipment employed for verification of aircraft position was the Motorola Mini Ranger III system, a microwave ranging system incorporating up to four transponders located on high ground in the test area. These transponders were triggered by the Master unit located in the aircraft and provided a measure of position accurate to 10 meters, 95% probability. Output of the Transponders was continuously recorded on data tape.

The airborne instrumentation package used in the Vermont E-50 Beechcraft was designed, fabricated and assembled, and installed by NASA's Langley Research Center. Calibration of ground truth system, Loran-C operation and correct data merging was accomplished at NASA's Wallops Island test range.

A key feature of the project was the assembly of an extensive data base derived from analysis of almost 18 months of continuous operation of four ground-based Loran-C receivers. Four ground stations and two mobile stations were supplied by the Transportation Systems Center, FAA and NASA. The data was analyzed with respect to SNR and ECD behavior and stability of geographic position. The resulting analysis described diurnal and seasonal drift of the basic Loran signals from which position is derived.

Data reduction was accomplished at NASA Langley Research Center and subsequently analyzed by personnel from the Transportation Systems Center and Vermont's Agency of Transportation.

The instrumented State aircraft completed 226 flight hours during which 194 enroute RNAV legs were undertaken, 66 of which were within range of the ground truth scoring system, allowing 23,000 measurements of position error to be made.

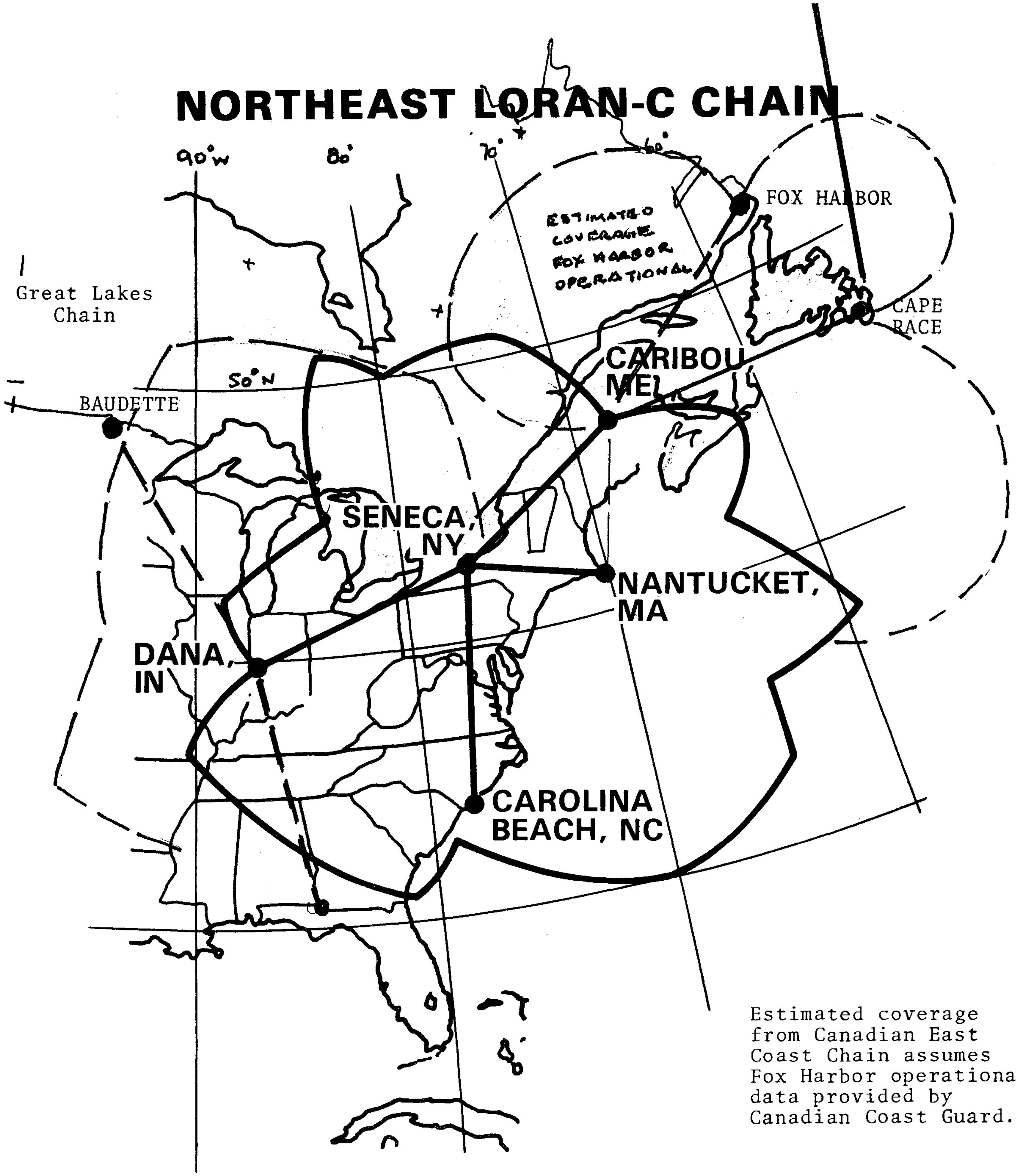

NORTHEAST LORAN-C CHAIN
90°W
80°
70°
60°
50°N
Estimated coverage Fox Harbor operational
FOX HARBOR
CAPE RACE
Great Lakes Chain
BAUDETTE
CARIBOU, ME
SENECA, NY
NANTUCKET, MA
DANA, IN
CAROLINA BEACH, NC
Estimated coverage from Canadian East Coast Chain assumes Fox Harbor operationa data provided by Canadian Coast Guard.

Figure 7

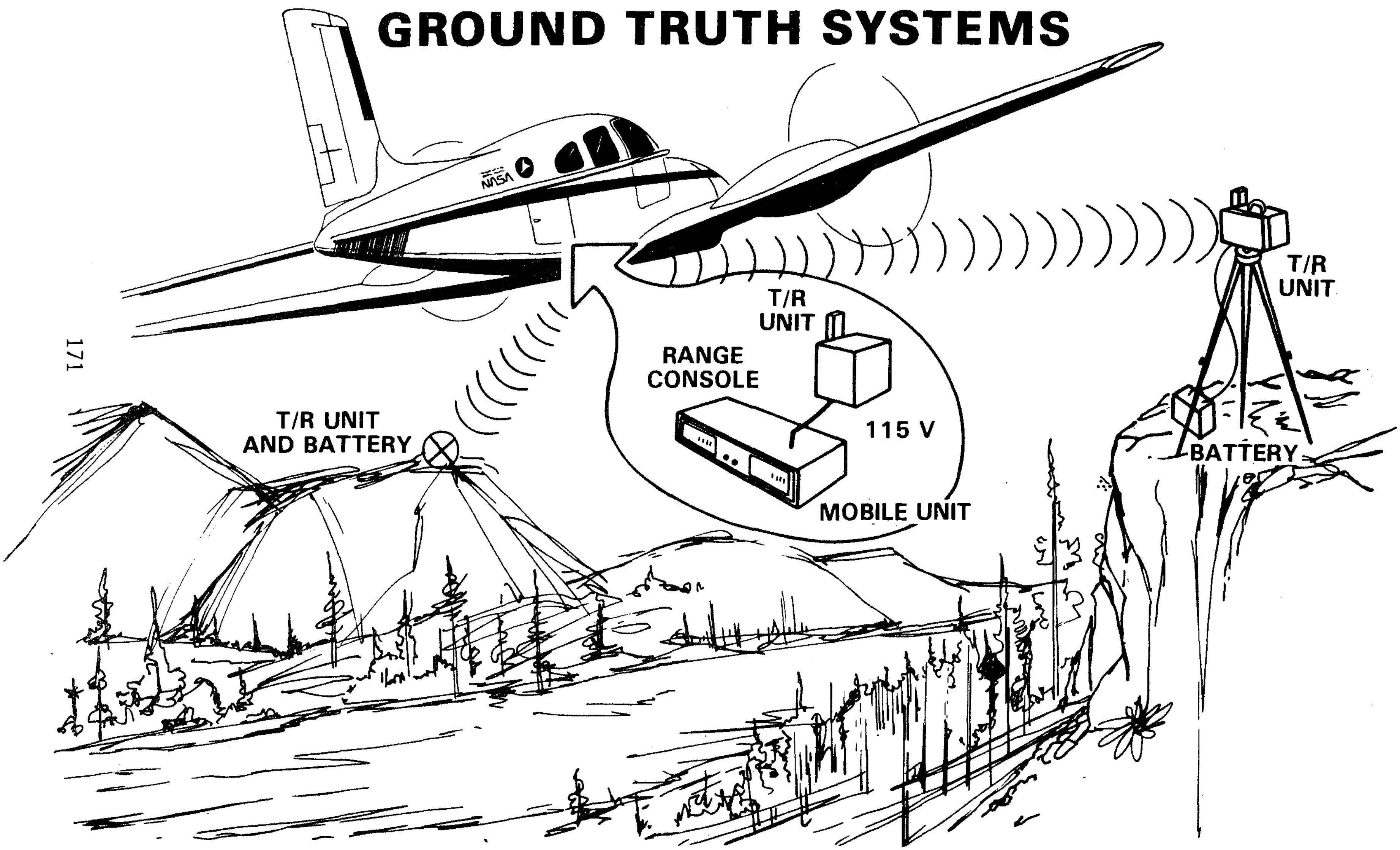

GROUND TRUTH SYSTEMS
T/R UNIT
RANGE CONSOLE
115 V
MOBILE UNIT
T/R UNIT AND BATTERY
T/R UNIT
BATTERY

Figure 8

DATA GATHERING PACKAGE

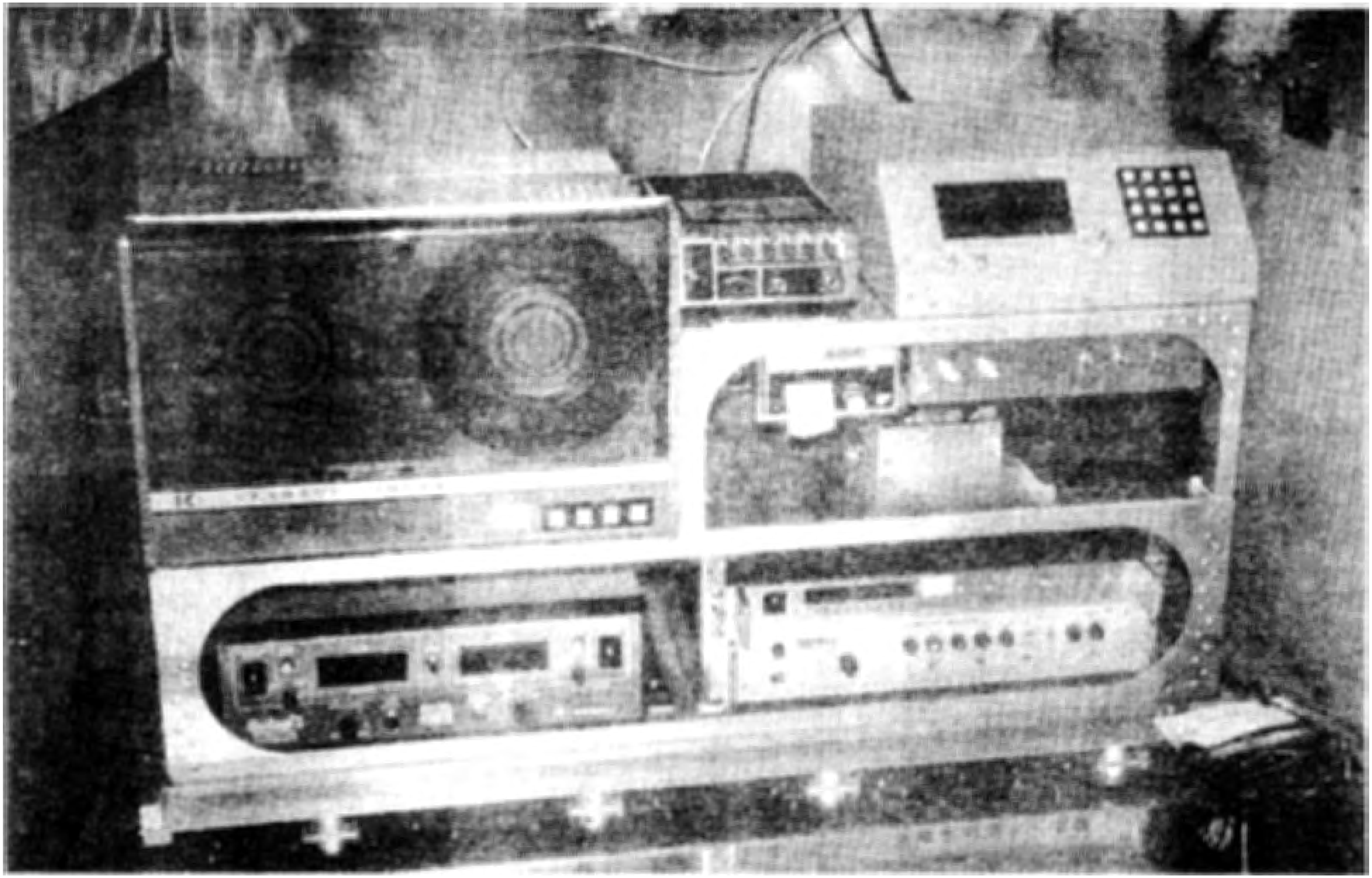


Figure 9

More than 300 non-precision approaches were completed to fourteen runways at ten airports. Seventy-six of these approaches were completed within range of the ground truth system and a total of 272 were scored visually by the aircrew. The ground truth system provided 11,200 measurements of position during the seventy-six electronically-scored approaches.

The results are illustrated below in Tables 5 , 6 and 7 , and summarized in Table 8 . It will be noted that the errors, expressed as mean-plus-two standard deviation values, range from 0.13 to 0.16 nautical miles, and are referenced to "equipment error"; the FAA term for navigation system error with flight technical error removed.

Enroute Phase: (Table 5)

Number of MRS-III scored navigation segments (legs)
Sample: 23,131 measurements.

Table 5 System Errors - Enroute

	Total Sys Error		Equip Error	Flight Tech
	Along Tk (nm)	Cross Tk (nm) (Calculated)	Cross Tk (nm)	Error (nm)
AC 90-45 Req'd Perf.	±1.5	±2.5	±1.5	±2.0
Achieved Performance	±0.13	±0.73	±0.15	±0.71

Note: 1. Total System Cross Track error is a calculated value from $TSCT = [(\text{Equip E.})^2 + (FTE)^2]^{\frac{1}{2}}$

2. Errors are (Mean + 2 σ) values.

3. Required Performance is from FAA AC 90-45A.

Transition or Terminal Phase: (Table 6)

Number of MRS-III scored transition segments ... 101
Sample: 12,410 measurements

Table 6. System Errors - Terminal

	Total Sys Error		Equip Error	Flight Tech
	Along Tk (nm(	Cross Tk (nm)	Cross Tk (nm)	Error (nm)
AC 90-45 Req'd Perf.	±1.1	±1.5	±1.12	±1.0
Achieved Performance	±0.15	±0.6	±0.16	±0.58

Non-Precision Approach Phase: (Table 7)

Number of MRS-III scored Approaches ... 76
Sample: 11,212 measurements

Table 7. System Errors - Approach

	Total Sys Error		Equip Error	Flight Tech
	Along Tk (nm)	Cross Tk (nm) (Calc.)	Cross Tk (nm)	Error (nm)
AC 90-45 Req'd Perf.	±0.3	±0.6	±0.33	±0.50
Achieved Performance	±0.16	±0.32	±0.15	±0.28

The conclusions reached by the team are summarized below in terms of measured Equipment Error. No compensation for grid bias is present in these data.

Table 8 . Summary of Results, Equipment Error

	Along Track	Cross Track
Enroute	0.13 nm	0.15 nm
Terminal	0.15 nm	0.16 nm
Approach	0.16 nm	0.15 nm

The observations were made visually as the aircraft arrived at or abeam runway threshold, thus are a bit less objective than the results obtained using the transponder system.

The Bar Graph, Figure 10 , illustrates the fact that more than 98% of the approaches arrived at runway threshold within ±900 feet of centerline.

