FAA TECHNICAL CENTER LETTER REPORT

LORAN-C MID-WEST ENROUTE FLIGHT TESTS

by

Robert Erikson

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U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
TECHNICAL CENTER
Atlantic City Airport, N.J. 08405

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1. OBJECTIVE

The overall goal of this project is to determine the suitability of Loran-C for airborne navigation using new technology receivers. It is the intent of this project to investigate new areas such as enroute operation in the Mid-West continental U.S. coverage gap, and non-precision approaches in mountainous areas thereby expanding the use of Loran-C. Operational performance of at least four types of production airborne Loran-C receivers will be evaluated. Flight data will be recorded onboard fixed wing aircraft flying enroute, within terminal areas and during non-precision approaches to several airports located throughout the U.S.

Areas of investigation will include:
a. Accuracy. This will be measured with respect to a special ground-based distance measuring equipment (DME) reference system and compared to criteria stated in Advisory Circular (AC) 90-45A for flight technical error, airborne equipment error and total system error.

b. Effective Signal Coverage. Signal to noise values as measured by each different model of Loran-C navigator will be recorded.

c. Operational Suitability. Problems in operation of the equipment pertaining to set up or following a prescribed flight profile will be noted.

It is not the intent of this project to evaluate a particular model Loran-C receiver, but to investigate the performance achieved by the general class of new technology receivers, thus demonstrating the suitability of Loran-C for certification in new areas. New technologies are unique to particular vendor model equipment and must be taken into consideration. This will include: Coordinate conversion sophistication, r.f. sensitivity, processing techniques, cross-chain operation, and auto tuned notch filters.

2. BACKGROUND

The Loran-C System has been used for navigation and specialized military air operations since the late 1950's. Serious application to civil air navigation is relatively recent. Technological advances in receiver design and commissioning of several new Loran-C chains in the late 1970's and early 1980's have stimulated interest in the potential of Loran-C as a navigation system for general aviation. The low frequency of Loran-C (100 Kilohertz) provides stable ground wave propagation and coverage at great distances (600-1000 nm), not limited to line of site between transmitter and receiver. Thus Loran-C is a likely candidate for navigation in areas not serviced by conventional navigation systems, e.g. VOR/DME.

Early airborne receivers were little more than reconfigured marine receivers requiring many manual operations and reporting position only in time differences (T.D.'s). It became evident that airborne Loran-C receivers must be automated, convert T.D.'s to geodetic position, include notch filters, operate without a master, and increase area of operation. New technology receivers have improved operation with respect to the previously described criteria. The improvements have included automatic selection of chain and secondaries, improved techniques for converting T.D.'s to geodetic position which results in better accuracy, automatically tuned notch filters to reduce interference, operation without a master, and use of several chains at once. Actual implementation by each manufacture of the above issues varies both in choice and technique. A detailed listing of specific Loran-C equipment features is included in the Airborne Equipment section.

A brief description of redundancy, coordinate conversion/position fixing and associated terminology is presented here as it will affect the data collection, analysis and conclusions reported by this project.

Redundancy

Historical data has shown Loran-C transmitters to be very reliable. This excludes off-air periods typically less than one minute in duration . Short off-air periods (<1 minute) are generally asociated with normal maintenance and may occur over 100 times per year per station. On occassion long off-air periods may be encountered due to scheduled maintenance or unscheduled emergency repairs. When discussing the operational capability of a Loran-C navigation system, stations used and available should be noted. While scheduled off-air periods may prohibit starting a flight, it would not present a safety problem.

If, however, an unscheduled outage occurs during flight and redundant signals are not available an unsafe condition may exist! Redundancy means different things to different Loran-C receivers because of receiver design. Actual reception of a signal depends on transmitted power, local noise at the receiver site, distance from transmitter and the minimum Signal to Noise Ratio (SNR) required for a receiver to operate.

In order for any Loran-C receiver to determine a position it must be able to receive a minimum of three stations (two if true range-range implementation). Single chain receivers require a master and two secondaries from the same chain, while master independent systems require three secondaries from the same chain. Master independent receivers may require the master to be in normal track before it can operate without it. The feature was originally intended to continue navigation in the event the master was lost during flight. It was not intended to extend range or initialize the receiver if a chain master is not present. At least one receiver uses the master independent technique to extend the usable navigation area. It is able to accomplish this by requiring only the peak energy of the master be received during initialization. The voltage at the peak of the pulse is twice that of the standard tracking point, thereby increasing SNR by 6dB or adding several hundred miles to the normal master coverage area. Tracking peak energy for normal position determination is not used because of the susceptibilty to skywave contamination. Recently, manufacturers have implemented crosschain operation using signals from several chains at once to determine position. Loran-C receivers typically have two minimum values of SNR that the set will operate at, one for acquisition and the other for track. Acquisition, the process of finding the right station, and then the standard tracking point (third cycle), requires a higher SNR value than required to maintain the proper tracking point (track). A receiver may be able to fly from a good SNR coverage area to a poor one and operate, but the reverse is not always true. Under normal conditions the way a receiver handles stations not used in the navigation solution has no effect, but if a station outage does occur, it may make the difference between successful and unsuccessful navigation .If the Loran-C receiver tracks all available stations for a chain and a primary station used in the navigation solution is lost, the set will substitute T.D.'s for a tracked and acquired station. For stations not tracked, additional time is required to acquire the substituted station. In areas of poor SNR, the station may never be acquired.

To summarize the above receiver characteristics, redundancy can mean the reception of one more station on any chain (provided peak energy from the master is available), one more station on the selected chain, or in the worst case the reception of a master and two secondaries from another chain. The geometry of the received signals which is discussed in the next section affects redundancy as well as accuracy.

