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Loran C Stability Integrity Assurance Project Plan

Robert Moore
Thomas Wisser

December 1987

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-TN87/18		

4. Title and Subtitle	5. Report Date
LORAN C STABILITY INTEGRITY ASSURANCE PROJECT PLAN	December 1987
	6. Performing Organization Code: ACT-140
7. Author(s): Robert Moore and Thomas Wisser	8. Performing Organization Report No.: DOT/FAA/CT-TN87/18
9. Performing Organization Name and Address: U.S. Department of Transportation, Federal Aviation Administration, Technical Center, Atlantic City International Airport, N.J. 08405	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.: T0702N
12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Aviation Administration, Program Engineering and Maintenance Service, Washington, D.C. 20590	13. Type of Report and Period Covered: Technical Note, June 1987
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This project plan describes a program to determine if an operational integrity check is necessary before beginning a Loran C nonprecision approach. Simulation testing and a questionnaire distributed to Loran C receiver manufacturers will be used to determine if present state of the art receivers can reliably acquire the Loran C signal. The questionnaire is designed to solicit from manufacturers the probability of reliable acquisition for state-of-the-art receivers and if improvements are possible. Limited flight tests will be conducted to gather preliminary information related to employing Loran C operational integrity checks prior to initiating a nonprecision approach.

17. Key Words	18. Distribution Statement
Nonprecision Approach Flight Inspection Loran C	Document is on file at the Technical Center Library, Atlantic City International Airport, N.J. 08405

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	21	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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EXECUTIVE SUMMARY

This project plan describes a program to determine if an operational integrity check is necessary before beginning a Loran C nonprecision approach. Simulation testing and a questionnaire distributed to Loran C receiver manufacturers will be used to determine if present state-of-the-art receivers can reliably acquire the Loran C signal. The questionnaire is designed to solicit from manufacturers the probability of reliable acquisition for state of the art receivers and if improvements are possible. Limited flight tests will be conducted to examine the feasibility of an operational integrity flight check.

INTRODUCTION

OBJECTIVES.

The objective of this program is to determine if an operational integrity check (OIC) is necessary before beginning a Loran C nonprecision approach.

BACKGROUND.

The Federal Aviation Administration (FAA) has made a commitment to implement Loran C as an interim supplemental air navigation system. Once implemented, Loran C will be approved as a supplemental navigation system that can be used in controlled airspace of the National Airspace System (NAS) until at least the year 2003.

Loran C expansion will be supported by intalling four Loran C transmitters to fill the mid-continent gap. Loran C nonprecision approaches will be supported by installing 196 monitors to provide an integrity check of the local Loran C signal in space and to provide local area bias corrections on a routine basis for the airborne receivers.

Loran C Minimum Operational Performance Standards (MOPS) (related documentation 1) have been developed through a joint effort of users, manufacturers, the FAA, and the Radio Technical Commission for Aeronautics (RTCA). The intent of the MOPS committee was to agree on a set of standards that all participants could live with and that would not compromise safety issues.

The safety issue was addressed in the MOPS by requiring the receivers to detect blink within 10 seconds and loss of signal within 15 seconds down to a signal-to-noise ratio (SNR) of -6 decibels (dB) in the approach mode. The blink and loss of signal detection criteria were increased to 60 and 30 seconds, respectively, down to -10 dB SNR for the en route and terminal mode. At present, the United States Coast Guard (USCG) detects out of tolerance parameters and manually asserts blink. The USCG is considering automatically asserting aviation blink by shutting down the affected transmitter. This may require the FAA to specify in the Technical Standard Order (TSO) that Loran receivers meet a 10-second loss of signal detection interval for approaches.

The FAA has addressed the safety issue by initially restricting approaches in the early implementation program to geographical areas meeting good signal in space criteria, i.e., SNR shall be equal to or greater than 0 dB, envelope-to-cycle difference (ECD) shall not exceed ± 2.4 microseconds, and geometric dilution of precision (GDOP) shall not exceed $\overline{3}000$ feet/microsecond. The approaches were also overlaid over another navigation aid (NAVAID) approach and a copilot was required to monitor the Loran approach with respect to the other NAVAID. These criteria could be relaxed if experience so indicates.

There is a concern over the ability of a Loran C receiver to reliably acquire and track the Loran C signal on the proper cycle. If Loran C is to gain wide acceptance and approval in the NAS, this issue must be resolved in the receiver design and by limiting operation to areas where wrong cycle acquisition is improbable. The MOPS addressed this issue by requiring receivers to detect or correct a cycle slip with 90 percent probability within 10 minutes in the en route and terminal mode and within 3 minutes in the approach mode. The MOPS did

not specify the probability associated with the approach mode. However, the test section of the MOPS requires the receiver under test to detect a cycle slip in 20 out of 20 test cycles. In addition, the MOPS requires the receivers to properly acquire and track with an ECD of 0 to -2.4 microseconds at SNR's from -6 to -16 dB and ECD's of -2.4 to +3.0 microseconds at SNR's above -6 dB.