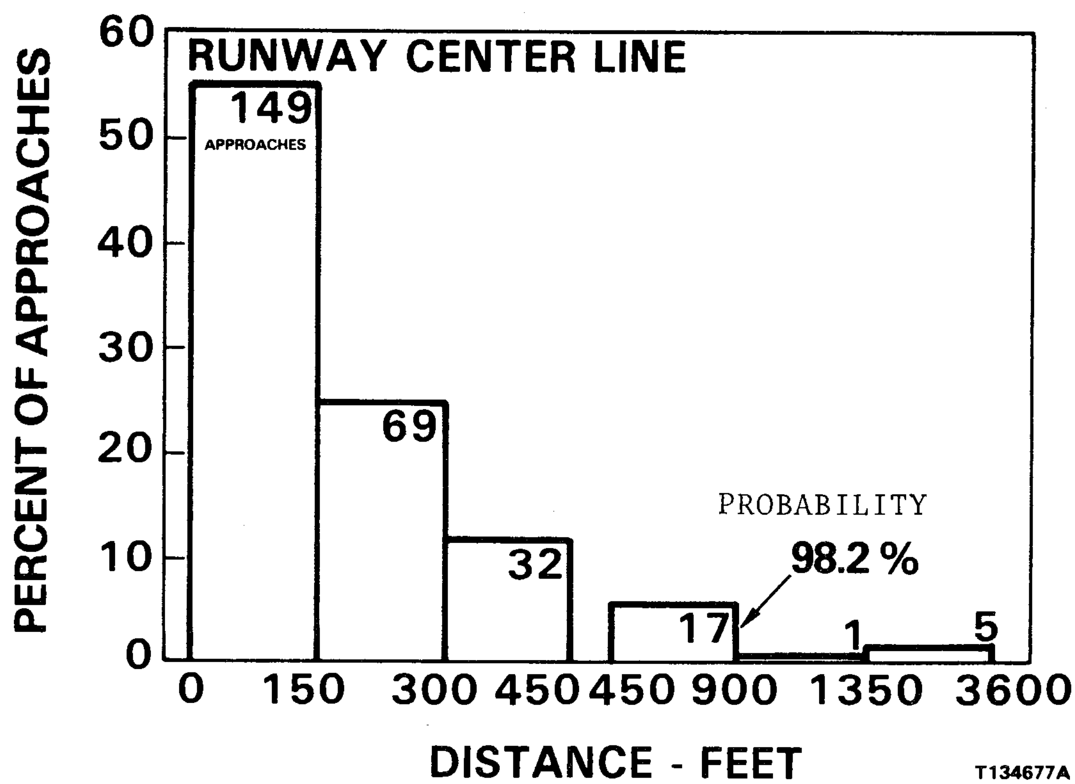


Figure 10 Performance Summary - 272 Non-Precision Approaches

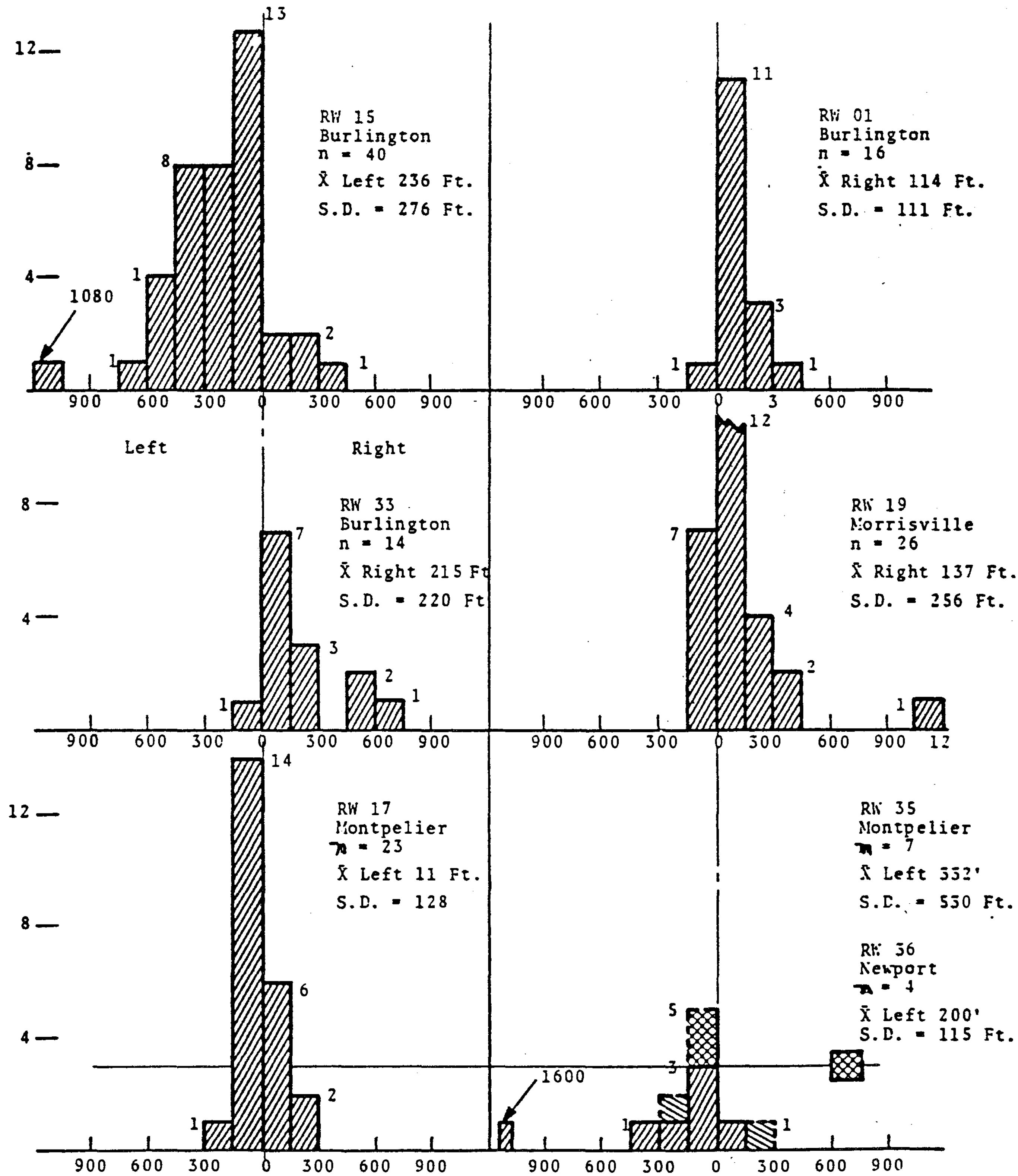


Figure 11 . CROSS-TRACK ERROR, 7 RUNWAYS

The results reported above were obtained across a broad spectrum of environmental conditions . . . broad enough we hope to have detected areas of potentially unsuitable behavior. A statistically significant number of operations were conducted in mountainous terrain; in conditions of heavy rain and snow (including very dry snow; heavy wet snow and light to heavy icing); during thunderstorm activity; at night, during twilight and in daylight.

Signal availability, useability and variability were determined by installing Loran-C ground monitor units and recorders at four locations at three airports in the test area. The measurements allowed determination of signal availability (on-air time), useability, Signal to Noise level (SNR) and Envelope-Cycle Difference (ECD) and temporal stability (repeatability of position as determined by variations in Time Difference values). The data summarized in Tables 9, 10 and 11 and Figure 16 are taken from DOT/TSC Final Report.

The U.S. Coast Guard goal for signal availability is an on-air record of 99.7 percent. During the period 3 December 1979 to 15 October 1980 the five stations of the Northeast U.S. Chain maintained a better than 99.7 % availability except the Master station at Seneca which reported an availability of 99.61%. Some of the 'down' time at Seneca was attributed to periods when the Master was actually on-line but 'blinking', i.e., indicating that a Secondary was out of tolerance.

Transmitter	Location	Availability
Master	Seneca	99.61%
W Secondary	Caribou	99.94%
X "	Nantucket	99.88%
Y "	Carolina B.	99.75%
Z "	Dana	99.91%

Table 9 Signal Availability

Capability to automatically acquire and subsequently to track the desired Loran-C signals is a function of signal to noise ratio and detectability of the correct tracking point on the signal as evidenced by a measurement of the shape of the transmitted pulse made within the Loran receiver. Both these quantities were recorded by the ground monitors but only the SNR value was ultimately used in the data evaluation effort. A deduced SNR value $\geq$ -10 dB (Micrologic Receiver) was used as the threshold value of acceptability.

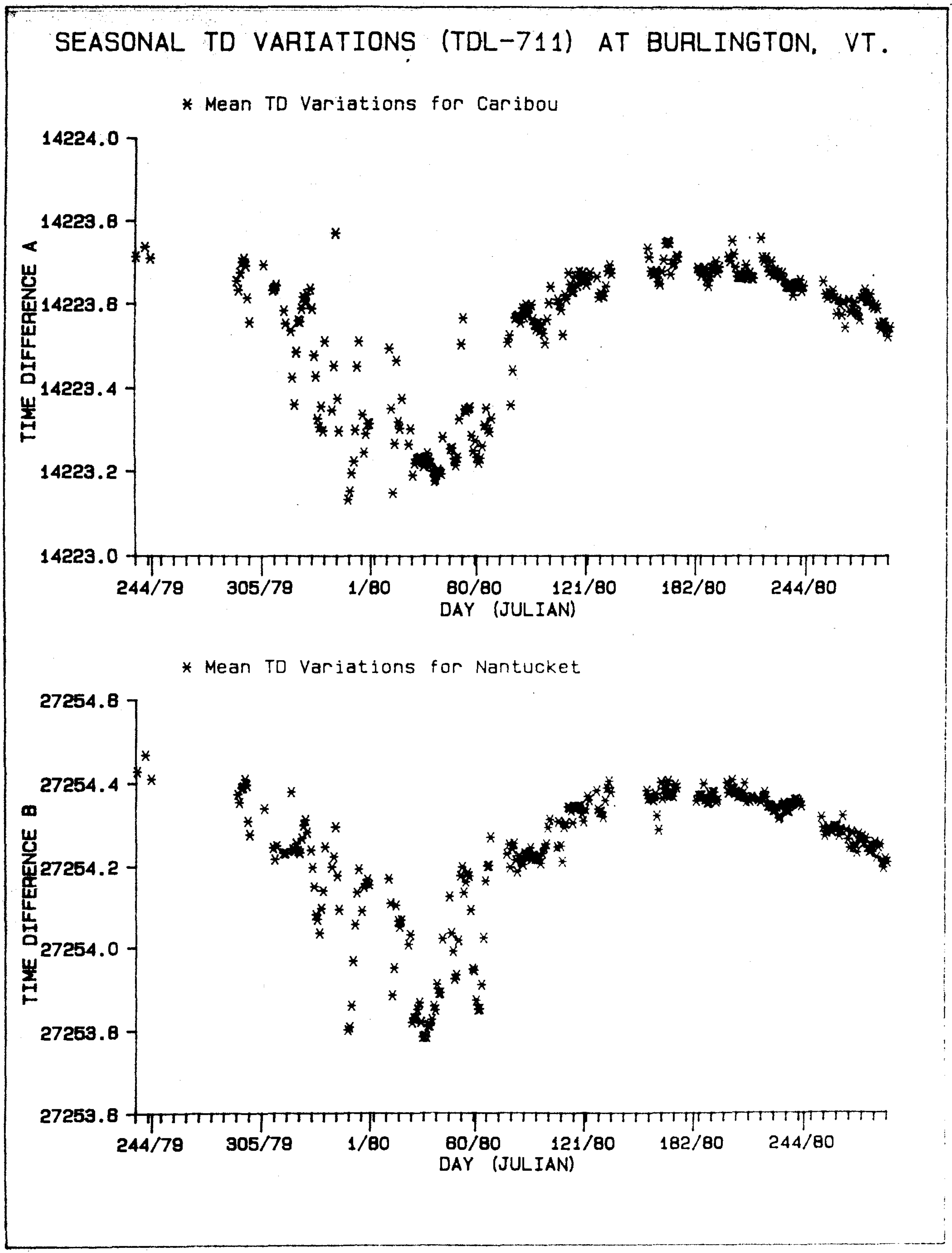
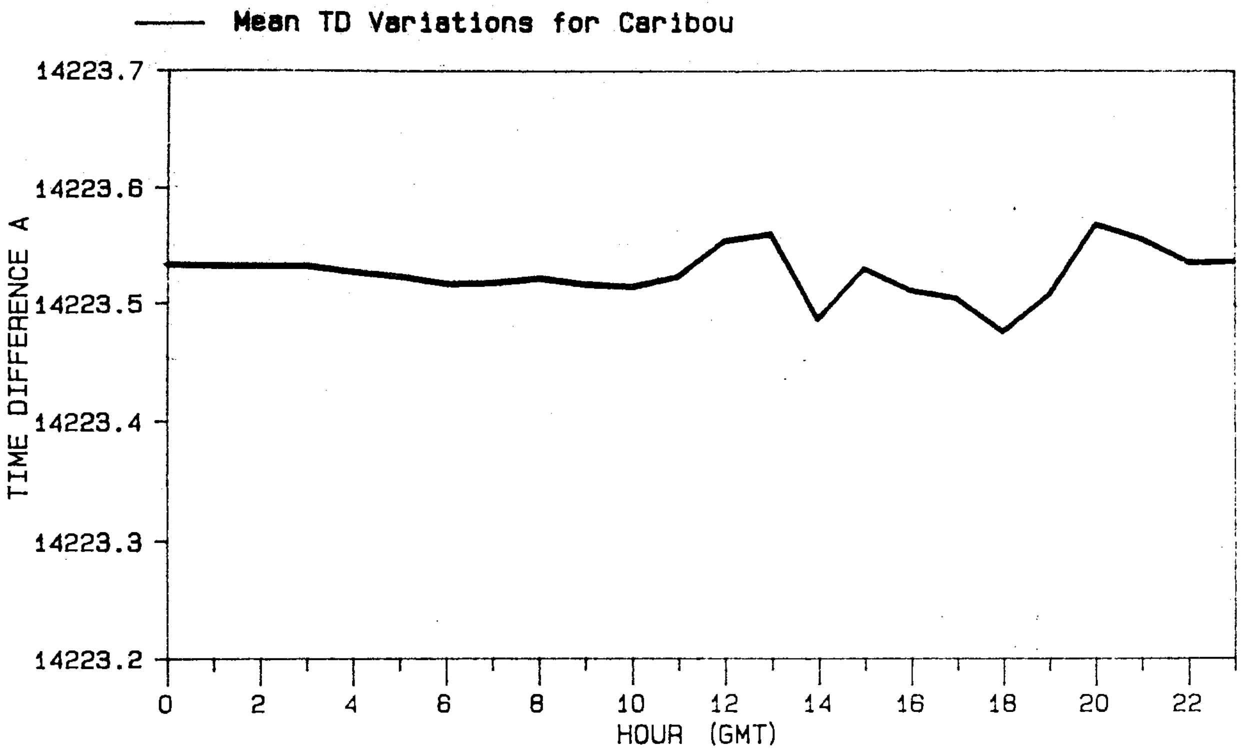

SEASONAL TD VARIATIONS (TDL-711) AT BURLINGTON, VT.
* Mean TD Variations for Caribou
TIME DIFFERENCE A
14224.0
14223.8
14223.6
14223.4
14223.2
14223.0
244/79
305/79
1/80
60/80
121/80
182/80
244/80
DAY (JULIAN)
* Mean TD Variations for Nantucket
TIME DIFFERENCE B
27254.6
27254.4
27254.2
27254.0
27253.8
27253.6
244/79
305/79
1/80
60/80
121/80
182/80
244/80
DAY (JULIAN)

Figure 12.

DIURNAL TD VARIATIONS (TDL-711) AT BURLINGTON, VT.



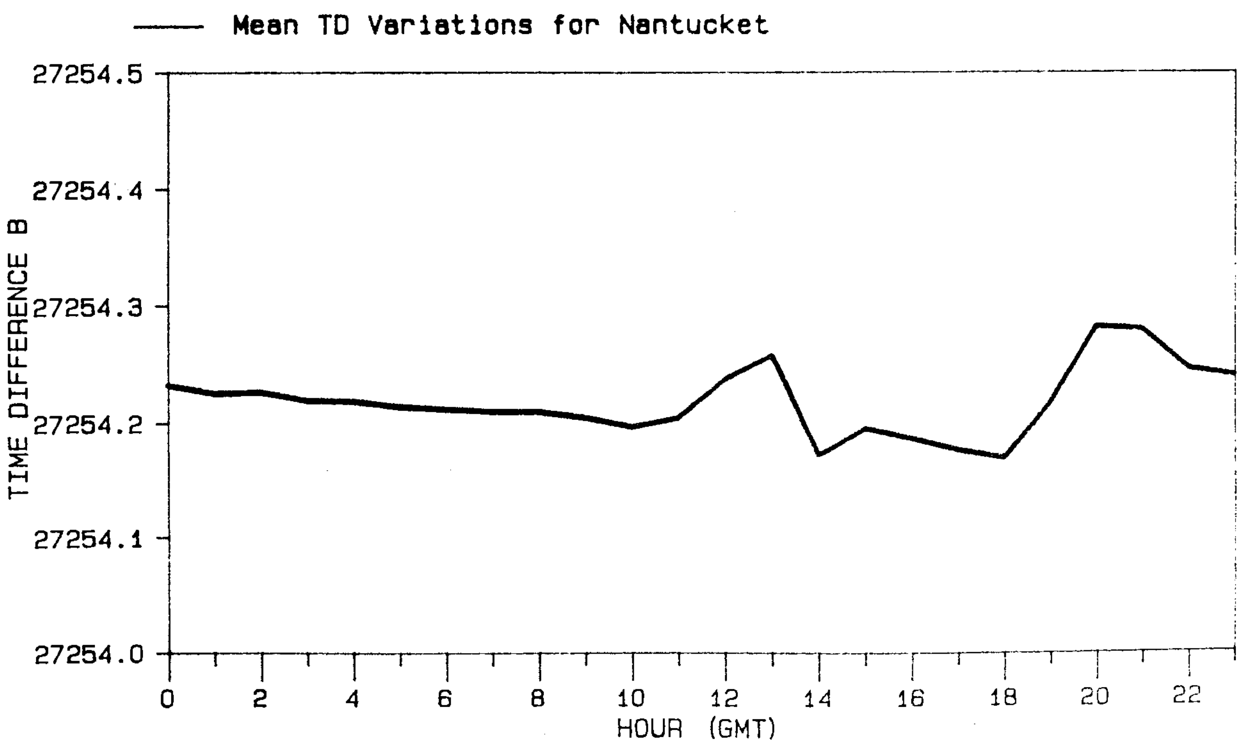


Figure 13

		Monitor Sites		
	Transmitter	Burlington	Newport	Rutland
Primary Triad	Seneca	100.0	100.0	100.0
	Caribou	100.0	99.9	99.6
	Nantucket	100.0	99.8	100.0
Back Up	Carolina B.	94.9	89.1	99.8
	Dana	63.6	76.9	96.1

Table 10. Percentage of Samples With $\geq$ -10 dB

A spectrum analyzer was used to evaluate electromagnetic environmental characteristics at each of the five test airports. All were found to be free of any interfering frequencies.