Coordinate Conversion/Position Fixing

Loran-C position fixing and coordinate conversion are affected by airborne receiver implementation and transmitter/receiver geometry. A position fix may be obtained using either hyperbolic or circular lines of position. The advantage of the hyperbolic technique is that it does not require a highly accurate clock. One disadvantage is that equally spaced time difference contours describe increasing displacements on the earth as one moves away from the baseline between master and secondaries. Position estimates degrade on baseline extensions to the extent where the information is totally unuseable. Although the ability of the receiver to measure the T.D.'s remains the same, it causes larger errors in the position solution. The term used to describe this characteristic is known as the gradient of the lines of position. Circular lines of position define equal earth displacements for equally spaced phase delay contours, however, a highly accurate and synchronized clock, which is very costly is needed to implement this method. New techniques are being developed to use less expensive, less accurate clocks for ranging.

In order to determine a position fix using either method, a minimum of two lines of position must intersect or cross. The angle at which the lines of position (LOP) cross affect the accuracy obtainable and are a function of receiver/transmitter geometry. Geometric dilution of precision (GDOP) is the term used to describe the LOP crossing angle. Selection of stations for the navigation position solution based on GDOP and the addition of more lines of position will improve the position fix.. Use of different lines of position for the navigation solution can also affect accuracy. With such a large number of possible combinations a variety of results are possible. Dedicated TRIAD mode goes one step further, by forcing the navigation solution to use specific combinations of masters and secondaries.

Conversion of Loran-C T.D.'s to a geodetic position is not straight forward. The major factor affecting the conversion is the delay of the signal versus distance. Phase delay is a function of earth conductivity. The most common methods to compute phase delay assume an all seawater path, an all average soil path, land/sea path combining the delays (based on Millington's method), and multi-conductivity path using conductivity maps combining results based on Millington's method. Phase delays may vary several microseconds depending upon the method used and geographic location. Some receivers have implemented a feature known as area calibration to compensate for these known variations in computed positions due to modeling. The technique requires pilot input,(known present position), and computes a correction to bring the Loran-C computed present position to the known position.The offset is applied to all computations until disabled. Corrections are valid for some area around the calibration point. The area of validity is still under investigation.

3. RELATED DOCUMENTS/PROJECTS

1. "Aircraft Tracking and Data System (ATADS), Enroute Accuracy" FAA Letter Report CT-82-100-75LR by Matthew Naimo and John Gallagher.

2. "Predicted signal strength based on NBS Circular 573 for fixed strength by System Control, Inc. Champlain Technology Industries Project" 5365-500, Dated 29 May 1981, titled "Loran-C Coverage Plots for Consus" by E.D. McConkey.

3. "Specification of the Transmitted Loran-C Signal", July 1981 by USCG, Report # COMDTINST MI6562.4.

4. "Approval of Area Navigation Systems for use in the U.S. National Airspace System",Advisory Circular 90-45A DOT, FAA 2/21/75.

5. "Federal Radionavigation Plan", DOD-4650 4-P-111, DOT-TSC-RSPA-81-12-11.

6. "Minimum Performance Standards - Airborne Loran-A and Loran-C Receiving Equipment". Radio Technical Commission for Aeronautics, Document #DO-159 October 17, 1975.

4. AIRBORNE EQUIPMENT DESCRIPTION

4.1 LORAN-C RECEIVERS

The Loran-C equipment that will be used for these tests are a Teledyne TDL-711, Teledyne TDL-424, Micrologic ML-4000 and Advanced Navigation Inc (ANI) ANI-7000. All units are production aviation Loran-C receivers available for public purchase. Additional Loran-C receivers may be included if they become available prior to flight testing. Summary tables wil be used to show the features of each type of Loran-C receiver.

Table #1 provides the important Loran-C features, table #2 the physical data and table #3 the navigation guidance data calculated by each receiver.

4.2 INSTRUMENTATION

Aircraft instrumentation is divided into three groups, Loran-C receivers, aircraft tracking system, and the data collection system. All Loran-C receiver computer units, control display units (except one ANI-7000 CDU), antenna coupler units, course deviation indicator, remote I.N.S. display, digitial clock and spectrum analyzer will be included in one aircraft rack. Each Loran-C receiver will be connected to a separate antenna. Although each manufacturer has specific procedures to adjust notch-filters, the technique is generally less then optimual, therefore, a spectrum analyzer will be used to verify adjustments. The spectrum analyzer will be connected to a Bayshore UPS-95 Loran-C antenna to provide unfiltered spectrum monitoring during flight. The following equipments will be installed on the rack.

1. 2 - ANI-7000 Receiver Computer Unit (RCU)
2. 1 - ANI-7000 Control Display Unit (CDU)
3. 1 - INS Remote Display
4. 1 - TDL-711 RCU
5. 1 - TDL-711 CDU

LORAN-C RECEIVER MANUFACTURE SPECIFICATIONS

Parameter	Manufacturer / Model	Teledyne TDL-424	Teledyne TLD-711	Micrologic ML-4000	Advanced Navigation Inc. ANI-7000
Area of Operation		11 chains 1 temporary	16 triads	All existing chains	All existing chains
Receiver Type					
# of Chains Simulatneously Tracked		1	1	1	4
Chain/Station Selectionously Tracked		5	3	6	8
a. Auto/Manual		Auto Advise Man. Select	Manual	Automatic	Automatic
b. Method				Geometry	Shortest Range
Acquisition		Automatic	Automatic	Automatic	Automatic
Notch Filters					
a. Numbers		9	2	4	3
b. Method Set		Manual	Manual	Manual	Automatic
Min. SNR for Operation					
a. Acquiaion		-14dB	-10dB	---	-12dB
b. Track		-26dB	-16dB	-17dB	-18dB
Max. Signal Imbalace		60dB	60dB	---	60dB
Position Fix					
a. # of chains (if >1 cross-chain)		1	1	1	4max.
b. # of stations		3	3	3	8max
Loran-C GRID		Hyperbolic	Hyperbolic	Hyperbolic	Hyperbolic/Range
Master Independence					
a. Acquision		yes	no	no	note #1
b. Track		yes	yes	no	yes
North Reference(operater selectable)		Mag/Tue	Mag/True		Mag/True
Grid Reference					
a. Lat/Long		yes	yes	yes	yes
b. T.D.		yes	yes	yes	yes
Coordinate Conversion					
a. Model		Note #2	Note #2	Note #2	Based on Millington's Method
b. Assumed Conductivity					Map
Area Calibration		yes	yes	yes	no
Dedicated TRIAD		yes	yes	yes	yes
Maximum Velocity(unaided)		950	950	5000	

Notes
1. Requires peak energy of the Master
2. Single Optimized Value which gives best results for both land and sea.