RELATED DOCUMENTATION.

1. Minimum Operational Performance Standards for Airborne Area Navigation Equipment Using Loran-C Inputs, Proposed Final Draft Second Revision, RTCA Paper No. 474-86/SC137-218, October 1986.

2. Loran C Monitor Analysis, Critical Design Review-2 Data Package Report, Report NL-21 Martin Marietta, ATC Division, May 1986.

3. Till, Robert D., Helicopter Global Positioning System Navigation with the Magnovox Z-Set, DOT/FAA/CT/TN83/03, February 1983.

4. United States Standard Flight Inspection Manual, 6/A, April 1978.

EQUIPMENT AND DATA COLLECTION

SIMULATOR.

The simulator used to test state of the art receivers is an ANI-2500 Loran C simulator described in appendix A.

QUESTIONNAIRE.

The questionnaire distributed to Loran C receiver manufacturers is enclosed as appendix B.

AIRBORNE DATA COLLECTION SYSTEM.

Flight test operations will be conducted in an FAA Convair 580 aircraft (N-91). Figure 1 is a functional diagram of the test instrumentation which will be employed for all OIC data collection. A Norden militarized PDP 11/34 computer and 9-track tape recorder will record Loran C data from two ANI 7000 Loran C receivers. Both receivers will be area calibrated and operate in approach, dedicated triad mode to insure basic single chain, three-station operation for all flight test phases. All data related to measurements of commissioned navigation aid parameters such as cone of silence, beam width, and radial intersection accuracy will be collected manually or by strip chart recorder using the appropriate system and indicators located in the aircraft flight deck and the flight inspection console. The extended area instrumentation radar (EAIR) and NIKE-Hercules radar tracking facility will provide timing and serve as position reference during all flight tests. This facility will generate plots and position reference tapes for data reduction purposes. In addition, Global Positioning System (GPS) receivers installed in the aircraft can be used for position reference system if the GPS satellite window coincides with the flight test.