Temporal variations in the received signals were observed and decomposed into diurnal and seasonal components. A peak to peak seasonal variation of 0.5 microseconds was determined from the ground data, a variance of approximately 360 feet in the Burlington area, Figure 12.

The diurnal variations were found to be less than 0.2 microseconds or less than 140 feet peak to peak; Figure 13.

A composite representation of the combined effects is presented in Figure 16. The circle which contains 98% of the data points has a radius of 0.06 nm (360 feet).

From these data we have drawn the conclusion that the mean plus two standard deviation quantities have been less than a microsecond, detectable by ground monitor equipment, and readily compensated for in the RNAV system by any one of three pilot-useable techniques.

In view of the results obtained during the program the State of Vermont applied for and received a Supplemental Type Certificate which permits use of the Teledyne TDL-711 Loran-C RNAV system for Enroute IFR operation. A proposal has been submitted to the FAA requesting approval of IFR Terminal Area and non-precision approaches at each of Vermont's airports.

We believe that other states will join us in our conclusions and invite Canada to take a serious look at the benefits to be realized from adoption of this form of RNAV procedures and equipment.

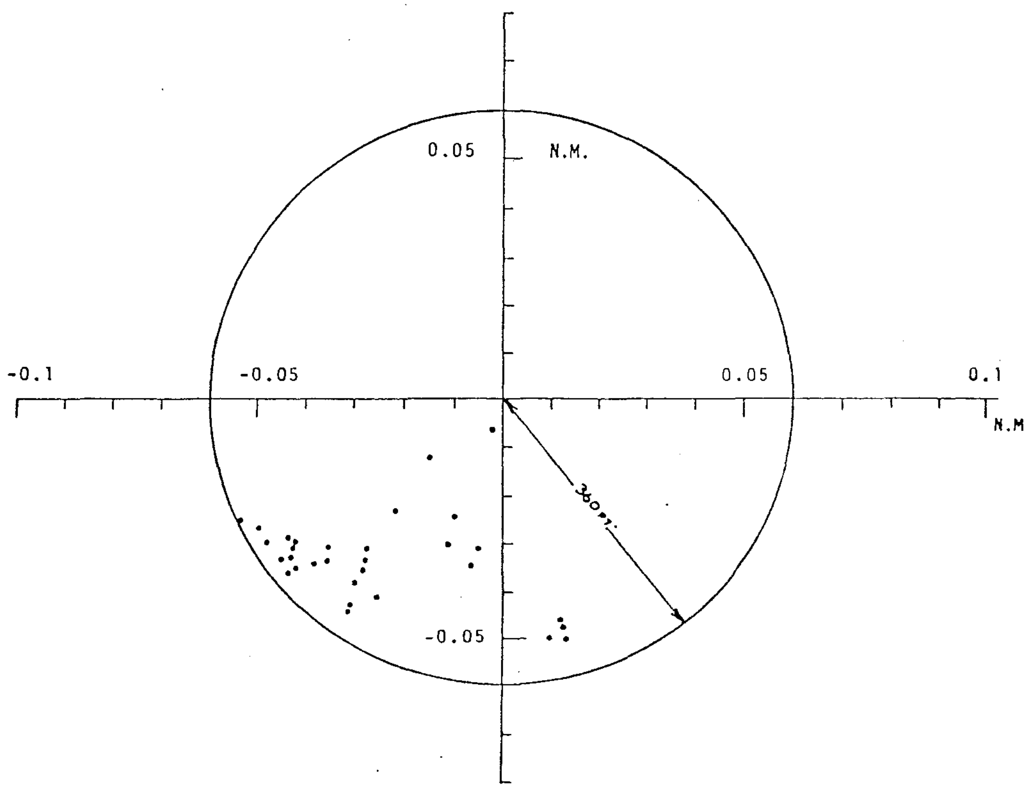


Figure 14. TEMPORAL VARIATIONS (14 MONTHS) NASA GROUND MONITOR SYSTEM

References:

1. RS 914-PM-79-29, Dec 1979; Test Procedures for Evaluation of Loran-C in the State of Vermont, W.C. Hoffman, US DOT/RSPA, Transportation Systems Center.

2. FAA Advisory Circular, AC 90-45A.

3. Telecons between W. Rosenkrans, Jeppesen-Sanderson Co., and W.L. Polhemus ré status of airports and approaches.

4. Telecons between Mr. W.H. Power and W.L. Polhemus, National Air Transportation Association, Inc. (NATA).

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8. DOT-TSC-RSPA Report 81-10, Flight Evaluation of Loran-C in the State of Vermont, F.D. Mackenzie, Sept. 1981.

9. DOT-USCG Document ComDTINST M16562.4, dated July 14, 1981: Specification of the Transmitted Loran-C Signal. Prepared by G-NRN-1.

DEVELOPMENT OF A PROTOTYPE LORAN-C GROUND MONITOR FOR USE BY THE FEDERAL AVIATION ADMINISTRATION

Alan E. Gould
JAYCOR
300 Unicorn Park Drive
Woburn, MA 01801

ABSTRACT

Because of interent limitations with the current VOR/DME (very high frequency omnidirectional range/distance measurement equipment) and ILS (instrument landing system) that depend on line-of-sight transmissions, the Federal Aviation Administration (FAA) is evaluating the use of Loran-C as a low-cost navigational aid for civil aviation users covering enroute, terminal, and approach phases of flight. As part of this evaluation JAYCOR, under contract to the FAA, has developed a computer-based real-time Loran-C ground monitor system. This monitor provides continuous information on Loran-C signal quality and availability for as many as two Loran-C chains in a geographical area. System response includes alarms and messages that would be suitable for issuing as Notices to Airmen (NOTAMs) as required in the case of Loran-C system manfunction.

The Loran-C ground monitor is a computer-based, parameter-controlled system that can be initialized by the user for a given location and chain configuration. Location information, messages, scheduled event information, and criteria for Loran-C performance evaluation are selected by the user under interactive program control. This paper will discuss the use of Loran-C as an aid to civil air navigation, and will treat the design, implementation, and operation of the Loran-C ground monitor system.

Alan Gould

BIOGRAPHICAL SKETCH

Mr. Gould graduated from Northwestern University in 1969 with a BA in Physics/Mathematics. He continued his eduction at Northwestern University and received his MS degree in Computer Sciences in 1974. His professional experience includes the design, development, and support of software used to maintain the Coast Guard's Omega Masterfile and the development of extensive Loran-C related software. Mr. Gould served as a systems development manager at Digital Equipment Corporation for three years. He joined JAYCOR in 1979 where he is Manager of Software Engineering.

INTRODUCTION

The FAA has broad responsibility for the installation, verification, maintenance and operation of all air navigation facilities within the National Air Space. Included among these systems are:

- VOR/DME
- Localizer Beacons
- ILS

Each of these systems is a very-high-frequency (VHF), line-of-sight aid to navigation. In many areas of the country, terrain characteristics severely reduce the effective range of these line-of- sight systems. In addition, many airports used by general aviation have minimal navigation aids.

In an attempt to meet the needs of civil aviation users for low cost air navigation aids which are available at all altitudes over all terrain, the FAA has begun studying Loran-C for use by the civil aviation community.

The Loran-C system is operated and maintained by the United States Coast Guard primarily for marine use. To support the use of Loran-C as an air navigation facility for civil aviation, the FAA requires a means of monitoring the quality and availability of Loran-C signals in an area, and of providing timely information to civil aviation users in the form of Notices to Airmen (NOTAMs). The JAYCOR Loran-C monitor system has been developed as a prototype design to meet these needs.

PROJECT OBJECTIVES

The FAA has responsibility for certification and performance monitoring of all air navigation facilities within the National Air Space. With these responsibilities in mind the Loran-C Signal Monitor was designed to perform the following functions:

- Monitor Loran-C signal availability and quality within a given geographical area.

- Provide alarms for any change in Loran-C status.

- Generate messages on Loran-C status to be used as a basis for issuing notices to airmen (NOTAMs).

- Provide built-in tests to isolate monitor system malfunctions.

The required functions listed above influenced each decision in the hardware selection, software design and software development processes. A summary of the steps performed in the system development process is given below:

- Performed tradeoff studies to select receivers, computer and peripheral hardware:

    - Low cost
    - Commercial equipment

- Selected following major components:

    - Two Micrologic ML220 Loran-C receivers
    - Hewlett Packard HP-85 computer with dual disk drive
    - JAYCOR 8600 signal director
    - Alerting Display Unit (fabricated by JAYCOR)

- Developed user-oriented software in BASIC to perform functions of:

    - Installation
    - Startup
    - Scheduled event maintenance

LORAN-C PARAMETERS OF INTEREST

Table 1 lists pertinent Loran-C signal performance parameters which can affect the performance of Loran-C in a given geographic area. While each of these 8 parameters are separate characteristics of the Loran-C signal, they manifest themselves in a limited number of ways at the receiver. The ML220 Loran-C receivers basically measure the quantities listed in Table 2. Thus, the impact of any of 8 factors which can affect Loran-C signal quality must be detected from the more limited data measured at the receiver.

Table 1

Loran-C Signal Parameters

- Signal-to-Noise Ratio (SNR)
- Signal Availability
- Spatial Propagation Anomalies
- Seasonal Anomalies
- Atmospheric Anomalies
- Envelope-to-Cycle Discrepancy (ECD)
- Interference
- Skywave Contamination

The Micrologic ML220 Loran-C receivers were procured with RS-232 output capability. Table 2 shows the data transmitted by the ML220 to the HP-85 computer for processing. By processing these quantities it is possible to monitor Loran-C chain performance in a geographical area and assess the usability of Loran-C for aviation users.

Table 2
ML-220 Receiver Output

DATA ITEM
Output Record Number
Day Number
Time of Day
Time Difference Reading (TD) for up to 5 Slaves
Signal-to-Noise (SNR) for Master and up to 5 slaves
Envelope-to-Cycle Discrepancy (ECD) for Master and up to 5 Slaves
Signal Tracking Mode for Master and up to 5 Slaves
Blink Indicator for Master and up to 5 Slaves

ATTRIBUTES OF THE MONITOR SYSTEM

The monitor is designed to be simple to use and provide a "friendly" user interface. All user inputs are verified for correctness, and extensive error trapping capability is provided. Dual-chain monitoring is available using the two ML220 receivers, and the monitor provides an indication of the best available triad at any given time.

Part of the monitor system software provides for user creation and maintenance of a scheduled event file. The user can enter time-tagged information defining scheduled events which may affect the performance of Loran-C. The monitor system will automatically notify the user prior to the scheduled occurrence of one of these events. The system also allows the user to enter NOTAM format messages to be issued by the system in the case of unscheduled events.

The monitor is designed for unattended operation and has extensive built-in-test capability. Automatic data logging is also provided to allow review of past events. An hourly printout of Loran-C status is provided automatically.

MONITOR HARDWARE CONFIGURATION

The monitor hardware consists of 6 principal components described in Table 3. The HP-85A computer is the controlling module of the system, and provides the following capabilities:

- Interface and communications among the monitor components.
- Program control of monitor activities.
- Interactive maintenance of required database information.

All peripheral devices are interfaced to the HP-85 on the IEEE-488 bus. The bus provides a two-way real-time communications path among the devices.

The two Micrologic ML-220 receivers collect Loran-C system data and provide it for analysis over RS-232C interfaces to the HP-85A computer. Two receivers are used to meet the requirements of monitoring two Loran-C chains simultaneously.

The JAYCOR 8600 Signal Director is used to provide a programmable conversion interface between the HP-85A computer/IEEE-488 bus and the digital input/output requirements of the Alerting Display Unit on one hand, and the RS-232C input/output requirements of the Micrologic ML-220 receivers on the other. The JAYCOR 8600 provides the needed interface conversions to allow these dissimilar devices to communicate with each other.

Table 3
Loran-C Monitor Hardware Components

Quantity	Component
1	Hewlett Packard HP-85A Computer
2	Micrologic ML-220 Loran-C Receivers
1	JAYCOR 8600 Signal Director
1	JAYCOR Alerting Display Unit
1	Hewlett Packard 82901M Dual Disk Drive

The JAYCOR Alerting Display Unit (ADU) provides an audio and visual indication of both the monitor and Loran-C chain status. This unit provides a loud (approximately 100 db) audio alarm if an event which requires operator attention should occur. The red and green light provide summary status information quickly. Figure 1 is a schematic of the front panel of the ADU. The HP-85A has independent access to each light, the audio alarms, and the state of the audio disable switch. The red and green lights can be on, off, or flashing to convey various system states.

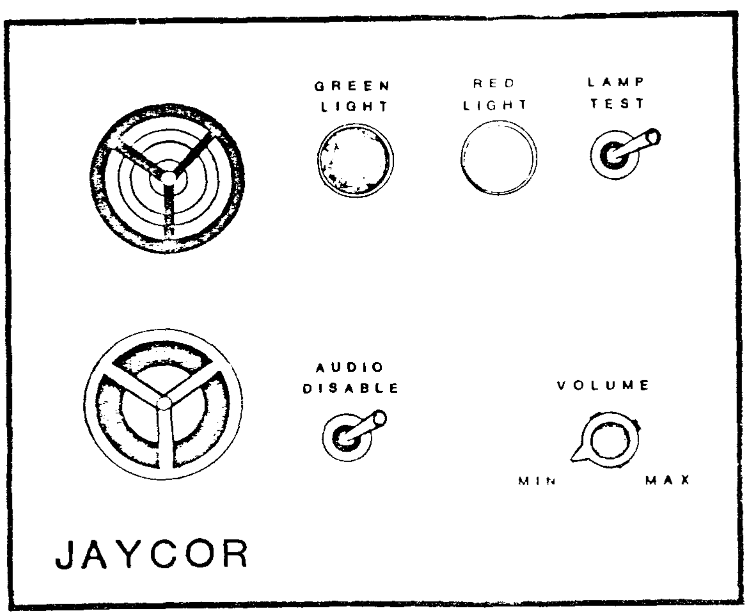


Figure 1 Alerting Display Unit (ADU)
Front Panel Schematic

Figure 2 is a block diagram which shows the interconnection of each of the major units of the monitor. All monitor components are rack mounted in a standard 42 inch high rack. This configuration provides a compact, portable unit and allows easy access to major components for maintenance.