Table 1

Loran-C Physical Data

Parameter	TDL-424	TDL-711	ML-4000	ANI-7000
Control Display Unit (CDU)				
a. Size (WHD)	5.75* 9.0* 6.5	5.75* 4.50* 7.80	6.15* 3* 12.0	4.97* 3.8* 6.65
b. Weight (lbs)	9	4.5	5.0	5.0
Receiver Computer Unit (RCU)				
a. Size (WHD)		7.50* 7.62* 14.17		7.38* 7.50* 12.50
b. Weight (lbs)		11.0		13.0
Power				
a. Voltages	28 VDC	18-32 VDC	10-16 VDC	18-32 VDC
b. Curent/Power	3.0 AMPS	40 Watts	2.1A max	60 Watts
Estimated Price Range	$30K	$12K	$8500	$19,500

TABLE 2

LORAN-C Navigation/Guidance Data

Parameter	TDL-424	TDL-711	ML-4000	ANI-7000
Receiver Status	x	x	x	x
Cross Track Error	x	x	x	x
Distance to Go	x	x	x	x
Bearing to To Waypoint	x	x	x	x
Desired Track	x	x	x	x
Ground Track	x	x	x	x
Ground Track	x	x	x	x
Estimated Time Enroute	x	x	x	x
Ground Speed	x	x	x	x

x - Parameter calculated by receiver

TABLE 3

6. 1 - TDL-424 Receiver
7. 1 - TDL-414 Antenna Coupler for TDL-424
8. 1 - ML-4000 Receiver
9. 1 - Datel Model DTC-8300 Digitial Clock
10. 1 - Tektronic 7603 Oscilloscope
11. 1 - Tektronic 765 Spectrum analyzer plug-in
12. 1 - Battery back-up system for Loran-C receivers
13. 1 - Collins IND-350 Indicator

ATADS, described in related documents #1, is already assembled in one aircraft rack and will be used in its' present state. Time tagged multi-DME ranges and channel numbers will be recorded on the built-in data cartridge system and by the data collection system. Aircraft position is measured as DME ranges and must be converted to geodetic position.

The remaining equipment will be grouped into the data collection system. A PDP-11/34M minicomputer is used to control the data collection and provide selected engineering data to the operator during flight. While on travel the system may also be used to read back the data collected and provide summaries. Figure #1 shows a block diagram of the system. The data collection system is already built and presently being used by other projects. It will only be necessary to design and fabricate interfaces for the ANI-7000's, ML-4000, TDL-424 and ATADS.

CRT/Keyboard

Floppy Disk Drive

PDP-11/34M

Line Printer

9 Track Digital Recorder

Time Code Generator

DME #1

DME #2

LTN-51 INS

VOR #1

ATADS

Aircraft Systems Coupler

ADC - 80 (Air Data Computer)

TDL-711

TDL-424

ANI-7000

ANI-7000

ML-4000

LORAN-C Receivers

Block Diagram of Data Collection System

Figure #1

Table #4 summarizes the data that will be recorded from the Loran-C receivers while Table #5 includes all other data to be recorded on the 9 track digital tape.

TABLE 4

LORAN -C Digitial Output Data

	TDL-424	TDL-711	ML-4000	ANI-7000
Present Position Lat/Long	x	x	x	x
Station Status	M + 4	M + 2	M + 5	x
Station SNR's	M + 4	M + 3	M + 5	8
Time Differences (TOA)	4	2	2	8 TOA
ECD		M + 3		8
To Waypoint name			x	x
To Waypoint Lat/Long		x	x	x
Cross Track error	x	x	x	x
Ground Speed	x		x	x
Dist. to go	x	x	x	x
Front Panel Switch Setting			x	x
Enroute/Approach				x
Annunicator Lamps				x
Receiver Status	x			x
Grid ref				x
Bearing to To Waypt	x			x
Desired Track	x			x
Estimated Time Enroute				x
Heading				Note 1
True Airspeed				Note 1
Notch Filter Setting				x
Secondary Phase Delay				x

Notes:

1. Require TAS & Mag Heading into ANI-7000, but is not used for navigation.
2. X = Data present in digital output.
3. M = Master

TABLE 5

REMAINING DIGITAL DATA TO BE RECORDED

TIME
DME #1: Range/FREQ
DME #2: Range/FREQ
LTN-51 INS: Present Position
Heading
Track Angle
Ground Speed

VOR #1: Bearing
TO/FROM
FREQ.

ADC-80: True Airspeed
Altitude

ATADS: Multi-DME Ranges with time tags

ANALOG CDI from system displayed to pilot.

4.3 ERROR BUDGET

As with any airborne data collection effort, sources of error exist in the aircraft tracking system, data collection system and data reduction system. To insure that the objectives of the project can be met, the errors must be addressed prior to commencement of data collection. AC 90-45A defines the accuracy a navigation system must meet. Table #6 is a summary of the accuracy requirements described in this document. To insure a decision can be made about the accuracy of a system, the measurement system should be 10 times more accurate than the requirements of the system under test.

The total measurement system errors including the aircraft tracking system, data collection and reduction should be 1/10 the values listed in table # 6. Although the present phase calls for the evaluation of only enroute performance, the data collection and analysis system will later be used for non-precision approaches and, therefore, these accuracies should be used. To meet AC 90-45A requirements the measurement system along track and crosstrack errors (mean + 2) should be less than .15 nm (912 ft) for enroute and .03 nm (182 ft) for non-precision approaches.

The following are areas which will contribute to the total measurement system errors. No one value can be assigned to these areas as implementation may require trade-offs in one area to compensate for another.

TABLE 6

SUMMARY OF AC 90-45A ACCURACY REQUIREMENTS

Based upon FAA AC 90-45A, existing airborne Loran-C equipment can meet the FAA accuracy requirements if error budgets (95 percent confidence) satisfy the following criteria:

	Crosstrack		Along Track	
Total System Error	(nmi)	(km)	(nmi)	(km)
Enroute	2.5	4.6	1.5	2.8
Terminal	1.5	2.8	1.1	2.0
Approach	0.6	1.1	0.3	0.6

	Crosstrack		Along Track	
Airborne Equipment Error	(nmi)	(km)	(nmi)	(km)
Enroute	1.5	2.8	1.5	2.8
Terminal	1.12	2.1	1.10	2.0
Approach	0.33	0.6	0.30	0.6

	Crosstrack		Along Track	
Flight Technical Error	(nmi)	(km)	(nmi)	(km)
Enroute	2.0	3.7	0	0
Terminal	1.0	1.9	0	0
Approach	0.5	0.9	0	0

Aircraft Tracking System

The ATADS enroute accuracy has been evaluated and reported in related documents, item one. The enroute circular error probable (CEP) was measured and found to be typically less than 400 feet. The non-precision approach accuracy using precision portable ground stations is still being evaluated.

Time Skew

Although a common clock will be used to time tag data it is possible to incur delays. It is expected the time tagging errors will be less than 100 ms. Each Loran-C receiver and aircraft sensor outputs data asynchronously, requiring interpolation to analyze receiver performance. Data will be collected at a higher rate than required for data reduction to minimize time skew between systems and simplify interpolation software. The problem is especially important when determining position accuracy during periods of high dynamic aircraft maneuvers. Data will be collected once a second. Loran-C receivers typically output new data every 1 to 4 seconds. Additional time delays may be incurred due to manufacturers' implementations of digital output routines. Use of straight line interpolation during maneuvers is a source of error.

Math

Loran-C receivers use great circle math in making calculations, therefore errors will exist between Loran calculated desired track and Victor airway (VOR) routes which are rhumblines. The errors will be a function of flight leg distance.

5. DATA COLLECTION

New technology receivers are designed to do at least one of the following:

1. Extend operational area (overcome problem areas)
2. Increase accuracy
3. Increase system reliability (hardware)
4. Increase number of stations that are useable for navigation
5. Reduce system cost

The evaluation of such equipment should measure performance during enroute, terminal and approach phases of flight as applied to AC-90-45A. Areas with known GDOP, propagation, and noise problems should also be included in the flight tests. The Mid-West continental United States, Alaska, and certain other parts of the U.S. are known problem areas due to lack of Loran-C stations, poor lines of position gradients or poor crossing angles. Many tests are needed to completely evaluate Loran-C but this test plan will be limited to three phases:

Phase 1 Receiver Performance on Simulator
Phase 2 Aircraft installation check-out
Phase 3 Mid-West flight tests

Additional phases to cover non-precision approaches and Alaska will be added later. All receiver background, instrumentation, data collection, data reduction, and data analysis will remain the same. All flights will be flown on a Convair CV-580 equipped with the Loran-C navigation systems under test on preplanned routes.

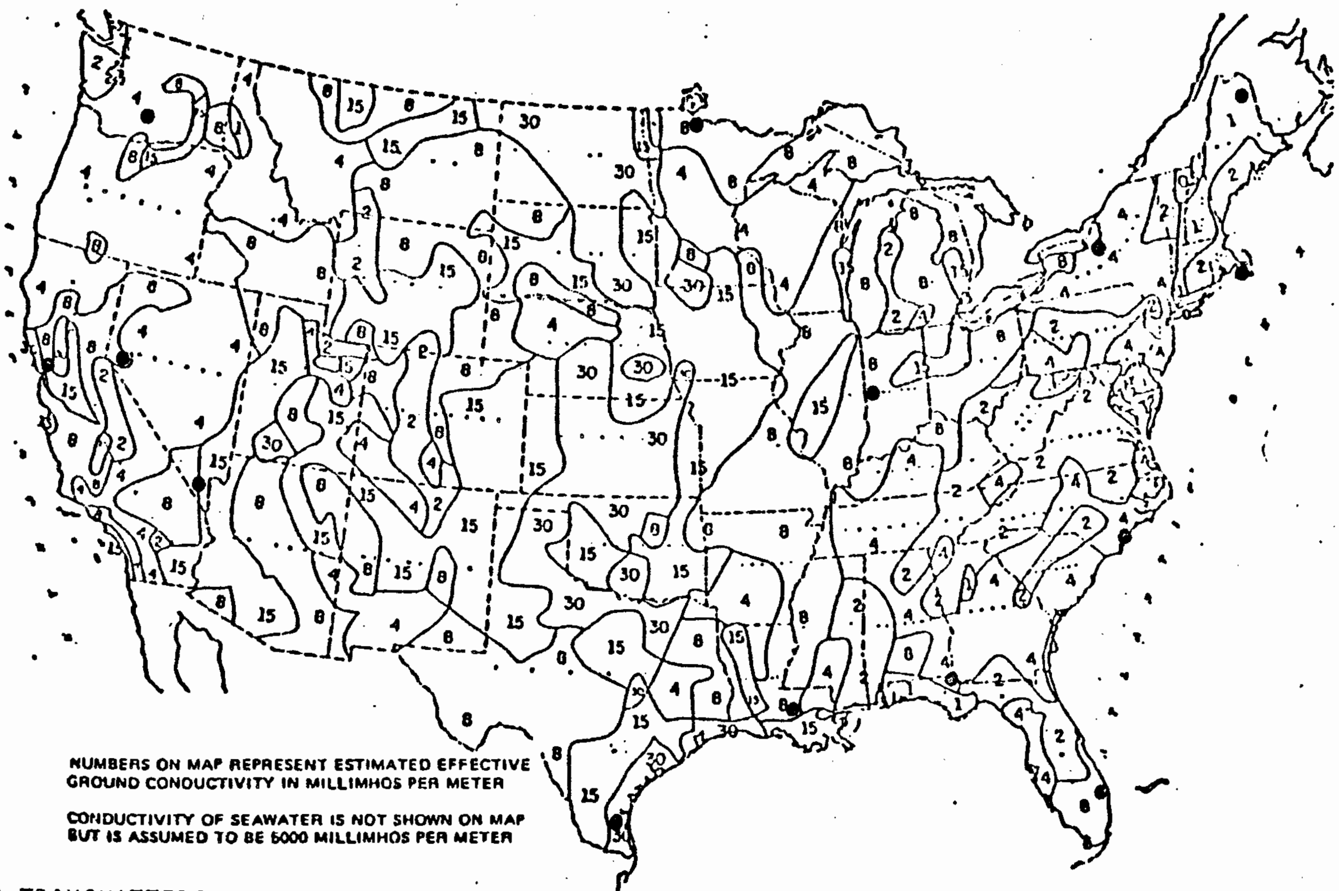
In order to obtain Flight Technical Error (FTE), one ANI-7000 CDU and CDI will be installed in the cockpit to permit the pilot to follow designated flight profiles. All other instrumentation will be installed in the CV-580 passenger compartment, and will be operated by the project team. A multi-DME system known as ATADS will be used as the aircraft tracking system.