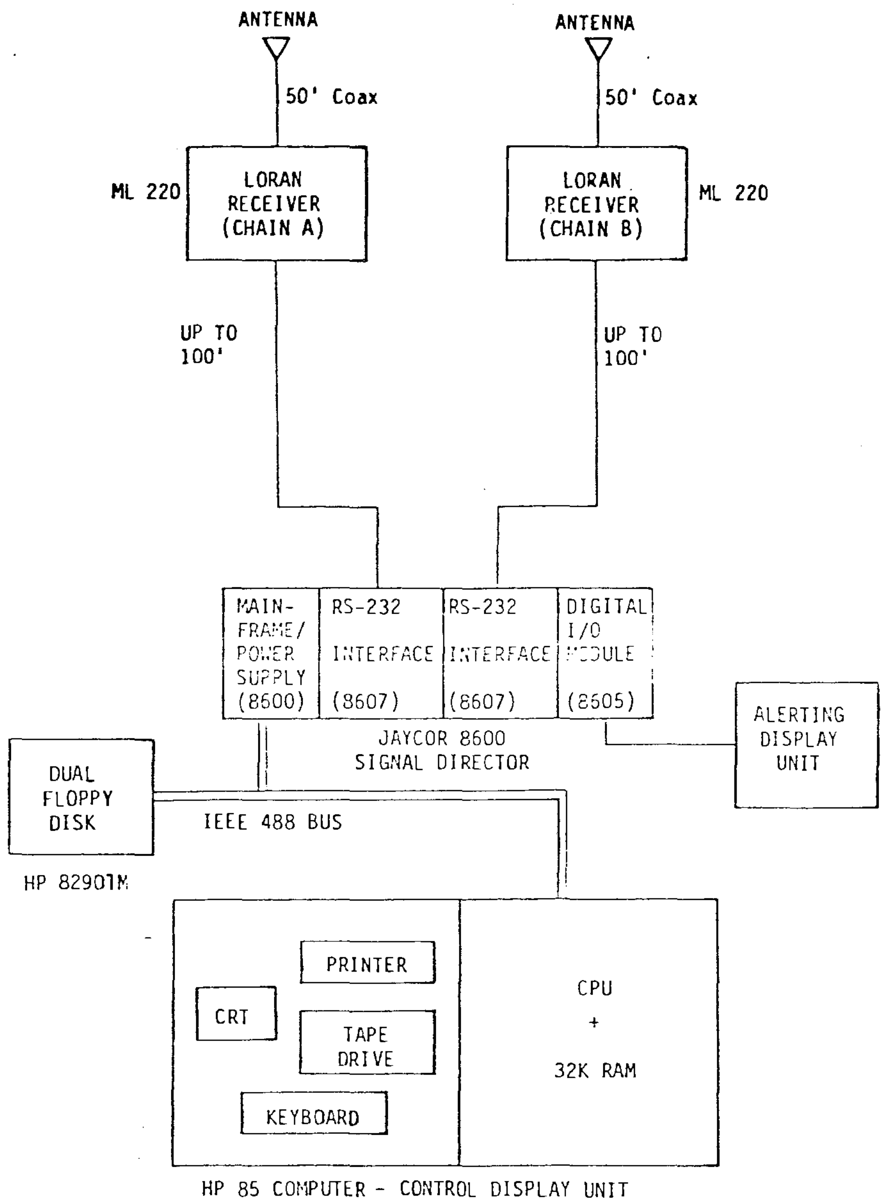


Figure 2 Block Diagram of Monitor System

MONITOR SOFTWARE DESCRIPTION

All software for the Loran-C signal monitor was developed in the BASIC programming language on the HP-85 computer. Modular programming techniques were used throughout to produce reliable, easily-maintained software. The system provides a menu-driven user interface and makes extensive use of the eight programmable special function keys (SFKs) on the HP-85. These SFKs allow the user to invoke standard processes and procedures by depressing a single key rather than entering a series of commands.

The system software is divided into four major modules which support installation of the monitor at a new location, the monitor power up and turn on processing, maintenance of a file of scheduled events, and the actual monitoring function. Figure 3 shows the data flow and interaction among the various system modules.

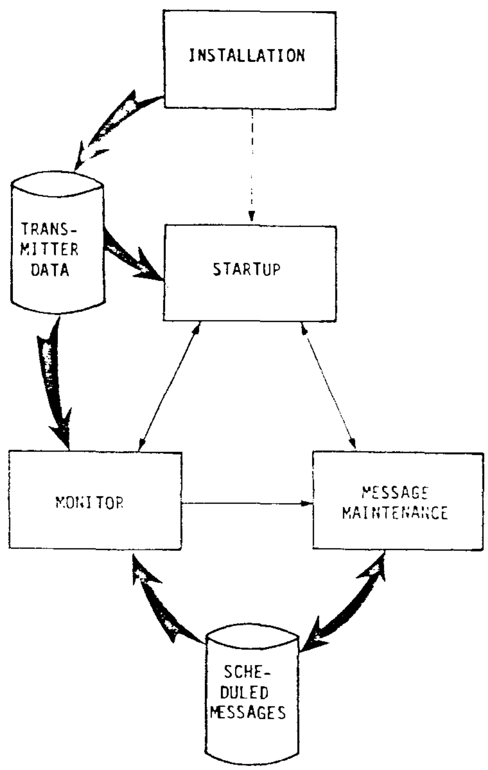


Figure 3 Software Module Interaction

As Figure 3 shows, the Installation module creates a file of site dependent parameters used by the Startup and Monitor modules. The Startup module allows the user to choose system initialization and monitoring or scheduled message maintenance. Each of these major functions is selected via the SFKs described earlier.

SAMPLE INSTALLATION PROCEDURE

The JAYCOR Loran-C Monitor system is a computer controlled data-base driven system. The monitor can be transferred from one location to another with no changes in the monitor software. The JAYCOR-supplied installation software leads the user through a question and answer dialogue which initializes all necessary data files.

Prior to beginning this installation process, the user has to make decisions about which chains and triads in an area are to be used, the priority of triads, and the NOTAM messages to be generated in the event of a chain failure. The rest of this section presents a rationale for determining what chains and triads to monitor, how to assign NOTAMs to various events, and the mechanics of running the installion software to install the monitor at a new location. It should be noted that the installation procedure is generally a one-time operation performed when the monitor is first moved to a new location. Unless the user decides to modify the installation parameters, the process need not be performed again until the monitor is moved.

The choice of primary and secondary chains and triads for the monitor is affected by a number of considerations as noted in Table 4. Most of these factors are a result of the relative positions of the monitor and the chains being considered.

As an example of the chain and triad selection process, consider installation of the monitor in Massachusetts. Figure 4 is a map of the Northeast U.S. with station locations for the Northeast U.S. Chain (9960 GRI) and the Canadian East Coast Chain (5930 GRI), and approximate station coverage ranges. The 9960 GRI chain is composed of a master

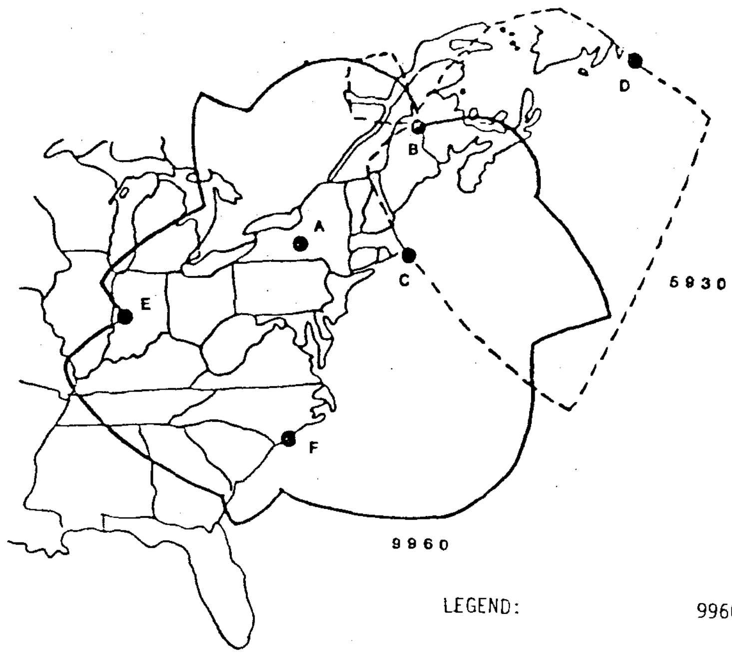
Table 4

Factor Affecting Chain and Triad Selection

- Chain Geometry
  - Number of secondaries in chain
  - TD gradients
  - Crossing angles
- Monitor Location
  - Signal-to-noise ratio
  - Multiple chain availability
  - Baseline extension area

transmitter and four secondaries while the 5930 GRI chain consists of the master and two secondaries. Two transmitters are dual-rated and perform functions in both chains. Caribou, Maine is the master for 5930 and the W-secondary in 9960. Nantucket, Massachusetts is the X-secondary in both chains.

The choice of a primary chain for New England is clear from Figure 4. The 9960 chain covers all of New England and provides both good signal strength and good crossing angles over the entire region. The 5930 chain with the master at Caribou, Maine provides backup coverage for the northern New England area (Maine, New Hampshire and Vermont). If the 9960 chain is unavailable due to some chain failure, the 5930 chain provides backup coverage for northern New England while no backup coverage is available for southern three states.



LEGEND:

		9960/5930
A	Seneca	M/None
B	Caribou	W/M
C	Nantucket	X/X
D	Cape Race	None/Y
E	Dana	Z/None
F	Carolina Beach	Y/None

Figure 4 Coverage Area of Northeast U.S. and Canadian East Coast Chains

The next decision to be made is the triads to be monitored from each chain. In the case of the 5930 chain, as seen in Figure 4, only one triad exists (Caribou, Nantucket and Cape Race). The situation for the 9960 chain is more complicated and Table 5 lists the possible triads available in the 9960 chain.

Based on the chain configurations shown in Figure 4 and the desired coverage of New England, a hierarchy of transmitters can be established and, therefore, the priority of triads can be determined. Each time a chain status change occurs (e.g., a transmitter goes off the air) a message in the format of a Notice to Airmen (NOTAM) will be generated.

Table 5
Possible Triads in 9960 Chain

NUMBER	TRIAD
1	M,W,X
2	M,W,Y
3	M,W,Z
4	M,X,Y
5	M,X,Z
6	M,Y,Z

For New England, a series of possible status changes and associated NOTAMS were developed. Table 6 lists these sample NOTAMS. These NOTAMs, or status messages are selected and displayed during system operation as a function of triad availability in the 9960 chain. Once the NOTAMs have been established and assigned to a given set of transmitter conditions, the installation process will not have to be performed again unless the monitor is moved to a new location or a deliberate decision is made to change the triad choices or NOTAM content.

Figure 5 is a sample monitor display produced during normal monitor operation. During normal operation the receivers are polled and Loran-C status is updated once per second. At any time, the operator can discontinue monitor operation and display or print detailed current data from the receivers by using the appropriate SFKs.

Table 6

Sample NOTAMs

- Loran-C Normal
  - Loran-C available in all of New England
- Primary Triad Fails
  - Loran-C unusable in Mass., R.I., Conn,: Available for en route navigation only in Maine, N.H. and Vt.
- All Triads Fail
  - Loran-C unusable in all New England

81 : 181   12 : 00 : 31

Loran-C Normal

M	Seneca	Good
S	Nantucket	Good
S	Caribou	Good
	Carolina B	Bad
	Dana	Good
	Cape Race	Bad

REINIT	TEST	STOP
HELP	DATA	MSG MNT

Figure 5 Sample Monitor Display

Three types of events can occur to cause the monitor to change operational mode. These are detailed in Table 7. When an event occurs, the status of the monitor changes. The ADU provides both audio and visual indication of chain and monitor status. An event which causes a change in status triggers the audio alarm and changes the light configuration on the ADU. When the audio alarm is sounded, the operator may override the alarm with the override switch on the ADU front panel. This is a temporary override, however, and the audio alarm will be retriggered in two minutes if the operator does not acknowledge the system status change by using the special function keys on the HP-85.

Table 7
Monitor System Event Types

Event Type	Examples
Chain Problem	Station failure, TD slip, high Signal-to-Noise (SNR), Blink, ECD
Monitor Problem	Receiver failure, antenna failure
Scheduled Event	Scheduled station outage for maintenance

Depending on the type of event detected, a particular class of message is printed for operator information. Once an event has been detected by the monitor, the operator can use the SFKs to acknowledge the event and then take the appropriate action. In the case of a chain problem, the operator may issue a NOTAM to the general aviation community. A monitor problem may require that the monitor be take offline, tested and repaired. A scheduled event may require that a NOTAM be issued, or may require no action at all.

CONCLUSIONS

Using off-the-shelf, low-cost components, the JAYCOR Prototype Loran-C signal monitor provides a reliable, flexible tool for assessing the capability to provide fixed ground monitoring of Loran-C signal quality when Loran-C is used as a navigation aid for general aviation.

In addition to the monitor's prototype role, it provides a basis for developing additional functions. The HP-85 computer has significant additional processing capacity and the monitor could become part of a distributed monitoring system if provided with communications capability. The modular and structured nature of the software would simplify the task of developing an intelligent data collection system with local data reduction and editing capability. Table 8 summarizes these factors for future expansion.

Table 8
Factor Affecting Future Expansion

• Additional machine capacity available
• RS-232 Interface available for remote communications
• Could become part of a distributed network
• Easy modification to perform Loran-C data collection

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FAA CERTIFICATION -- IS IT REALLY WORTH THE EFFORT?

J.C. Hart and R.H. Wehr
Aerospatiale Helicopter Corporation

ABSTRACT

Loran-C, despite its technological and system maturity, has had far less impact on the aviation community than its newer counterparts, the Omega and VLF Navigation Systems. Evidence of this apparent disparity can be seen in the volume and effects of regulatory documentation and industry standards pertaining to each of the systems. Further indication can be seen in the levels of knowledge and awareness of system capabilities displayed by potential users. There is a stark contrast in the solutions to operational requirements implemented by those users and the capability afforded by Loran-C for the same requirements. For example, only a small percentage of CONUS airports and heliports have FAA authorized instrument approaches. Additionally, there is a need for navigation reference, flight following, and vehicle control and dispatch in the adjacent offshore areas. Loran-C counterparts can partially satisfy the navigation requirements, but they lack the accuracy to fill the remaining roles. The intent of this paper is to focus attention on present regulatory and certification activity, while highlighting the technical problems associated with that activity. The question is posed: "Is FAA certification really worth the effort?"

Bob Wehr

BIOGRAPHICAL SKETCH

Jake Hart is Manager of Flight Test and Certification for Aerospatiale Helicopter Corporation (AHC). He began his aviation career in 1955 as an Air Force pilot in both airplanes and helicopters. In 1965 he left the Air Force for Bell Helicopter Company, where he performed as a production and experimental test pilot until 1970 when he joined AHC. Though initially a sales demonstration pilot, he was promoted to Chief Pilot where he assumed the additional responsibility of FAA certification of all company development projects. Perhaps the most noteworthy of these was the world's first single-pilot IFR helicopter, the SA341 Gazelle.

Jake has amassed over 11,000 flight hours and presently functions as an FAA Designated Engineering Representative for company projects. His primary project at the moment is the development and certification of the U.S. Coast Guard's newest helicopter, the HH-65A.

Robert (Bob) Wehr of Aerospatial Helicopter Corporation is Deputy Director-Avionics for the SRR Program. He is a retired officer whose service included assignment as Chief of the Coast Guard's Avionics Engineering Branch. His aviation qualifications include both fixed and rotary-wing aircraft.

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ABSTRACT:

Loran-C, despite its technological and system maturity, has had far less impact on the aviation community than its newer counterparts, the OMEGA and VLF Navigation Systems. Evidence of the apparent disparity can be seen in the volume and effects of regulatory documentation and industry standards pertaining to each of the systems. Further indication can be seen in the levels of knowledge and awareness of system capabilities displayed by potential users. There is a stark contrast in the solutions to operational requirements implemented by those users and the capability afforded by Loran-C for the same requirements. For example, only a small percentage of CONUS airports and heliports have FAA authorized instrument approaches. Additionally, there is a need for navigation reference, flight following, and vehicle control and dispatch in the adjacent offshore areas. Loran-C counterparts can partially satisfy the navigation requirements, but they lack the accuracy to fill the remaining roles. The intent of this paper is to focus attention on present regulatory and certification activity, while highlighting the technical problems associated with that activity. The question is posed, "Is FAA certification really worth the effort?"

Assessment of Airborne Use

Despite Loran-C's system maturity, accuracy, and potential capabilities, it has had relatively little user impact when compared to such systems as OMEGA and VLF. This is, perhaps, best illustrated by the September 1981 Rotor and Wing article, "How Do North Sea Pilots Rate Their Navaids." Capturing the disparity of system use, the article states, "The engineers at Global came up with a new model that used the best of either VLF and/or OMEGA signals. This model, the now famous GNS-500A, was such a vast improvement over the (GNS-200) that Helikopter Service now uses it in all offshore helicopters."

The disparity is evident in the certification level achieved by the Global equipment. The GNS-500 is approved for enroute instrument flight rules (IFR) and visual flight rule (VFR) navigation. Caveats have been placed upon it precluding use as "sole means of navigation" in terminal areas or for instrument approaches and departures, but these caveats have had little impact on sales to potential users. Other VLF/OMEGA referenced systems have achieved similar certification success. The major portion of the four-page Rotor and Wing article was devoted to discussions of the GNS-500A. One small paragraph of the same article mentioned Loran-C, and only three of the pilots interviewed acknowledged any experience with Loran-C.

Further evidence of the disparity is illustrated in FAA Advisory Circular 91-49, General Aviation Procedures for Flight in Atlantic Minimum Navigation Performance Specifications (MNPS) Airspace. The directive cites in its list of acceptable equipment combinations, dual inertial navigation systems (INS), dual OMEGA, single INS with OMEGA update, and single doppler with OMEGA update. Loran-C, in any combination, is excluded from the list. AC 91-49 was promulgated in 1978.

Decision Near

Time is slipping away. The following quote appeared in the April 20, 1981 issue of Aviation Week and Space Technology. "By the end of 1982, the Federal Aviation Administration is scheduled to recommend whether the Defense Department's Navstar Global Positioning System (GPS), or Loran-C should be adopted as a future replacement for the long used VORTAC navigation system, under the terms of the recently issued Federal Radionavigation Plan." Activity in the market place reveals that large expenditures are being made in the research and development of GPS. Further, the latest design and manufacturing technology is being applied to the development. In the final analysis, the number of active and potential system users will have a major influence on the decision.