5.1 PHASE I, RECEIVER PERFORMANCE ON SIMULATOR

The USCG maintains a high quality dynamic Loran-C Simulator (LRTC II) located in Wildwood, N.J. In order to calibrate and better understand the characteristics of the various Loran-C receivers, each will be operated on the USCG simulator. The simulator output will be coupled to the active antenna of each system. It is important that the active antenna be part of the test as it provides impedance matching, gain and frequency rejection/ selection.

The following receiver parameters are to be determined for each receiver using USCG standard procedures:

1. Search Time
2. Lock-On Time
3. Step response to 1 s T.D. jump
4. Time difference error vs SNR
5. Dynamic range/sensitivity
6. Differential Signal level
7. Skywave Performance
8. Continuous Wave Interference (CWI)
9. Calibrate Field Strength (SNR) numbers
10. Calibrate Envelope to cycle deviation (ECD)



● LORAN TRANSMITTERS

Effective Ground Conductivity Map for the United States

Figure 2

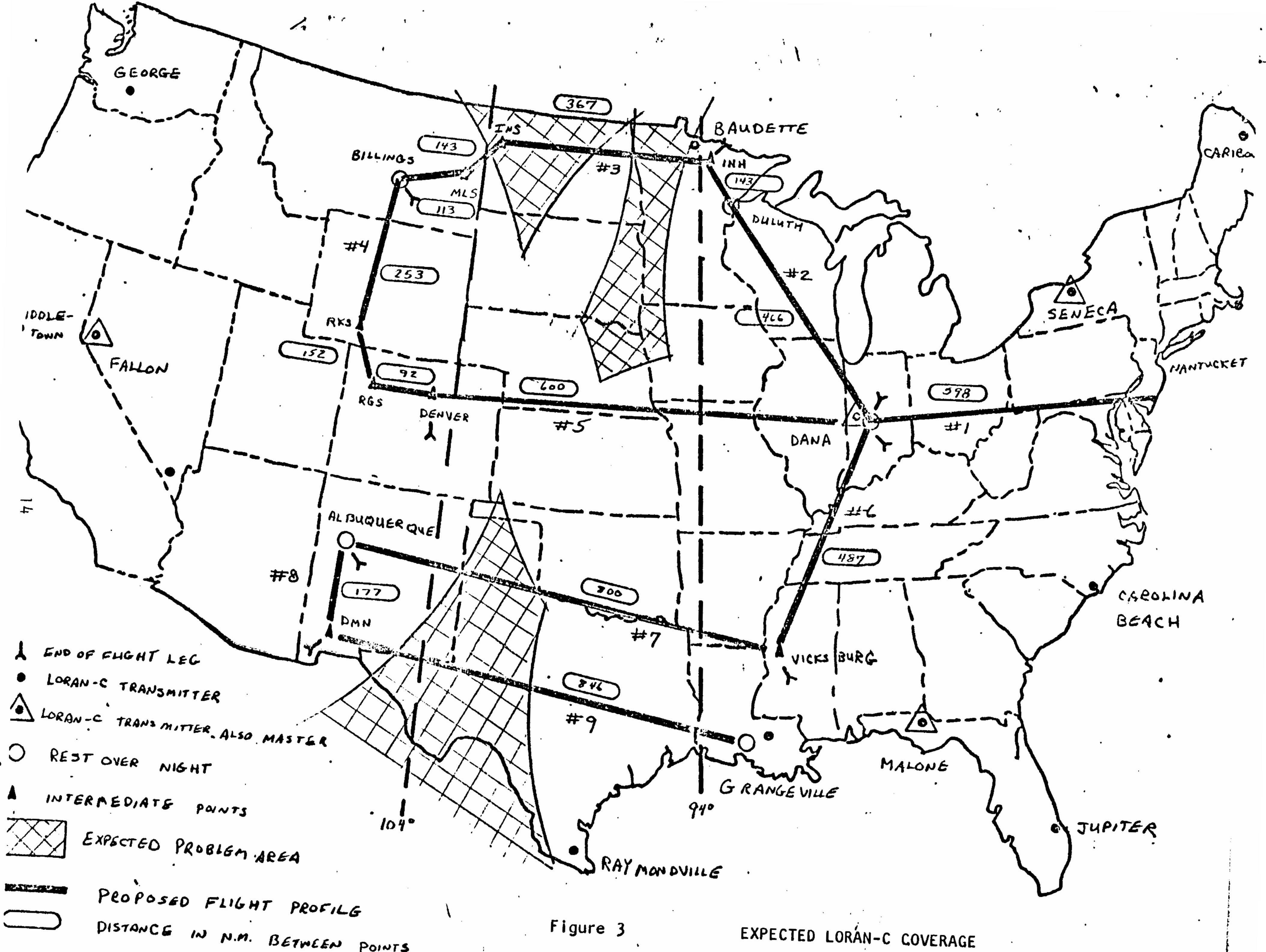


Figure 3 EXPECTED LORAN-C COVERAGE

5.2 PHASE II, AIRCRAFT INSTALLATION CHECK-OUT

The following checkout is designed to determine possible problems and quantify the Loran-C receiver aircraft installation. Locally generated aircraft noise in excess of atmospheric noise, distortion of the Loran -C signals and local interference will greatly affect Loran-C receiver performance. Ideally the aircraft installation should be optimized for best receiver performance but this is not always possible. The following test, although, appearing to be very lengthy should be completed in one 8 hour ramp test.

Measurements will be made to determine the pertubation caused by system installation.

1. Park the Loran-C stability van within 500 feet of aircraft. Collect Loran-C data in one minute intervals on the 9960 chain using the Austron 5000 receiver. The Austron 5000 is a calibrated Loran-C instrumentation receiver and will be used as a local independent control monitor.

2. On-board the aircraft, operate each Loran-C receiver individually from a battery while the aircraft is disconnected from all other sources of power. Record T.D., SNR, and ECD for each station in the 9960 chain.
3. Repeat the test described in step 2 with aircraft powered from an external ground power unit.

4. Using a ground power unit, turn all equipment (aircraft and project) on and record T.D.'s, SNR and ECD for each receiver.

5. Start aircraft and with all possible equipment turned on, again record T.D.'s, SNR and ECD for each receiver.

5.3 PHASE III, MID-WEST FLIGHT TESTS

As stated in the background and airborne equipment descriptions each Loran-C receiver operates differently. Accuracy and coverage is a function of both geography and Loran-C receivers. The limited flight profiles described are an attempt to provide as much information about the Mid-West coverage gap as possible for various receivers and also limit the amount of flying. Routes were selected to obtain receiver performance under the following conditions:

1. Various signal to noise ratio's
2. Various GDOP's
    a. Crossing Angles
    b. Line of position gradients
    c. Baseline extensions
3. Various ground conductivities
4. Effect of mountainous areas
5. Multichain reception
7. Crossing of chain boundaries
8. Close proximity to Loran-C transmitter

Performance will be a direct result of the manufacturer's selection and implementation of minimum SNR for operation, choice of signals for navigation and conversion of T.D.'s to Lat/Long. Refer to table #1 for summary of receiver specifications.

Figure #2 shows the effective ground conductivities in millimhos/meter (mmho/m) for the continental U.S. From the figure it can be seen that the values range from 0.5 mmho/m to 30 mmho/m with the highest values in the Mid-West. Signal attenuation, being a function of ground conductivities, means signals should propagate futher in the Mid-West than on either coast. Loran-C transmitter locations have been added for reference.

Figure #3 is a summary of expected signal coverage and problem areas compiled from several sources. Item #3 of the related documents predicts Loran-C signal coverage for a 1:3 SNR, and 1/4 nm fix accuracy. Only the 4 chains with coverage within the continental U.S. have been included in figure #3. Additional assumptions are hyperbolic navigation using best TRIAD, with a T.D. standard deviation of .lus (95%, 2DRMS). Redundancy using other secondaries, cross-chain, or master independent receivers were not addressed. As expected a coverage gap is predicted to exist. The actual size of the gap will depend on receiver SNR, aircraft installation, accuracy of prediction, and allowable accuracy degradation. Use of cross-chain receivers should improve navigation coverage because less constrants are placed on the stations used.

To determine those areas which might be a problem for cross-chain operation, predicted signal coverage (signal strength only) from related documents item #2 was used. The highest ground conductivity of the report, 5 mmho/meter and 0dB SNR receiver sensitivity was used to determine those areas which would not receive a master and those areas with only two station coverage. Location of the problem areas should be accurate, but the size will vary. North Dakota and western Texas may not receive a master, therefore, some systems will not be able to be initialized. Loran-C receivers have vendor quoted specifications for track and acquisition SNR's of -24dB and -17dB, but 0dB was used in case some receivers are aircraft noise limited. Use of a receiver sensitivity of -10dB reduces the size of the expected problem areas.

It should be stressed that this was not intended to be a rigorous study of Loran-C propagation, but to use existing documents to identify possible problem areas.

General Flight Requirements

1. Loran-C coverage is not limited by altitude. To obtain data perturbed by city or industrial noise, flights should be conducted at the lowest altitude possible. The aircraft tracking system is, however, a line of sight system and, therefore, an altitude of approximately 10K feet will be required to obtain enough DME's for a position solution.

2. To make sure all Loran-C receivers are given the best chance to acquire, each system will be started east of 94° west longitude and west of 104° west longitude. The technique will insure that the system is started in a "good" SNR region and then flown into a poor region. A second ANI-7000 will be installed in the aircraft and cycled on/off/on in flight to determine if acquision is possible in a "poor" SNR region.

3. Actual flight profiles are to follow existing Victor airways. In order to determine FTE one ANI-7000 CDU and CDI will be installed in the cockpit and used by the pilot for navigation. The co-pilot will use VOR position data as a safety check. During times when Loran-C navigation is not possible conventional navaids will be used for navigation.

4. Sequence of flight legs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 9, 8, 7, 6, 5, 4, 3, 2, and 1.

5. First flight sequence to Baton Rouge will be flown during normal working hours; repeat flight will be flown at night to obtain highest noise conditions.

6. Actual flight routes and altitudes will be selected to stay in VFR conditions and receive at least 3 DME's for the aircraft tracking system to provide accurate positioning.

Test Rationale for Each Flight Legs
Refer to figure #4 for flight leg designations.

Flight Leg #1

1. Single chain receiver useage: 9960 XY, XZ, YZ, 8970 WX
2. Overflight of Dana (within 10nm) to determine effect of close proximity to a transmitter. If 8970 selected, it will also be Master
3. ECD and SNR versus distance for conductivities of 4 to 8 mmho/m using Dana.
4. Navigation, accuracy, and redundancy expected to be good.
5. Flight crosses predicted coverage boundary for 7980 chain.

Flight Leg #2

1. Single chain receiver useage: 8970 XY.
2. ECD and SNR versus distance for DANA (4 to 8 mmho/m) and Baudette (4 to 8 mmho/m).
3. Dana - Baudette baseline, GDOP increases as the flight approaches Baudette. Therefore, errors should increase for single chain receivers while the ANI-7000 errors should remain relatively constant.
4. Flight crosses predicted coverage boundary for 9960, and 8970 chains.