Opportunity Knocks

There is a total of approximately 13,000 military, civil and private airports in the United States. Additionally, there are 4000 heliports of which about half are located in adjacent offshore areas. Less than 15 percent of the airports and even fewer heliports have any IFR approach capability. Considering the relative ease with which heliports can be established, as compared to cumbersome airport development programs, significant increases in the number of heliports should be anticipated within the next decade.

The March 1981 edition of Professional Pilot revealed that the free world has approximately 22,000 helicopters and forecasts an increase in that number to 31,000 by 1985. The article further stated that the helicopter will probably outpace the manufacture of any other type of aircraft. Stimulating the growth rate in helicopters is its utilitarian capability. Aerospatiale Helicopter Corporation, for example, has a backlog of almost 700 aircraft. Clear indication of helicopter interest was exhibited by the 8600 people attending the Helicopter Association International (HAI) Convention held in Anaheim, California this past January.

Glen Gilbert, of HAI prominence, cited the following growth factors in his article, "Northeast Passage." Industry is seeking to move out of high cost areas, relocating in smaller surrounding communities. Life for the employees is more relaxed, and the company obtains the benefits of lower investment, land, and overhead costs. The helicopter provides the mobility to executive and marketing personnel to permit such moves. One air cargo company is presently making plans to move its fixed wing operations to low traffic "feeder" airports and shuttle its cargo to the large metropolitan terminal areas. The savings in overhead more than offsets the investment and operating expenses of the helicopters, and return a tidy profit as well.

The recent PATCO strike provided further impetus to decentralize air operations. The wholesale replacement of large numbers of air controllers, of necessity, was accompanied by a decrease in scheduled air traffic to major terminal control areas. The training problems imposed by the replacement process will hold the reduced traffic level relatively constant for quite some time. Maintaining present operations, and providing for some modest growth potential, will require operators to further decentralize their activities.

The quest for additional petro-chemical development in the offshore areas uses the helicopter as a vital link in its growth. No other vehicle can function so effectively in that environment. With the growth, comes the demand for more efficient vehicle tracking for flight safety. In addition, costs can be significantly reduced by optimum assignment of aircraft in day-to-day operations. The latter is highly dependent upon knowing where each aircraft is. Hence, vehicle tracking serves two purposes. The FAA Southwest Region is presently experimenting with Loran-C Offshore Flight Following (LOFF). Teledyne TDL-711's are being used in combination with VHF communication data downlinks in that project.

These are but a few of the many diverse roles fulfilled by today's helicopters. The common denominator for all of these roles is "IFR Capability." Loran-C could be a major factor in providing that capability.

Required Navigation Characteristics

Helicopters need wide area navigation coverage which includes the adjacent offshore areas. The navigation system must provide highly accurate position information. Pilots must depend upon their equipment to pinpoint an oil rig sometimes as far as 150 miles offshore. Adverse weather demands that the same navigation system, in concert with any other available navaid, facilitate an instrument approach and a safe landing on the platform. The system signals must be available at low altitude great distances from navigation sources. User equipment must be reliable, maintainable, and low in cost.

Equipment Requirements

The implication chain, IFR capability implies FAA certification, ultimately ends with the requirement for FAA approved equipment. Avionics manufacturers quickly recognize this as the Technical Standard Order (TSO) process. Historically, the TSO uses as foundational documents the Minimum Operational Performance Standards established by the committee activities of the Radio Technical Commission for Aeronautics (RTCA). Loran-C at present has no qualifying TSO. RTCA document DO-159 does provide minimum performance standards for airborne Loran-C receivers, but it is woefully inadequate. FAA concern for the aspects of "master independency" and "chain reconfiguration" are not even addressed. At the very least, a revised DO-159 must be produced. That action can only be initiated through user or industry demand. Without a TSO, each manufacturer must "go-it-alone" in establishing "equivalence of quality" to a TSO for his equipment.

FAA Certification Dilemmas

The FAA, motivated by a need to assure the safety of the aviation community, must adopt a conservative attitude toward certification. (Motivation quite often is stimulated through intense user demand.) Therein lies the dilemma. While trying to sort out such problems as "suitability of the signal" in the airspace, the FAA must struggle with adapting established procedures to new situations. Flight checking of instrument airways and approaches, for example, is done by individually flying each and every route segment. How then can it adapt such inspection techniques to a navigation system which affords an infinite number of route segments. A companion problem lies in determining the compatibility of the established VORTAC system (with its attendant aberrations and perturbations) and other wide area or electronic grid navigation systems. This is particularly critical when aircraft operating with either equipment must operate in close proximity to each other. Pressure is further applied by the proliferation of more "alphabet systems" such as ATCRBS, B-CAS, MLS, etc. If progress is to be made, the Loran-C community must step in and help. FAA Loran-C certification has, to date, taken the following three modes:

- Restrict the use within the National Airspace System (NAS) to very strictly controlled conditions
- Permit the use only if supplemented by VOR navigation information. Loran-C information, under this provision, must be locked out of the navigation solution during instrument approach operations
- Permit the limited use in narrowly defined geographic areas for which extensive Loran-C flight data is available. The NASA/DOT/FAA project in the State of Vermont is an example of this mode of limited certification.

Summary

The question has been posed "FAA certification-is it really worth the effort?" Problem areas confronting Loran-C have been highlighted, and the balancing motivational factors have been presented. Only the Loran-C community can answer the question. If the answer is negative, aviation must forego sorely needed IFR capability. If the answer is affirmative, there is a significant level of effort required, and very little time remaining. Which will it be?

GAO PANEL DISCUSSION

GAO REPORT (GPS AND LORAN-C)

Technical Chairman: John D. Illgen, Kaman Tempo

Panel Members:
Walt Dean, Morrow Electronics
Capt Jim Culbertson, US Coast Guard
Leo Fehlner, APL/JHU
Lloyd Higginbotham, EPSCO
Jim Van Etten, ITT
Barney Ambroseno, EPSCO
Ed McGann, Megapulse

John Illgen - I would like to point out that there is a lot of literature that goes back quite far. The GAO report is dated 18 September 1981 but the first real critical report on the Loran-C system that I found was back in 1978 which brought up many of the same issues that are in the current GAO report. This is something that has not occurred overnight; it has occurred over the past few years. It's a report to the Secretary of Transportation. The item on the front of the report says: "DOT should terminate further Loran-C development and modernization and exploit the potential of the NAVSTAR Global Positioning System." That's pretty direct. This report is addressed to The Honorable Drew Lewis, the Secretary of Transportation who resides at 400 7th St., SW, Washington, DC 20590. Key items in the report and indications from the GAO state that the Loran-C system is not needed by the early 1990s. They caution against further Loran-C investment. They indicate that the Secretary of Transportation should be more involved with GPS to insure timely availability of low-cost civil receivers and that GPS should be considered a national asset and they make some statements that, I feel, are unfounded about the proliferation of navigation systems. I think that earlier, Admiral Manning made some comments that should certainly put that to rest, particularly when he talked about the dynamic versus static rates. Very key point.

GAO's perception of DOT. What is it? DOT continues to develop, expand, and improve navigation systems that GPS could replace. DOT has devoted little effort to GPS evaluations, capability for marine and land. DOT has not initiated a program to develop and demonstrate the technology for low cost GPS receivers. GAO concerns and these are concerns that are pointed to the Coast Guard. The Coast Guard should recommend to the Secretary of Transportation the future role of GPS versus Loran-C and again in that part of the report they comment on the low-cost GPS receivers. They indicate some dollar values about the operational aspects of Loran-C until the year 2000. I personally do not know if these numbers are correct or not but they claim that they're currently 35 million per year now. By '84 they'll be 60 million per year. By 1984 I'm not sure myself today what the importance of those numbers are but I'm sure we ought to find out. Another GAO concern regarding Coast Guard is the DOD plans to discontinue Loran-C in the early 1990s. Many of us on DOD programs know that many of the DOD SPOs and military programs aren't planning for that. I know of 2 that we're working on where that's not in the cards. The spending of 25 million to replace existing Loran-C transmitters was questioned by GAO also. They also came down upon RSPA which is part of DOT and said there are not enough dollars to evaluate the overland GPS usage. Not enough dollars for Loran-C land use in general. The result, further expansion of Loran-C in terms of dollars is 22 million. Then there were some issues that I felt were directed at both the CG and RSPA combined. Again these were in terms of dollars. The past four years they claim that 6.7 million dollars were to develop and demonstrate Loran-C land and marine applications whereas 1.2 million was steered towards GPS which they indicated based on those dollar figures is a bias towards Loran-C.

Now I would like to, after the other panel members say something, summarize my thoughts on the issue but I'd now like to turn over the microphone to Leo Fehlner.

Leo Fehlner: For the last three weeks or so I've been tracking this and I think others have been too. I've been tracking it in Washington and had many conversations with some people, many people, some of whom are in Congress and have made a series of notes on what I believe the situation some of which may be redundant with what John has just said but I'm going to go through it because that's the way I see it logically.

Point 1. Mostly on the basis of the GAO preliminary draft of their investigation, the House of Representatives has deleted from the Coast Guard's 1982 budget the line item for Loran-C improvement. This was to go to replace some transmitters or solid state transmitters or some other things, I think.

Point 2. The GAO has sent to DOT a formal memorandum relative to the Loran-C versus GPS. Also there's quite a bit of material supporting their position, they think.

Point 3 is kind of a long one and I'll go through it as quickly as I can. The central theme of the GAO report, in my view at least, is well developed, and on face value it cannot be contridicted. To do so is to call people liars and you can't do that. So here are the points that I think they make: GPS is going to go. GPS will provide geodetic accuracy. GPS receivers will not be prohibitively expensive. I don't subscribe to some of these things but this is what the report says. GPS will provide position fixes as good as Loran-C. GPS will do this continuously all around the world except the Polar caps with a high data rate. GPS user base will be larger than Loran's therefore prepare to use GPS and phase out Loran-C. That's the gist of that report, I think.

Certain specifics of the GAO report are just plain long and others can be argued with on the basis of your technical judgment.

Point 4. However, the GAO report is final. It is therefore too late to discuss the specifics of the GAO report relative to the 1982 budget. 1982 budget is essentially fixed.

Point 5. The Department of Transportation is required by law to respond to the GAO recommendations by 17 November 1981. Their response has got to be to the House committee on Government Operations and to the Senate Committee on Governmental Affairs.

Point 6. The GAO recommends among other things that the Coast Guard develop tentative plans to phase out Loran-C by mid-1990s.

Point 7. In 1983 the DOT and the DOD are currently planning to decide the best mix of nav aids for air, marine, and land use.

Point 8. If the DOT supports GPS at this point, that is 1983, publically announce the Loran-C phase out plan which by the way GAO would like to have happen in the early 1990s.

Point 9. The WGA position on these matters needs to be developed and polmagated.

Point 10. I've listed my suggestions as to possible action items. A. Let future events take their course and the WGA will plan its last gallop convention. B. As soon as possible respond to the DOT with a response relative to the GAO memo. C. Perhaps recommending that DOT take the same position as the Navy did on GPS. That's an interesting thing, the Navy's position on GPS. I've read the letter the CNO wrote. It says that we're happy with what we've got. It satisfies our requirements. We don't expect it to stop satisfying our requirements necessarily on its own. And when you can show us that you have a GPS system in place and declared operational we'll then consider converting to it. And I think that's a good position to take. D. We could wait until we could see the DOT response to this memorandum which they're committed to deliver to the Congress by 17 November. Then we could possibly wait to see the 1983 plans for phase out and then take some real presipitious action at that point and be preparing for such a thing in the meantime. E. This is the one that I like and I think the WGA should stimulate a series as long as we can keep it up. A series of writing campaigns to let Congressmen know that votes depend upon keeping Loran. That can even be on a basis of motions pushed. If enough people tell them that they seem to believe it. Failing all these and others that, I'm sure, will come forward then we should advise the WGA members how to cope with GPS. Get ready for our big gallop. That's all I have to say at this point.

Capt J. Culbertson: Well my input to start out with on the panel will be a report on as I know it today on what the Coast Guard's planning to do about the GAO report as conveyed to me by Commander Pealer with some recommendations or some thoughts to put across to the WGA concerning how the Coast Guard feels about the whole affair. First, the Coast Guard rebuttal has gone to the Department's representative, Dr. Harvon of RSPA who is coordinating the CG/FAA/TSC rebuttal and to prepare what will become eventually the DOT response to Congress that Leo Feldner says is due 17 November 1981. The input that is being prepared for approval by Secretary Lewis will be put before the Federal Radionavigation council for a meeting on Wesnesday, 28 October, and they will review this and make their recommendations and are looking for their support in this response the Secretary is going to send forward to this group people who I'm familiar with includes: Rear Admiral Bauman, and/or the commandant of the Coast Guard's representative to this council. Appropriate officials of this stature from the FAA, RSPA, Secretary staff, and of course the DOD reps on this council. So that will be the input that will be prepared and put forward to Congress. It would be my impression at this stage of the game, knowing how things work back there, it is probably too late for a WGA input to affect the content of this response at this time. I think that anything that our WGA does has to follow along behind this. In following up another comment that Leo made, the fiscal year solid state transmitter funds were deleted by the House Appropriations Committee and it is the Coast Guards' opinion that if these funds are not restored we must scratch our transmitter buy and if we don't buy this year when we are increasing it that we are making it very highly probable that we'll never be able to put forward a satisfactory economic analysis that would convince people to make those procurements. So we think its extremely important that the funds be restored in the 1982 budget. The Coast Guard will do everything they can on their part to develop. In fact, they have provided an economic analysis that is included in the letter going back to Congress that will justify the solid state transmitter and this is done based upon the replacement of the FBN42 transmitters station sets and the only recommendation or consideration that has come out from our people is that perhaps there is some mechanism for which public hearings could be held before the appropriations are finally terminated. This might be one avenue to get an input from a wide spectrum of users and other people who have a direct interest in Loran-C. Another area that the CG would like to, and this is one that I've been after for years, the Coast Guard does not have a good user data base and (I think we all ought to appreciate this) the user data base is a difficult data base to acquire. An example of a lack of good data base is a national plan for navigation of those of you who are familiar with it has certain parts of it that by 1981 or 82 there will be something of the order of 2000 marine users of Loran-C and I think a count that we took last week by doing some general polling around that the number of receivers is something around 100,000 now. So the data base is not accurate. The GAO I'm sure is looking at whatever data's available to them. Leo points out that it's a good thesis that if the data is available they might be able to make strong arguments. From what's been said we think the data base is an area that needs to be improved. We feel that WGA can perhaps play a role in helping to get the user data base in hand. I think that's a wide spectrum data base. Its users; its looking ahead. The data base includes what industry is planning and perhaps what's in peoples marketing minds for the future on equipment and a lot of other areas. It all involves what the user is using and what they will expect to be using in the future. The Coast Guard, of course, is concerned with the way the GAO report has stated accuracy, expectations for GPS/NAVSTAR and comparing that to the absolute accuracy of Loran-C and, of course, we feel that this is an issue that I'm sure will be included in this letter that's going back to Congress. There's more to be said about it in the future particularly zeroing in as Admiral Manning said on the ability as opposed to the geodetic accuracy of the system. We believe, as Admiral Manning pointed out at lunch, that the CG cannot go out and tell people to or themselves write letters but we would encourgage that the users, individual users, affiliation of users, representative of users, somehow be able to convey their needs and concerns to the Secretary of the Department and to members of the Congress, particularly to the House Appropriations Committee, and that this should be a continuing thing and not just something that dies after the magic date of 18 November shows up here when the report goes out. I think we're all sensitive to the fact that even though words I'm sitting up here as a Coast Guard officer telling you we should be doing things, I'm not asking you to go out and do the Coast Guard's job for them but I think that it's important that we work together to get the true facts before Congress and before the people who are making decisions on the future of the system which we consider to be a valuable national asset in which a lot of us have worked very hard to have installed. Those basically are my comments for now. I have some things I would like to say later when we wrap up. Thank you.

Walt Dean - My comments are of a technical nature largely. First of all I assume that all of you know how GPS works. In general, it's a spread spectrum system with two sets of codes. One called the CA for Clear Acquisition Code which is supposed to be unclassified and be useful to anyone and the P code which is presumably to be classified and which is supposed to be the highly accurate code. Now, we ran some tests using a Magnavox Z set which uses only the CA code. We ran these a few years ago and we discovered somewhat to SAMSO's and the Air Force's embarrassment that the accuracy you could get with the CA code itself is something in the order to 50 and 100 feet. This is absolute accuracy. Then they started talking about the probability of degrading the accuracy by introducing some sort of jitter into the code so that unauthorized users would be about to obtain accuracies only to a quarter of a mile and so what they presumably are going to do (although it depends upon what particular time you talk to them whether this is actually going to take place). But presumably it will and that is the planning on which is based and so you then have to say: Okay, here's a system that's been jittered and so the accuracy is only one-quarter mile and that means it'll be a quarter mile anywhere. But then they start double-talking and say: Well, but then you may be able to get a differential system where you could put a receiver in and operate in a differential mode and get back your accuracy. But if anyone can do that, that means the enemy can do it and they wouldn't want to put in something where they could do that. It doesn't make any sense that such a thing could be possible. They also make a comment in this report that perhaps they would allow certain users somewhat better accuracy but they can let certain users on an unclassified basis have better accuracy and not let everyone have better accuracy is a little difficult to see because if anything is unclassified it most certainly is in the hands of the enemy. You get into that problem and now you're in a situation where you have a system whose accuracy can only be a quarter mile as opposed to the discussion that we just had here in which we talked about the repeatable accuracy of Loran-C where you can get considerably better than that and Leo, of course, has been running experiments where he talks about getting accuracies down to measure of feet. Those things are actually useful and extremely important. Not only that but they are important to people who have aeronautical and terrestiral uses and the papers that were given today are of importance in that respect also. The other subject, of course, is one of cost. And the fact that they put in there an apples and oranges assortment of estimates of costs for Loran receivers and GPS receivers. It's, of course, very difficult to obtain a good estimate of the cost of a nonexistent receiver will be. The guy who would like to get a contract to design and build one will tell you how cheap it will be and someone else may have a different opinion but one way of estimating may be to compare it with the cost of a transit receiver because transit is a similar sort of a system. It depends upon using satellites which fly around and whose afirmers has to be known in the afirmers has to be transmitted down to the receiver and the receiver has to use that information on a real-time basis in order to figure out where it is and so the computational problem of a satellite receiver which must use this complex code must use the complex information as to the path of the satellite is considerably more difficult as opposed to that of the Loran where you are measuring a relatively simple transmitted pulse operating from fixed locations of the transmitters and so the computational problem for the Loran receiver is that much easier and so it should be possible to get a reasonable guess as to the comparative cost of the GPS and the Loran receiver from the comparative cost of the transit and Loran receiver and the transit receivers typically run two or three times the cost of the Loran receiver. It will be probably always be that way because of the additional complication required. Both of those points are things that are weaknesses in the GAO report which essentially result if you apply those to the reasoning which is carried out in the report. You will then come to a different conclusion as to whether we should be continuing to push forward on Loran or whether we should abandon all Loran. Of course the title is a nebulius thing because it says exploit the potential and you cannot exploit the potential, the potential isn't there. You can really only exploit things that you have and the potential is not there and it might possibly never be there. That's about all I have to say.

Barney Ambroseno - What I want to talk about is what I can do to bring this to the user. One thing I want to do first is read an article of one or two paragraphs from the Wall Street Journal I made a copy of on Thursday, July 9, 1981, which wasn't too long ago. Rather than read the whole thing I'm going to take one little short excerpt which says that just as this argument is warming up potential NAVSTAR users products there is news in Congress. The House Arms Services Committee abruptly says NAVSTAR should be terminated and denied all the money that is requested for the coming fiscal year. In a report accompanying it, weapon procurement, the Committee said the new fiscal 8 billion dollar projected cost is starting to rise. NAVSTAR fate will be decided in the House negotiations with the Senate which has already approved next years' money. However, the AF apparently doesn't feel totally devasted about having to delay this project. The NAVSTAR data after all would be mainly used by non Air Force free loaders. Indeed, a certain amount of attention can be involved in the intentional use of the navigation satellites created for military purposes. Currently, 93 percent of all Loran-C system users are civilians, Americans, and foreigners. This was not too long ago, just a few months ago when all of a sudden you get this type of report from the GAO. Apparently someone other than the GAO is pushing for the demise of Loran-C. One thing that I cannot understand is if you can maintain and service a transmitter on land where you can walk or ride to how are you going to take care of a satellite that breaks down in space that needs cleanup and maintenance. Also what is the lifetime of a satellite? Is it six years as they say? If it is six years thats a pretty costly thing. It'll continually need to be replaced. I think this is very, very important to us where transmitting can be maintained for on and on and on. The Columbia cannot get to the satellites from what I understand. It cannot fly that high. My plans at the moment are to get this information from this document to all the manufacturers and see if they can do what I'm trying to do. I plan to have sessions with the fishermen who are probably the most boat conscious and if the particular representative of our state, Mr. Studs, who is involved with fisheries and marines, have meetings with him and a group of fishersmen, or perhaps fishing organizations instead of fishermen themselves. Then the next step would be to get to all of the fishermen in some form or way: get a letter off or a memorandum off to the agencies that are most responsible. What I propose the WGA should do is to have a system proved to them before any change is made to Loran-C. This cannot be done until we have a navigation GPS system up there fully implemented. And I have to agree that this quarter-mile system is impractical only if you can actually in many places measure from one side of the Gulf to the other side without moving your ship or taking the antenna off a longer ship and go from the bow to the stern with an accurate measurement. I don't think you're going to be able to do that with GPS. I don't think they plan to get across the GPS down low enough to realize that. That is going to hurt the Loran system. And I think that one of the things that I plan to do is set up a letter plan to involve the many, many users we have here in the United States and Europe. I know that when I was in Europe a short while ago I visited a fishing area in Italy in the Adriatic coast. They were so impressed with Loran-C that when it was working well they said it was fantastic. When they took a couple of rides out and they hit a buoy and came back, went back to that buoy and the numbers were the same. They really thought it was fantastic. How are we going to tell these people when we told them a short while ago you must have a Loran receiver within a 200-mile limit. You cannot enter. In Norway I was told we will buy the cheapest receiver we can buy just to meet that requirement because there's no telling what the United States is apt to do next, they took Loran-A away from us, they might just as well take Loran-C away from us. How real those words are. My father says this country is sure but uses a lot of procedures.

Jim Culbertson - I have to apologize for not being too orderly in my thoughts and I really didn't prepare. Three years ago I gave a paper in Plans '78 in San Diego right here in Mission Bay. The paper was called Loran-C and Sea Faring the Shadow of GPS. I have reprints of that if anyone wants to write to me and get them or, of course, you can refer to Plan '78. But I think that everything I said then is even more applicable today than it was then. GPS is going forward. GPS is a good navigation system. I don't think there's any question on that. It has the capability to fly very high geodetic accuracy and it isn't cheap however. The Military has been funding the program for only one reason and that would be because it has a military potential. And assuming that that is still true, that it has a military potential, they probably will continue to fund the program. They should not fund it, however, for a civil application, this is not a good way to spend defense money. If it has a military potential they should fund it, it will get implemented, eventually like all other good military systems it will become available to the civil community in due course. It took Loran-C 20 years to get there and it will take GPS 20 for a good civil application. On the other hand maybe the military will not fund GPS. It is not a survivable system. If it is not a survivable system what does it benefit if there would be an all out war. They'll certainly turn it off or the Russian's will turn it off. One or the other. If it's a benefit to the Soviets they'll leave it on and we'll turn it off. If it's a benefit to us militarily they'll turn it off. Assuming that military funding continues it will be determined to be a useful system for military purposes it certainly is indeed useful whether or not the expenditure is worth the potential for peacetime navigation is questionable. But if they do the satellites are in place, receivers have been made workable, civil community will benefit and will probably benefit from whole accuracy of the system. But if it is just put up for military purposes and millions of taxpayers really don't want that system to be made available to civil users, if that is it's ultimate purpose, then they better fund it from the DOT and fund it from a civilian application unless DOD is spending their money on things . Going back to Loran-C, Loran-C, I guess, justified the expenditures of keeping Loran-C on the air and modernizing on the basis of cost. That's the only way one can justify. They start modernizing their statements, and reducing the manning level they will save money. The taxpayers will save money and the Coast Guard should answer this GAO report with a plan and puts it very clear that there will be money studied by the taxpayers by the modernization program by the reduction of the manning level. WGA's position should be an objective, practical position. We have to respond and recognize what the value of GPS would be to the community but how is it going to be paid for. Are we going to invoke a users tax? It's a fairly expensive system to keep in place. It's primary application in civil use really need a worldwide authority to pay for it. I have really no other comments at this point but I would like to refer you all back to the paper that was written much more than hearing what I've said (I think).

Jim Van Etten - Tape distortion.

Lloyd Higginbotham - Tape distortion.

Ed McGann - Tape distortion.

John Illgen - Thank you Ed. Before we open the discussion up on the floor I would like to turn over the discussion to Leo Fehlner.

Leo Fehlner - I would like to reinforce Ed's view that GPS might be the one that's really in trouble and I'll show you these books and you can look at them as you wish or you can take notes on them and get your own copies. Here's the one that set it all off in 1978. It says, "Navigation planning needs new direction." This has to do with proliferation of NAVAIDS. In the next one I have (these are in chronological order). Here's one for the Congress. Same GAO report. "The NAVSTAR Global Positioning System -- A Program With Many Uncertainties." 1979. Remember these titles. The next one I have is 1980. It says: "NAVSTAR Should Improve the Effectiveness of Military Missions -- But the Cost Has Increased the Systems." These reinforce Ed's other view that the fellows that do this sort of work don't have any ax to grind: they pick at everybody. One other thing, I would like to say something having to do with what Walt said. He said that they were going to degrade the CA channel so that you could get only a quarter-mile accuracy. If they do not degrade it, it will be a single-frequency channel which is subject to the ionospheric problems and the amount of accuracy you will be able to get with that one frequency will vary with the sun cycle which is an 11-year-old cycle and may vary between 150 and 200 meters.

John Illgen - Thank you Leo. Before we present the WGA near term action items, which will of course change as time goes on I would like to open this up to the floor but if you have a comment please come up, we will give you the microphone, and give us your name.

Eric Slauson - I'd like to take up mostly on the comment that Leo made when he spoke originally. I read the report. I had no doubt what the gentlemen from GAO were saying. It comes through loud and clear. It is unambiguous. I may perhaps have a little advantage over some. Keep in mind differential now has been adopted by France, Portugual, and numerous other places. There are a couple sides to that corner. But one thing that is technically true and always has been. Loran-C is a good system. Don't make the mistake in saying that GPS is necessarily bad. I have used it. I won't refer to using it. It does work. If you can afford it is another question. Regarding the Navy's position. It was alluded that the Navy was sitting back. I think there are two aspects at least in the Navy. The Navy is not ignoring GPS. There is a Naval officer at SAMSO. We at the Naval Systems Center are now and have in the past done work with GPS. There are distinct Naval problems: how you can use an antenna from ship. What about moment path on the ship? There are quite a number of questions unique to the Navy. What about pitch and roll? Those types of plans. The Navy has been active in that regard. Some people in the Navy have experience and are enthusiastic. Some of the people who are definitely not enthusiastic are the ones who have prime money instead of equipment. Let's take the first one back. The main point I would like to make is the report does come through loud and clear. The authors obviously did their homework. Perhaps Congress has more time for bean counting than it does in engineering. But, that is the point that needs to be addressed. Whey they come down and refer to the solid state transmitter replacement their position was very ambiguous. They talked to Coast Guard people. The answer they got back was the vacuum to the transmitters. On the other hand, they talked to the solid state people. And the problem from that side was the solid state transmitters themselves. As far as the point, the main problem here is the economic justification. You read the report it does not say the Coast Guard should carte blanche any solid state transmitters. What it says is it ought to be argued on the economic ground one side at a time. This is cost effective for that particular side. What they have gone through in some detail is their economic justification and I think any counterarguments would have to be on those terms. They should certainly be done conservatively.

I would like to say just 2 things. I think that the few of us who are here from the Coast Guard have all at one time or another been faced with a GAO audit of some kind. They're people doing a job and the type of job they're doing is helping you work and eventually you find that they are helping quite a bit. Some are real good at their jobs; some are experts. Some are not so good because they are people being observed. The few that were involved in this over the years were very good people. They're protecting their job and consequently they're fighting bad information that makes a point in their report. That's what they're hired for. In the Coast Guard itself all of us have been faced with these questions. I don't think anything put in the report is meant to be total attack. They were out there doing their job. I think then on our side a number of people probably could have given them accurate and the right answers are few and far between.

John Illgen - Is there anyone on the floor or on the panel who would like to say anything before we start our summary and present our action items?

Capt Culbertson - In response to Ed McGann's comments on writing cards and letters to the Coast Guard I would only recommend that any inputs to the Coast Guard be based on something other than pure emotion. I think that is going to go to just a deaf ear and they might agree with you but perhaps do no good because Ed makes a very important point. There's no central place back there right now in Coast Guard Hq which has any axes to grind about Loran-C in now that we've now done our implementation and installation. About the only active thing now regarding a bunch of engineers working together is getting this transmitter thing sorted out. But as far as working on a day-to-day basis with the rest of the Loran community and trying to percipitate and get thoughts going back and forth as happens when you're working with these systems afterward, simply isn't going on. There isn't a program office per se as there is for GPS/NAVSTAR. The inputs that, if I were back there now, I'm trying to put my hat around and put myself back in that position where I'm responding to an input I think there would have to be some things to support the facts that are needed to provide good input from us, the Coast Guard, during things such as hearings and other times. The facts that we need regarding the users as I mentioned, facts that we don't have information on that addressed the specific issues in the GAO report where there are some economic and other types of data needed where we might not necessarily have in our possession. That would be my comment on that. I think that if you are going to go to the next step here, John, I would say that I would agree too that perhaps we would need to go to: What are we supposed to be doing? What do we have to do in the way of a job? Who's going to do it? When does it have to be there? Who does it have to go to? Would be my comments. I would say that from the CG standpoint, they're going to continue with CDR Alexander's program and ours to maintain contact and create contact with the users and with the Loran manufacturers and people who have been so helpful to us in the past in maintaining a close relationship and contact with the people and I hope we can utilize this conduit to perhaps provide some of the user information that I think is desparately needed on a day-to-day basis.

Bob Frank - Tape distortion.

Jim Culbertson - Tape distortion.

Barney Ambroseno - Tape distortion.

John Illgen - Now I would like to discuss near-term action items and believe me if anyone has a good suggestion I know that all of the Board of Directors and the officers of WGA will accept those suggestions at any time. For the near-term we would like to use the newsletter to get out the names and addresses of the people these letters should be written to. This means simple addresses like the DOT secretary, Congressmen, people on the various committees. Those types of organizations. Leo Fehlner has a list of some of those people and their addresses here today. If you want to obtain that, you may do so today. I feel very strongly that these letters should be written and that they should be very factual. I feel like Ed does that they should come from individuals and corporate types. I think those letters should recognize the attributes of both systems (that's a personal thought). I think there has to be a very careful distinction between the civil and the defense applications. Some of our NATO allies like to have their own independent systems, whether its communication, navigation, whatever. I think we have to obtain a clear understanding to the accuracy that's going to be available and to whom. Those are questions that have to be raised. We know what we can do with Loran-C. As Jim Van Etten said earlier we have been dealing with the propagation problems that are unique to Loran, discovered ways to compensate for these propagation problems. The GPS system has several types of error sources and so forth associated with ionospheric, tropospheric, range errors, delay effects, multipath effects in the treatment and applications of the aircraft and satellite, buoy and satellite, I could go on and on. It's just beginning to be looked at. It's not just a matter of putting up 20 satellites and constellations and expect that once you turn it on you've got an operational system. There will be years and years of evoluation just as it has happened in other navigation systems. I guess I feel also from the GAO report, does the GAO recognize the enormous investment that the Coast Guard and the manufacturing people have made and just as Adm Manning had mentioned earlier today, it just seems like yesterday that we turned Loran-A off. What did that mean? It meant a great amount of expense to the Coast Guard and training people in how to use Loran-C. It took a lot of investment from manufacturers to change plans. When you have a new change of product it costs a lot of money. There's the issue regarding receiver cost we brought up. Accuracy versus dollars. That's a very crucial question. So I would hope that everyone thinks about those kinds of problems and many very excellent points that were brought up by the Board and Panel today. In the responses, Leo Fehlner and I are going to work very hard on this next issue, in the newsletter. Our goal is to get a newsletter out in a few weeks. We hope that the WGA members in turn will contact people that you know. Perhaps every WGA member can contact ten people or so and get the story and facts across. One of the worst things we can do is write letters that do not contain facts.

Walt Dean - John, may I interrupt a little. When you say facts that brings me to the fact of some of the items you brought up which I don't think are quite facts. You talk about the possibility of retractive errors, things like that. You don't have any hard facts. As a matter of fact, when we made our measurements using the Z state we did not observe any great errors due to the fact so I wouldn't try to run down the GPS system.

John Illgen - Wait, I don't think we should run GPS down. What I'm saying is that there are error sources associated with any navigation system and theoretically there have been a lot of investigations that have shown different applications the require compensation of some of these error sources. You were looking at it in one way. But there are numerous others.

Walt Dean - All I'm saying is that there is plenty of information that the system is inherently, sufficiently accurate to do anything you were going to do so that is not a point that should be emphasized in this discussion.

John Illgen - Well before we move away from that point that was made, Walt, an additional feeling is that the GPS system is not here yet. Today it provides no accuracy for many (not all) of the applications we are discussing today. Complete tests for all applications have not been conducted because the system is not operating yet. Only 5 or 6 satellites are now in orbit.