Flight Leg #3

1. Flight crosses predicted coverage boundaries of 8970 and 9940 chains.
2. If signals are present, errors should be large for single chain receivers due to poor GDOP. Use of cross-chain receivers should improve accuracy.
3. Flight goes through an area where only two stations (cross-chain) may be received, therefore, no navigation solution would be possible.
4. Initialization of Loran-C receivers may not be posible, due to lack of master peak energy coverage.
5. ECD and SNR versus distance for Baudette (= 8 to 30 mmho/m) and George (= 1 to 30 mmho/m).

Flight Leg #4

1. Operation near predicted coverage limit for 9940 chain.
2. Possible cross-chain reception of 8970 chain to improve accuracy.
3. Baseline extension 9940 M-X.
4. Signal from Searchlight will propagate over ground conductivities of 4 mmho/m and then jump to 15 mmho/m.
5. Flights and transmitter-receiver paths in mountainous area.

Flight Leg #5

1. Flight crosses predicted coverage boundaries of 9940, 9970, 7980, and 9960 chains.
2. ECD and SNR versus distance for Fallon, Middleton and Dana.
3. Flight profile has the highest probability that a single chain receiver can navigate across the mid-continent coverage gap.

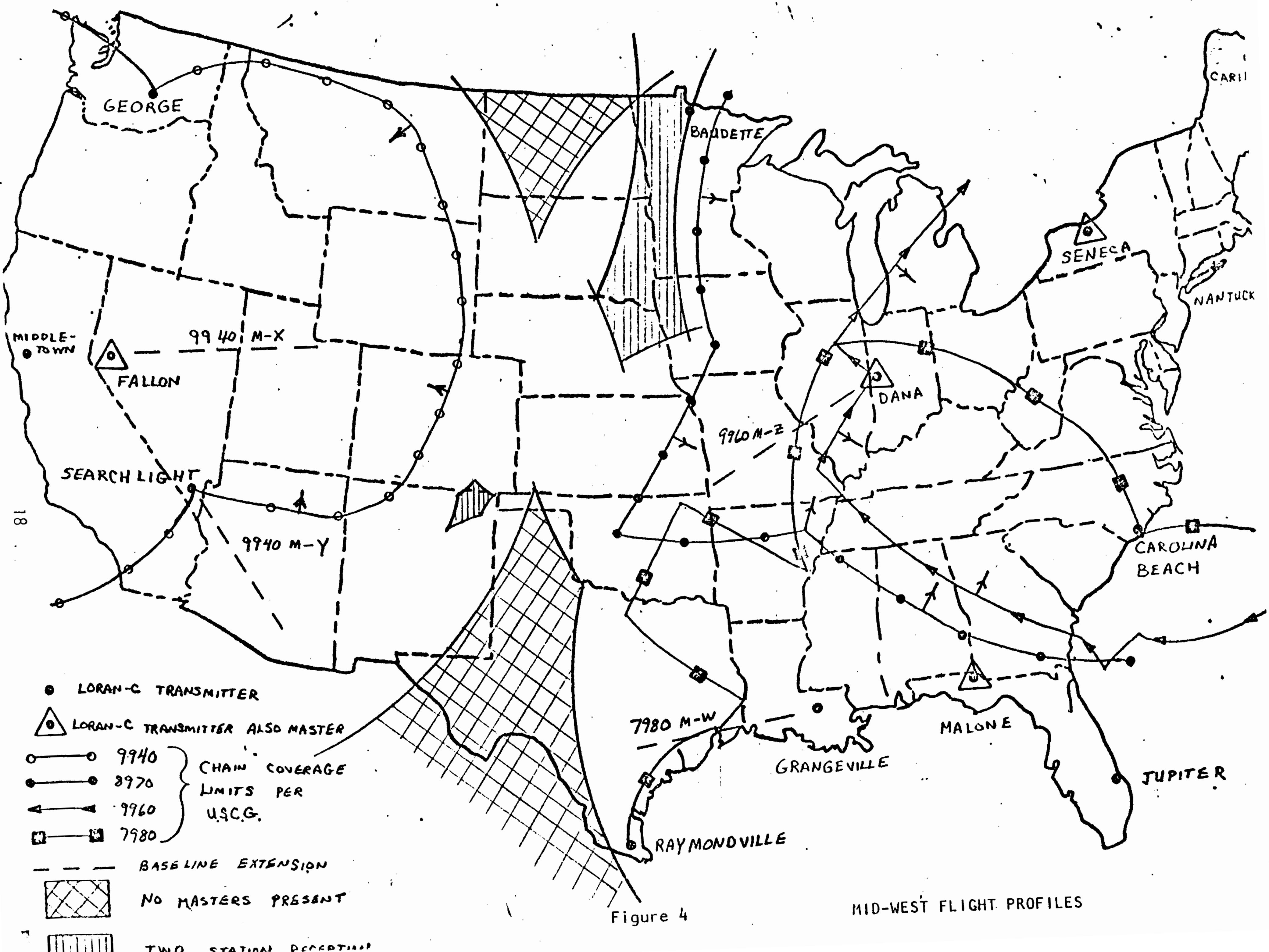


Figure 4

MID-WEST FLIGHT PROFILES

Flight Leg #6

1. ECD and SNR versus distance for Dana and Georgeville.
2. Traverse boundaries of 9960, 8970, 7980 chains. Check ability of automatic selection of chain/stations when many choices of navigations signals exist, especially in and out of chain coverage.

Flight leg #7

1. ECD and SNR versus distances for Fallon, Middletown, Searchlight, Malone and Grangeville.
2. Flight profile covers areas of poor GDOP, poor signal coverage, possibly no masters, and possible 2 station reception . Flight legs 7, 8, and 9 contain problems which even the best receivers are not expected to overcome.

Flight #8

1. Operation in the area of the 9940 M-Y baseline extension. Because of transmitter geometry it is expected cross-chain operation will be of little help and high position errors will exist.
2. Single chain receivers should perform as well as cross-chain receivers.