Walt Dean - That's not strictly true. The trouble with getting to an argument like that is that you get into a further series of name calling and different things where you're not getting to the point. There have been tests and people are convinced that GPS can work and can provide the accuracy they're talking about. So I don't think there's any benefit to us to try to refute that argument. It's a generally accepted fact and if we try to hang anything on that we're going to be wasting our time.

John Illgen - That point I'll accept (that is, that GPS works so far). However, I do not believe you can turn a new system on and expect error-free performance. The magnitude of these errors could impact depending on individual requirements. Studies and tests have shown that GPS works. Also shown are interference factors (propagation) that can impact performance (again depending on requirements). More work has to be achieved to prove GPS User Performance. That is one of the reasons why the GPS program office plans a series of tests under Phase II.

Walt Dean - I think the point in that discussion was the solid state receiver and that the fact that the transmitter and the GAO report states that the Coast Guard has not fully justified the replacement in terms of cost effectiveness.

Tape distortion.

Ed McGann - I'd like to make a few comments on the cost benefit and economic analysis. In summary specs on the solid state transmitter economic analysis done by the Coast Guard presented before this report calls out the economic analysis on a system-wide basis: completing a whole program due in 12 stations. GAO did not criticize the economic analysis of that report. What they did criticize was that we did not call individual stations that we were going to go. They claimed that we had a package program. We claimed this program was economically suitable. And they went down in and tried to identify well this particular station was not possibly justified. You did not justify each increment of the program. Now what we have done subsequent to that and what was included in the Coast Guard rebuttal that had gone through the Secretary is breaking down the increment parts station by station and showing how each station fits into this overall program. True, some stations are not as economically beneficial to change to solid state as other stations although they all show an economic cost benefit, yet the whole economic analysis for any one station depends on it being a part of the whole program. So these economic analyses have been completed by the Coast Guard. Now some previous economic analyses were in some ways a little bit misleading in that the solid state transmitter procurement and installation in itself is not economically beneficial. The solid state transmitter itself does not give us a cost benefit. The fact that the solid state transmitter allows us to implement a remote operating system to allow us some personnel reductions that installation is where the solid state transmitter achieves it cost benefit and cost analysis. That has been demonstrated. But the past that the GAO called out in the previous solid state transmitter were never put in such a respect that they could be remotely operated. Even though you have less maintenance hour demand that does not give you a personnel cost savings because you have to stand watches and people have to be there anyway.

Capt Culbertson - In our cost benefit analysis, Ed by the way I'm not rebutting I'm perhaps just explaining what you said, were based more on comparing a vacuum to a solid state as an energy device and things of this nature and we did more on that because it was in vogue to do it at that time. I don't think we knew how we were going to control it and we had our reductions of people when we modernized our stations with our solid state timing equipment. That was our first personnel reduction.

Ed McGann - Tape distortion.

Additional Papers Not Included in Last Years' Technical Proceedings

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LORAN-C SYSTEM SIGNATURE

CDR FRANCIS W. MOONEY, USCG
Executive Officer, USCG Supply Center
Brooklyn NY 11232

ABSTRACT

For the past two years the Coast Guard has been working with the Wild Goose Association to develop and publish a Loran-C signal specification. One of the most difficult areas involves describing the signature actually transmitted by Loran-C stations. This paper will address the signature of stations equipped with the AN/FPN-64, AN/FPN-44(A,B,etc), AN/FPN-45, AN/FPN-39 and AN/FPN-42 Loran-C transmitters. This signature includes normal maintenance, pulse shape variation/control fine phase control, momentary outages, BLINK and recovery after transmitter failures. Correct interpretation of the signature can optimize receivers performance.

INTRODUCTION

The Coast Guard has been operating the Loran-C system for over 20 years. Representative of other radio/navigation systems, it was developed in a "crash" manner to satisfy high accuracy navigation requirements for the Department of Defense. In the ensuing years the sophistication of all equipment associated with the system has increased and Loran-C is certainly one of the most "tested" radio navigation system in existence. After twenty years, the Coast Guard, working in conjunction with the Wild Goose Association, will soon publish a Loran-C Signal Specification. This paper will address one area of that document, the signature of the Loran-C transmitters.

TRANSMITTER MAINTENANCE

Four distinct generations of Loran-C Transmitters have been designed and deployed. All are still in active use. The first three transmitter types were designed within 7 years of each other, although redesign and "tinkering" to achieve improvements has continued since installation. These three types, the AN/FPN-39,42,44/45 are all identical in that they use vacuum tube technology. They are significantly different in size and maintainability. Each generation has physically grown, increased power to some degree and maintenance has decreased. The tube transmitter stations all have redundant transmitters with a common antenna coupling unit. The fourth generation transmitter, AN/FPN-64 differs radically in design from the first three as it is solid state and fail soft. All AN/FPN-64 sub-units are redundant, even the antenna coupler.

Maintenance requirements for the transmitters reflect the type of design. The FPN-39 is relatively small and parts are cramped. It requires 90 maintenance man hours per week (MMH/WK). Technicions primarily clean air cooled components and recheck tube and relay performance. The AN/FPN-42 is larger, has bigger tubes, is easier to balance and requires only 70 MMH/WK. The AN/FPN 44/45 transmitters were designed for higher power and maintainability. Water cooling of the power amplifiers and walk in enclosures result in only a 35 MMH/WK requirement. The AN/FPN-64 is essentially maintenance free, requiring only changes to air filters and occasional tests of the automatic recovery circuits. Comparisions of the transmitters are presented in Table 1.

TABLE 1

LORAN-C TRANSMITTERS

DESIGNATION	DESIGNED	MMH/WK
AN/FPN-39	LATE 50's	90
AN/FPN-42	EARLY 60's	70
44 & 45	MID 60's	35
AN/FPN-64	MID 70's	4

PULSE CHARACTERISTICS

For years it was known that receivers performed well when operating in a Loran C chain where all transmitters were the same, but occasionally had overlap indexing problems when receiving signals from stations with different transmitter types. It is impractical to manufacture a power supply with enough energy storage to permit building either 8 identical pulses or identical pulses at a double-rated station as the rates cross through each other. Standardization of the leading edge and pulse rise time plus introduction of new pulse building equipment did much to mitigate the pulse variation problems in the 70's. Leading edge of pulses from all transmitters have been matched to within 2% of the ideal pulse shape in the region of 10-50 US in the pulse. While none of the transmitters are linear, it is possible to predistort drive waveforms in the tube transmitters and readjust trigger times in the FPN-64 to partially compensate for power supply sag.

There is some variation through the pulse trains, but it is held to within 2 US. The pulse trains, especially at a double-rated station, actually are in a semi-stable state which requires integration on the part of the receiver. The train of pulses is, however, predictable in that once tuned, etc. the shape does not change and the composite envelope shape for a pulse train is stable.

The carrier crossovers are affected to a lesser extent than pulse shape. The tube transmitters are driven at the third cycle with 100 khz precisely (±10 ns) phaselocked to the Loran-C time base. Integration time for the loop is variable with repetition rate but normally it is set to within a few seconds. Samples are taken on all pulses. Tube transmitters utilize push-pull stages in the final power amplifiers, and all use multiple tubes on each side. Tube balance and power supply droop can affect positive to negative carrier pulses differently and some phase offsets are produced. There is no "hunting" of the cycle control servo loop and balance is maintained. The AN/FPN-64 has servo loops which adjust fine-time firing of the pulse forming circuits, again phase locked to the Loran-C timing base. For all transmitters, the net carrier offset is balanced and stable when all pulses are sampled.

All transmitters are closely coupled to the antenna and its characteristics are used to build the radiated pulse. The AN/FPN-39,42, and 44/45 transmitters have a common antenna coupler and fine tuning must be accomplished with the navigation signal interrupted. Normal component variations associated with the antenna/transmitter mesh caused by weather can produce tuning variations of 1-2 khz. The resultant pulse is affected by these variations in the fifth and later cycles. There are no tuning servos on these transmitters and it is therefore possible to have cycle variations of ± 100ns at the fifth cycle building to microseconds in the pulse tail. The AN/FPN-64 was designed to maintain a precise match and the coupling is maintained to a 100khz resource. This is accomplished by a special servo loop which drives an inductor in the antenna coupler. Table 2 summarizes the variation experienced in the transmitters. They are referenced about a mean rather than any cycle zero crossing.

TABLE 2

THIRD CYCLE STABILITY/
FIFTH CYCLE OFFSET

THIRD CYCLE	FIFTH CYCLE
39 +/- 75NS	+/- 100NS
42	
SR +/- 25NS	+/- 100NS
DR +/- 75NS	+/- 100NS
44 & 45	
SR +/- 25NS	+/- 50NS
DR +/- 75NS	+/- 50NS
64	
SR +/- 10NS	+/- 25NS
DR +/- 50NS	+/- 25NS

MOMENTARY OUTAGES

All Loran-C transmitters occasionally cease transmission of the navigation signal. If the usable transmission is interupted for less than 60 seconds, the interruption is called a momentary. Tube transmitter stations designate one transmitter as operate and one as standby. The operate transmitter is kept on-line for either a one or two week period, then the other is placed on-line. When a transmitter is in standby, routine maintenance is performed and use of load banks permits basic retest. Final proof can be obtained by placing the transmitter online for a brief period. Transmitter changes require a momentary transmission interruption and the stations try to limit the number of required tests. Actual failure of the operate transmitter casualties are few and weeks between. The standby transmitter is placed on line automatically and transmissions return, in-tolerance, within a minute.

The bane of continuous transmissions is the loss, or puturbation of commercial power. Most stations use commercial power due to the decrease in operating expenses. The stations with AN/FPN-39's are all on generator power. All the transmitters are automatically shut down if commercial power is lost, or there is a sufficiently large spike/surge. The transmitters also return to normal operations after power is restored. All newly built Loran-C stations have automatic start generators and older CCZ stations are being retrofitted. At present, only LORSTA Nantucket and Carolina Beach utilize commercial power and do not have auto-start generators. Momentaries vary from station to station, but typical performance, for all interruptions, is presented in Table 3.

TABLE 3

TYPICAL MOMENTARIES/MONTH

AN/FPN-39	20 (GENSET POWER)
AN/FPN-42	40 (DR ON COMM'L PWR)
AN/FPN-44/45	30
AN/FPN-64	20 (GOOD PWR), 100 (BAD POWER)

After a transmitter switch, or signal interruption due to a power transient, all stations, regain transmissions in a very similar manner, and all return to normal transmissions in one minute or BLINK is initiated. The time periods associated with the signal interruption are contained in Table 4.

TABLE 4

SIGNAL AFTER TRANSMITTER CHANGE
OR TEMPORARY POWER LOSS

0-25 SECONDS	-- NO, OR UNSTABLE SIGNAL
25-45 SECONDS	-- SIGNAL WITHIN 200NS
45-60 SECONDS	-- SIGNAL IN TOLERANCE

SIGNAL AVAILABILITY

The Loran-C system is on air almost continuously. When the signal interruptions noted as momentaries are discounted, availability per station is comfortably greater then 99.9% when examined on a monthly basis. If a station is scheduled for some abnormal maintenance operation, notice to mariners are normally issued 1-3 weeks in advance. Emergency off-air periods are announced on local broadcasts.

SIGNATURE INTERPRETATION

Using the signal specification provided by the Coast Guard and to some extent, this supplemental information, it should be possible to further improve receiver usage to the navigator. Receiver design is certainly one of trade-offs. For years the Coast Guard has openly stated that use of later cycles for phase tracking can produce errors. A receiver tracking the 5th cycle of a chain using AN/FPN-42 transmitters could easily have 0.2 US errors without any contribution from noise. In a similar fashion, sampling on less than eight pulses for either indexing purposes or fine timing could produce some unusual results. Perhaps most frustrating to the user, However, is a receiver which initiates a five minute alarm due to monmentary loss of the signal. The stations either return to normal timing or BLINK within 60 seconds. I have found an explanation of these receiver's performance virtually impossible to a newly trained user.

ACKNOWLEDGEMENTS

Data for the performance signatures of the transmitters was gathered from operational reports for CCZ chains and informal inputs from ACTEUR and CCGD17. The assistance by personnel representing these areas of command is acknowledged and appreciated.

Operational Experiences With Precision LORAN Radionavigation Equipment

LT John J. Anthony
LCDR Andrew J. Sedlock
Office of Research and Development
U. S. Coast Guard Headquarters
Washington, D. C. 20593

Results of last fall's field testing of the APL-built PILOT (Precision Intracoastal Loran Translocator) encouraged the Coast Guard R&D organization to deploy a system, consisting of a precision Loran-C receiver and the PILOT, aboard units operating in the St. Marys River. The selected vessels included a Coast Guard 140' icebreaker tug, three ore carriers and a Canadian aids to navigation ship. Accuracies better than 10 yards are consistently reported while transiting the St. Marys River system, with the exception of winter, when offsets up to 25 yards were observed in places. We can not discern any appreciable operator difficulty in using the system in its prototype state. As with any navaid, the confidence of the user in the accuracy of information appeared to grow directly with operational exposure but total reliance on this system, if it ever comes to pass, requires more operational usage and education in the fundamentals of repeatable Loran-C.

A compact, portable version of this equipment was developed for Delaware Bay, where it is presently completing test. Initial comparisons of navigational performance between the short baseline St. Marys System and the long baseline East Coast Chain show little significant difference in bottom line capability. Operational evaluation with pilots of the local association is being conducted this winter.

We can now conclude precision navigation in restricted waters with Loran-C has been achieved with practical and economical equipment and technology and is ripe for optimization in the competitive marketplace.

INTRODUCTION

The PILOT navigator (Precision Intracoastal Loran Translocator) is an OEM computer terminal adapted to compute position fixes from Loran-C time differences and display pertinent navigation information on a CRT for the ship operator. For reference purposes, a complete description of the technology and equipment are provided in a report entitled, "Precision Loran-C Navigation for the Harbor and Harbor Entrance Area" (AD-A086001) (reference (1)). An abbreviated description is provided in the paragraph below. As reported in that reference, the first field test of PILOT was performed in October, 1979, and largely confirmed the results we had experienced in the development stages with the aid of a Loran-C simulator. Though no quantitative assessments could be performed at the time, the overall display agreed well with the vessel's position established with visual cues (e.g. when the display showed there to be a buoy abeam, one actually saw a buoy abeam). This kind of confirmation of the system's accuracy was enough for us to pursue an operational test in preparation for test deployment on commercial carriers. This paper reports on the operational test, a more quantitative analysis of PILOT's performance and the results of a user evaluation aboard three commercial carriers.

BACKGROUND AND DESCRIPTION

Spurred by a charter to exploit Loran-C as a navigation system suitable for piloting in restricted waters, the Coast Guard has sponsored development of several user equipments that effectively transform Loran-C time differences into useful information for the ship operator Technical feasibility having previously been demonstrated, PILOT is the result of an approach which stressed the requirements of compactness and simplicity in a device that could be competitively produced. The Applied Physics Laboratory (APL), chief designers of the equipment, chose to adopt a microprocessor based OEM graphics terminal, the HP2649, for the task. Development was very much user oriented with the final product a self-contained unit pictured in figure 1. Output of the system

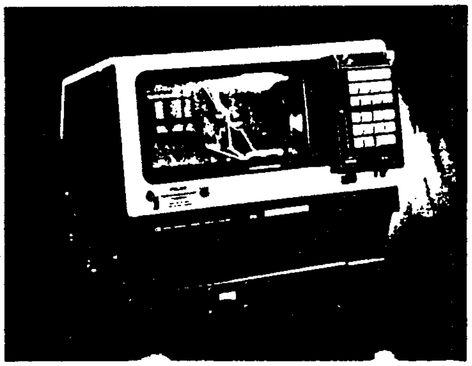


Fig. 1 - PILOT Terminal

features a flexible combination of graphic and alphanumeric presentations.

In previous developments, our lack of precision in predicting the Loran time differences pointed out the need to physically tie several Loran and geographic coordinates together by means of survey. Survey technology developed for this purpose was reported in reference 1. These data, along with graphics coordinates for the CRT, are stored in separate files on a magnetic cassette tape. This becomes essentially a chart catalogue for the harbor of interest; the operator may initially index to any location and subsequent chart selection becomes automatic as the vessel proceeds along the channel. Both large and small scale graphics may be selected, the former featuring a scaled vessel image with channel boundary/shoreline details.

The system block diagram in figure 2 shows the basic configuration of receivers and gyro compasses for PILOT operation. TD bias entries are made manually and the printer is optional. Figure 3 summarizes the functions taking place within the terminal. Transformed Loran data are used to continuously compute and update navigation parameters such as cross track position and speed for digital and graphical display. The operator may also select a number of features, such as projection of future position.

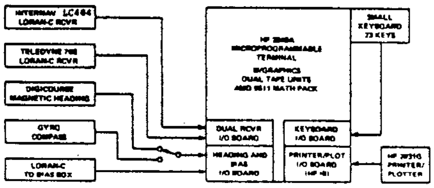


Fig. 2 - System Block Diagram

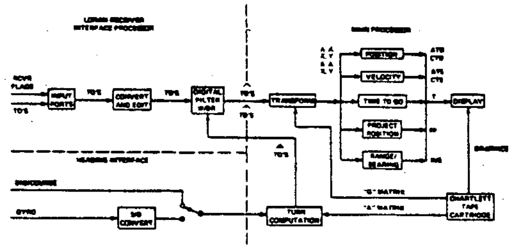


Fig. 3 - Functional Flow Diagram

Field testing of PILOT was a successful demonstration of the survey and the navigation algorithms within the terminal software. Immediately evident was the value of a high resolution (10 ns) receiver, which provided precise data to PILOT for smooth, high quality output on the screen. All future installations then utilized an Internav LC404 or similar type receiver. The original goal of an accurate, compact, easy to use and economical (system costs are less than $20K) Loran-C harbor navigator had been accomplished. What remained was to determine commercial user acceptability of the system.

VALIDATION OF VISUAL SURVEY

Two months after its first field tests; PILOT began service on an operating vessel with a trial installation aboard CGC KATMAI BAY, an icebreaker in the St. Marys River. Only on such a ship could we practically determine the performance of the Loran chain during the winter months, when this system should be more useful due to the scarcity of visual aids to navigation. However, only weeks after the installation, the winter navigation board voted to suspend shipping from 15 January to 1 April, causing us to abandon all plans for winter operations. In the limited underway time we had in ice, some small shifts in the Loran-C grid were observed. Time and a policy to minimize icebreaking, however, prevented us from examining it more completely. But the observance of these discrepancies pointed out the need for a complete validation of PILOT's performance prior to any commercial installation. Upon completion of an assessment of PILOT's accuracy for navigation, we could confidently inform the users of the first commercial installations exactly what they can expect. Furthermore, upon collecting user comments, it will be informative to compare their perception of PILOT's performance with our more quantative evaluation.

To perform the validation, the computed output from PILOT and time differences from the receiver were input to an HP9845 desktop calculator. This machine was programmed to record this data on the vessel's track and draw a trackline. At the same time, an observer's estimation of the vessel's crosstrack position could be entered. The two positions appeared simultaneously on the display, which was later printed and recorded on tape. Estimations of along track position were made in a similar fashion whenever objects with known locations along the channel passed abeam of the antenna.

Though the above description may read like a crude method of data collection, it in fact was very successful in pointing out areas of good and poor performance. Visual ranges in the St. Marys River are extremely sensitive so our reliance upon them with this method is justified, provided we made no large deviations from the centerline. With experience, it becomes easy to estimate to within 10 yards cross track deviations of up to 50 yards. The obvious disadvantage of the technique is that it does not permit a verification of larger offsets which could be important in other harbors when the channel size permits one to maintain a track to the right of the centerline. Validation techniques in such circumstances would probably include use of microwave positioning systems.

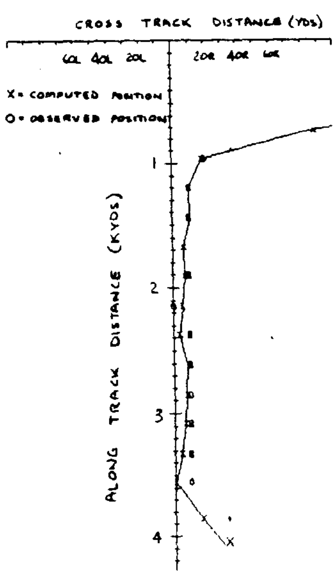


Fig. 4 - Consistent Tracklines

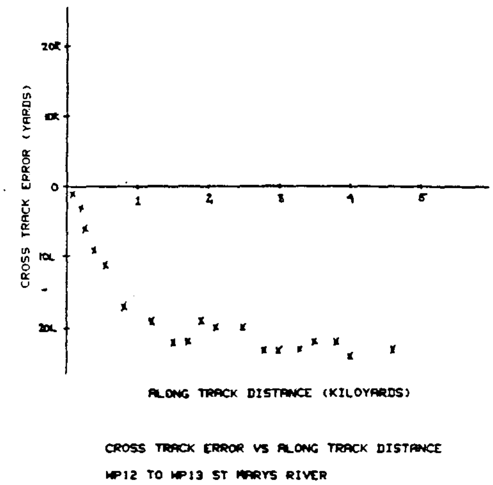


Fig. 5 - Trackline with Nonlinear Bias

The program in the calculator performed the same function as the navigation routine within PILOT, providing a history of the vessel's path, referenced to a surveyed waypoint. An example plot showing a region where Loran determined and observer estimated positions agreed closely is shown in figure 4. This type of result was typical of most of the river. In at least two stretches, however, our validation confirmed a previously suspected bias in the signals, an example of which is shown in figure 5. Note that the time path of observations lies on the channel centerline while PILOT consistently shows the vessel 20 yards to the left. At the waypoint, the navigation solution coincides with the observation, thereby validating the survey. One of three choices exists for resolving the cross track discrepancies.

(1) Establish one or two surveyed "track points" along the centerline. This will provide accurate navigation along the leg until the end, when the bearing angle between waypoint and track point will be in error.

(2) Deliberately move the waypoint 20 yards, which will correct for the warp along track, leaving the very end in error. This is a satisfactory solution since a user will have turned or begun turning well before reaching a waypoint.

(3) Mentally correct for this discrepancy when using the equipment.

Looking at the comparisons for the entire river, only three areas exhibited less than satisfactory performance (i.e., 10 yard accuracy) and none exceeded 30 yards error. These, as in the example, were due to local anomalies and did not invalidate the survey. While recognizing this as less than optimum, the uncompensated errors were not serious enough to prevent PILOT's introduction into commercial use.

COMMERCIAL USER EVALUATION

PILOT terminals, LC404 receivers and gyro converters were then installed on three Great Lakes ore carriers for a three month evaluation. Size of the vessels ranged from 700 to 1000 feet long and up to 105 feet in breadth. Considering the requirements in parts of the St. Marys River to remain within a 300 foot channel, this evaluation promised to be very demanding of the navigation system's capabilities. Vessel operators were given some initial instruction on the use of the receiver and PILOT and provided with copies of operator's manuals for further reference. Additionally, units were installed on CCGS VERENDRYE, a Canadian Coast Guard buoy tender, and retained onboard CGC KATMAI BAY.

Evaluators visited and rode the vessels periodically over the course of this evaluation, taking notes on particular discrepancies that may have gone undetected during the validation. Equally important were the on scene observations of particular likes and dislikes of the operators with respect to the navigation display and ease of operation. These were subsequently compiled for inclusion into future PILOT software revisions and new approaches in the preparation of data tapes. A brief but comprehensive questionnaire was distributed at the close of the three month evaluation period to which we received nearly unanimous response.

Results of this user survey are presented in Table 1. Note that there is considerable interest in using the equipment and, when working properly, appears to provide acceptable service with respect to accuracy. The question of navigating "blind" refers to using a combination of PILOT and radar only. Unfortunately, our reliance upon an experimental Loran-C chain (the St. Marys minichain) for the evaluation caused several "failures" which could not be attributed to the onboard equipment. Participants, however, were understanding of this limitation and strove to evaluate PILOT

Table 1

SUMMARY of PILOT QUESTIONNAIRE

	Every Trip	Almost Every Trip		None	
Pilot was used:	10	2			
	Excellent	Good	Fair	Poor	
Reliability:	3	4	5		
	Chain	Receiver	Terminal		
Cause of failures:	11		1		
	10yds	20	30	40	Unusable
Accuracy:	2	6	2	2	
	Yes	Yes with Reservations	Probably not	No	
Would you use PILOT/radar to navigate "blind"	2	8	2		

independent of chain nonavailability. Certainly, use of the Great Lakes chain as the positioning data base will greatly improve the reliability of the entire system. Whether the long baseline chain will provide the desirable accuracy remains to be seen. In overview though, the user reaction is encouraging and our goal of demonstrating practical and economical precision Loran-C navigation devices has been largely achieved.

Written comments accompanying the questionnaires emphasized interest in becoming more familiar with PILOT to the point of requesting a reinstallation for the 1981 season. Also, the Canadian Coast Guard independently compared PILOT performance to a microwave positioning system and found them to be in close agreement. This then generated interest in applying PILOT for the positioning function of buoy tending as well as general navigation. Partly in response to these desires and in order for us to fully evaluate performance on a long baseline chain, our immediate plans are to conduct another grid survey (Great Lakes Chain) of the St. Marys River, revise PILOT software and produce new data tapes. All of this will be provided to the same commercial carriers for the 1981 season. The VERENDRYE, meanwhile, will be conducting their own Loran-C survey of the buoys they service for eventual input to a specialized buoy tending data tape.

PILOT GOES PORTABLE

A second, closely related effort in Loran-C harbor navigation has involved the packaging of the PILOT system into a small hand carried box

Fig. 6 - PLAD

designed for use by ship pilots. This self-contained unit consists of a Loran receiver and processor, and houses a hand held data terminal, antenna and antenna coupler and power cord. Designed for use only in a particular pilot area, all the survey data is permanently stored in PROMS, eliminating the requirement for tape cassettes. Of course there are no graphics presented on the hand terminal, but two lines of navigation style output are available at any time. A photograph of PLAD (Portable Loran Assist Device) and its equipment is shown in figure 6.

When a ship's pilot carries PLAD aboard to use, he will first unpackage and connect the power card, terminal and antenna coupler. A convenient rail on the bridge wing will serve as an adequate location for the coupler while PLAD and the operator remain inside. Once the receiver is locked up, the navigation program automatically determines the vessel location with respect to surveyed waypoints and future navigation output is at the choice of the operator. Similar to PILOT, speed and position within a channel are continuously updated and may be displayed concurrently, Time difference biases, if any, may be dialed in at the front panel. Upon reaching the destination, PLAD is easily repackaged and carried off.

The trial area for PLAD is the Delaware Bay/River, where low lying land and scarcity of fixed aids require great concentration of the pilots. The situation is compounded when winter ice and winds move the floating aids off station so a device such as PLAD has the potential of significantly aiding the quality of navigation. Waypoint data from a survey conducted in the spring was burned into PROMS for an initial trial in November, 1980. What appeared to be relatively good performance observed in the lower bay was offset by some erratic results closer to Philadelphia. Some receiver related problems were identified and solved. In the most recent trials (February, 1981), PLAD performed flawlessly with an accuracy that motivated one pilot to remark he could have conned the entire passage from the mess deck!

PLAD is presently undergoing an extensive quantitative comparison with positions in the channel as measured by the Corps of Engineers' Autotape network. The results from passages made to data reveal a trackline standard deviation of 25 feet while validation with autotape has enabled us to fine tune the surveyed points to where there is negligible bias.

Should this be observed throughout the river system, we shall conclude that PLAD is ready for operational use by the pilots.

SUMMARY

Overall, our work in exploiting the available Loran-C signals to precisely indicate position within a harbor can be termed a success. Most users until now have been totally unaware of the high potential accuracy existing in time difference radionavigation signals. What is most encouraging is that the entire effort has required little original equipment development on our part. Precision Loran-C navigation is a commercial reality because of economically priced 10 ns receivers, microprocessors and well monitored chains. The marriage of these technologies, as demonstrated in PILOT, now promises to be a commercial success. Though already simple, straightforward and compact, units like PILOT and PLAD will require more real world exposure before earning the trust and respect due a sophisticated piece of navigational gear. And like radar, acceptance is inevitable because through automation it reduces the human burden of navigating restricted waterways. Our operational experiences now give us confidence for a bright future of precision radionavigation equipment.

REFERENCE

1. Olsen, D. L. et al, "Precision Loran-C Navigation for the Harbor and Harbor Entrance Area", CG-D-34-80.

APPENDIX A

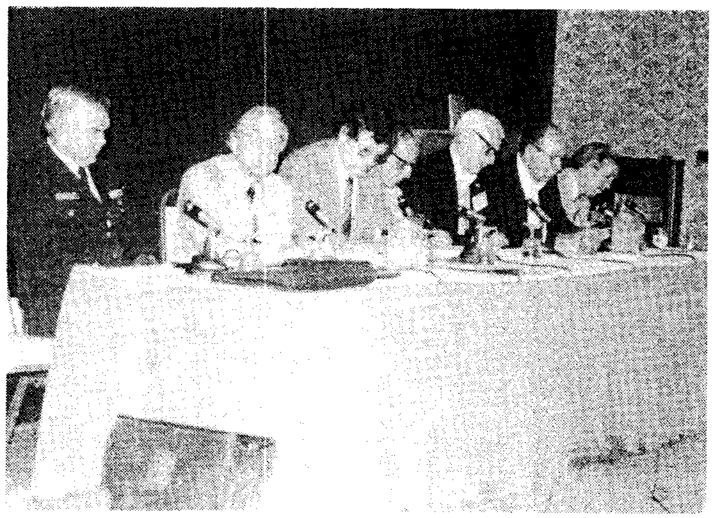
THE CONVENTION SCENE

WGA RECOGNIZED INTERNATIONALLY

Japan

Scandinavia

THE SYMPOSIUM



Panel Discussion: GPS and Loran-C GAO Report Discussions. A subject dear to all WGA members

Technical Session in Process

THE BAHIA BELLE

Vern Johnson, Bill Rice, and John Hopkins
and John Hopkins enjoy hors d'oeuvres

Mr. and Mrs. Paul Johansen

WHAT WAS DICK "RACE" DISCUSSING?

THE BANQUET

Walt Dean introduces the banquet speaker, Mr. Chuck Slocombe, who discussed "Whales." The Wild Goose shown on Chuck's fishing hat could really fly as we all found out.

A good turn out at the reception before the banquet.

AWARDS

Leo Fehlner (left) receiving award from Bob Frank (right).

Jim Van Etten (left) receiving award from Bob Frank (right).

ADDITIONAL AWARDS

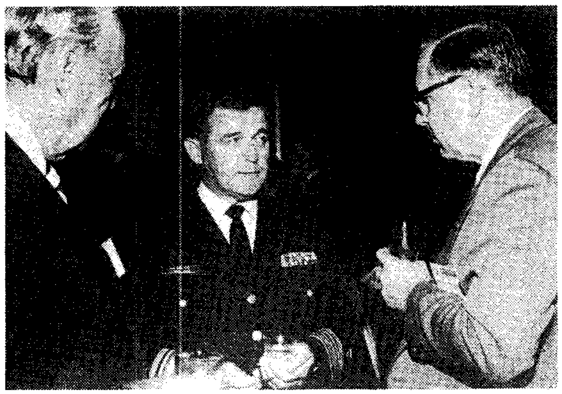
Vice President Walt Dean presenting award to Jim Alexander.

Bob Frank presenting award to Commander Dave Amos.

ADDITIONAL AWARDS

Bill Rice receiving award from Bob Frank.

AWARDS ON THE LIGHTER SIDE —
WGA GOLF TOURNAMENT



Left to right, J. Regan, Admiral Al Manning, and Vern Johnson.

Right to left, Vice Admiral Stewart and Walt Dean.

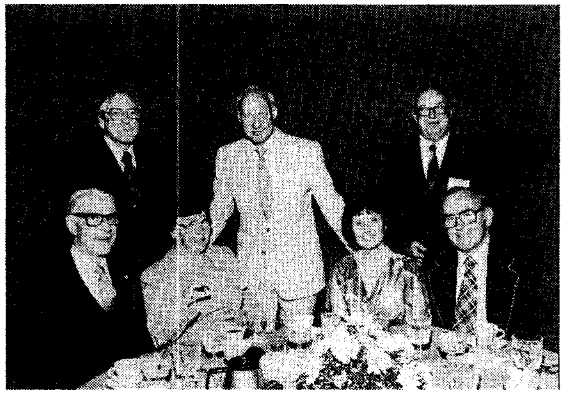
Lois Campbell, Bill Rice, and Barney Ambroseno.

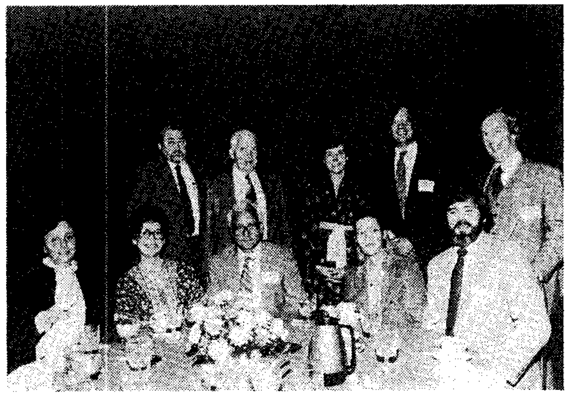
Paul Johansen, Al Manning, and John Beukers.

Left to right, Al Manning, Grace Van Etten, Jim Van Etten, and Claire Manning

Left to right, Leo Fehlner, Walt Dean, and Allan Cook.

GROUP PHOTOGRAPHS
THE BANQUET





Sandy Fox (Bahia Hotel Coordinator), Marge Dean, and Walt Dean (Convention Chairman) are all smiling at the banquet and should be since the entire convention was a hugh success. Thank you Marge and Walt!