Flight #9

1. Expect same results as in flight leg #7. Should give good indication of how wide spread the coverage problem is regardless of receiver implementation.

6. DATA REDUCTION/ANALYSIS

Several levels of data reduction and analysis will be done. While in flight, summary data will be displayed on a terminal and line-printer to verify that correct data is being received by the data collection system. In the field, post flight data reduction and analysis will read data from the previously recorded 9 track tape and provide another summary. Final data reduction and analysis will be conducted at the Technical Center on a PDP-11/34 minicomputer. A section describing each of the above areas follows.

6.1 Receiver Performance on Simulator

The following information will be tabulated for each Loran-C receiver.

1. Search Time
2. Lock-on Time
3. Step response to 1 s. T.D. jump
4. T.D. error vs SNR.
5. Dynamic range/sensitivity
6. Differential signal level
7. Skywave Performance
8. Continuous wave interference
9. Curve of Loran-C receiver noise/field strength numbers versus actual simulator values.
10. Curve of Loran-C receiver ECD numbers versus actual simulator values.

6.2 Aircraft Installation Check-out

Data obtained during the check-out will be processed as follows. Values of SNR, ECD and T.D.'s obtained on the Austron 5000 during testing of the individual receivers on batteries will be baseline values. All additional test results in the aircraft will be adjusted the amount shown on the Austron 5000 minus baseline values. In most cases no difference will be measured. Using the adjusted values an average value of SNR, ECD, and T.D. error will be calculated and results presented in a table. Shifts of ECD, SNR or T.D.'s due to the aircraft installation will affect the performance of each receiver especially during flights in marginal coverage areas. Table #7 is typical of the way data will be presented.

Summary of Aircraft Installation
(average values)

		Baseline	Test Conditions		
		1	2	3	4
SNR	ANI-7000				
	ANI-7000				
	TDL-424				
	TDL-711				
	ML-4000				
ECD	ANI-7000				
	ANI-7000				
	TDL-424				
	TDL-711				
	ML-4000				
T.D.	ANI-7000				
	ANI-70000				
	TDL-424				
	TDL-711				
	ML-4000				

Test Conditions

1. Each receiver operated individually on batteries.
2. Each receiver operated individually on ramp power.
3. All receivers operated on ramp power with all equipment turned on.
4. All receivers and equipment operating with aircraft engines on.

6.3.1 IN FLIGHT ANALYSIS

In flight analysis is limited in complexity and data rate by the amount of CPU time available on the PDP-11/34 M after data collection routines are completed. Calculations must be done as a single pass operation. New summaries will be produced every 30 seconds. Each summary will contain the following:

1. Time of sample
2. I.N.S. present position
3. ATADS present position
4. DME #1, DME #2 ranges to selected facilities
5. VOR bearing to selected facilities
6. Present position of each of the Loran-C receivers under test. A warning or advise character will be displayed next to present position to indicate receiver status. The summary data is intended to provide verification to the data collection team that the navigation and data collection system are operating correctly.

6.3.2 IN THE FIELD POST FLIGHT ANALYSIS

Data reduction will read data from the previously recorded 9 track tape and provide the same information as stated in the in-flight analysis. In addition the mean and standard deviation of North and East errors comparing ATADS position to each Loran-C receiver position will be calculated for each flight.

6.3.3 POST FLIGHT DATA REDUCTION/ANALYSIS

For each flight leg the folowing information will be derived using ATADS as the correct aircraft position:

1. FTE, cross-track errors and total system cross-track error for the pilot used ANI-7000 #1 will be statistically presented (mean and standard deviation plus plot) in tabular form with flight leg position. The statistical errors will also be plotted with respect to flight leg position.

2. The mean and standard deviation for along-track and crosstrack (airborne equipment) errors will be calculated for the TDL-711, ML-4000, ANI-7000 #1 and ANI-7000 #2. All data will be plotted with respect to flight leg position.

3. The ratio of time (total minutes) each receiver was in track mode to the time (total minutes) of each flight leg will be tabulated for a quick look comparison of each receiver.

4. Plot each Loran-C receiver SNR versus track position for all stations received.

5. Tabulate all operation notes recorded in flight.

6. Plot ANI-7000 atmospheric noise versus position.

7. Plot selected ANI-7000 field strengths versus distance from Loran-C transmitter Results will be a composite of field strength versus distance for various ground conductivities.

Final analysis will include a map of the U.S. showing the actual flight profiles. Each flight profile will note where each of the 5 Loran-C receivers were properly tracking and in compliance with AC 90-45A specification for enroute operation. Each flight profile will be accompanied by written text to describe any problems or special items which might affect operation. The test will include, but not be limited to the following list.

1. Redundancy as applied to single chain receivers, master independent, master dependent and cross-chain.

2. Adequacy of signal strength for both acquisition and track modes.

In addition to the above report on actual results, application of results will be used to project performance in areas not flown.

INSTRUMENTATION AND FACILITIES

a. U.S.C.G. Loran-C simulator, Wildwood, NJ High quality dynamic Loran-C simulator.

8. COORDINATION AND AREAS OF RESPONSIBILITY

ACT-100B will provide Center program and project management, and other technical support available within ACT-100B. ACT-100 will be responsible for conducting the data flights, collecting, reducing, and analyzing the flight test data and for writing the final report. Coordination will be acomplished between ACT-100, ACT-50, ACT-600, ARD-300, and USCG.

ACT-600 will be responsible for providing project pilots and aircraft maintenance and for approving flight test scheduling. ACT-100B will be responsbile for coordinating with ACT-600 for optimum aircraft scheduling and submitting a flight schedule. ARD-300 will be responsible for subprogram management and allocation of project funding.

9. SCHEDULE

Test Plan complete	8/82
Fabricate airborne Loran-C receiver rack	10/82
Fabricate airborne data collection system hardware	12/82
Complete airborne data collection system software	2/83
Phase 1 testing	2/83
Phase 2 testing	2/83
Phase 3 testing	8/83
Complete enroute letter report.	10/83