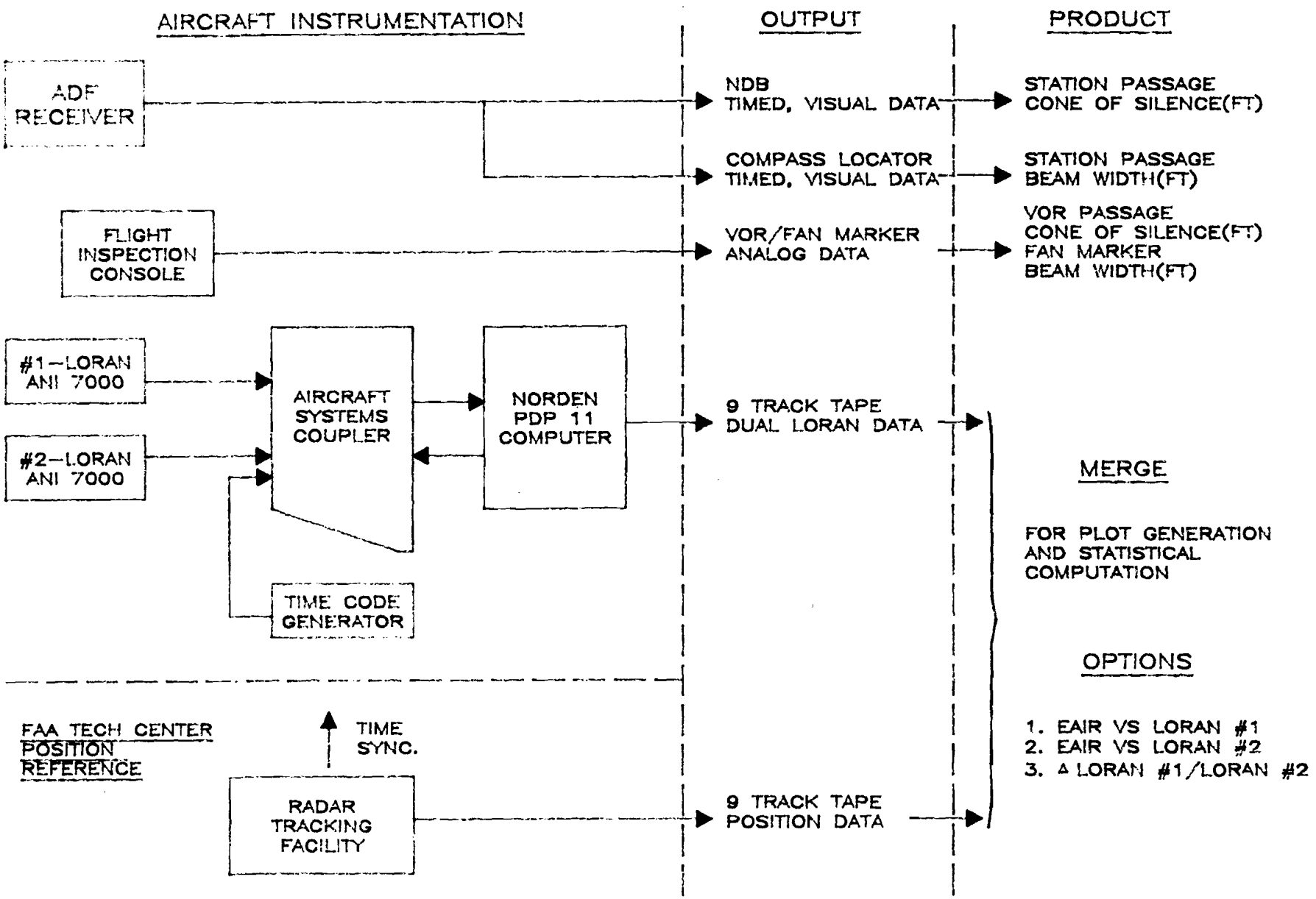


FIGURE 1. AIRBORNE DATA COLLECTION

TEST PROCEDURES

LABORATORY TESTS.

Simulation tests will be conducted using the ANI-2500 Loran C simulator described in appendix A. The tests will be designed to determine the minimum SNR where state-of-the-art Loran C receivers operating in the approach mode can properly acquire Loran C signals with a high degree of probability. Typical test values are shown in table 1. The acquisition test will be repeated for a minimum of 100 times to provide meaningful statistics.

TABLE 1. LORAN C SIMULATOR TESTS

Chain 9960 GRI

Triad	Test Location
(M) Master, Seneca, NY	Atlantic City, NJ
(X) Secondary Nantucket, MA	Latitude 39°27'N
(Y) Secondary, Carolina Beach	Longitude 74°34'W
	GDOP 938 ft/μs

Station	Field Strength dB/micro volt/meter	Noise dB/micro volt/meter	ECD Microseconds
M	100	?	+3.0
X	50	?	-2.4
Y	50	?	-2.4

? = Value to Determine

Gaussian noise scaled to atmospheric with an 8 dB scaler will be used as a noise test input. Gaussian noise was selected because it is the easiest to describe and reproduce. The station geometry at the FAA Technical Center was selected as a test location because of the ideal Loran C GDOP. A dynamic range of 50 dB was selected between the master and the secondaries. The ECD of the master was selected as +3 microseconds and the secondaries were set at -2.4 microseconds. This will be the baseline condition for all tests.

A failure will be declared when the receiver does not acquire all three stations properly within 500 seconds or the set fails to annunciate a wrong cycle acquisition.

QUESTIONNAIRE.

The questionnaire in appendix B has been distributed to several receiver manufacturers. The results of the questionnaire will be to reinforce or validate

the findings of the simulation tests to determine if the integrity can be improved in the next generation receivers.

FLIGHT TEST.

Approximately 10 hours of tests will be conducted in an FAA aircraft (CV-580). Testing will be divided into two phases as follows:

Phase 1. A series of over flights of several commissioned navigation facilities located in the vicinity of the Millville and Atlantic City International Airports will be made in order to measure the width of signal reception or signal loss characteristics of typical commissioned NAVAIDS. Repeat flights at altitudes appropriate to terminal area operations will aid in establishing the propagation pattern with relation to height above the facility. The navigation aids to be tested are incorporated as intermediate, initial, and final fixes for published approaches to the two airports involved. Figures 2 and 3 illustrate typical approaches to be used in testing. NAVAIDS to be incorported in flights will include Rainbow nondirectional beacon (NDB), Cedar Lake and Atlantic City very high frequency omnidirectional range/tactical air navigation (VORTAC's), and the compass locator at the Atlantic City runway 13 outer marker. This phase of flight test will terminate with an NDB approach to the Millville Airport and an instrument landing system (ILS) approach to the Atlantic City International Airport using NAVAIDS and procedures described in published approach plates. Phase 1 flight tests will also serve to check out Loran area calibration, psuedo cycle slip technique, and approach routing to be employed during phase 2 flight testing.

Phase 2. A minimum of four published approaches, including holding patterns, will be flown at Millville and Atlantic City. The two Loran ANI 7000 receivers will be calibrated and programmed identically for local approach mode operations. Additionally, Loran receiver No. 2 will have its weakest received signal station adjusted +10 microseconds. With this configuration, when Loran No. 1 is remoted to the flight course deviation indicator (CDI), the aircraft should be on course, and when Loran No. 2 is remoted to the flight CDI, the needle will operate with a position error similar to that caused by an undetected cycle slip. Approaches will be made with the pilot-in-command flying Loran only for guidance. The pilot will not know if the guidance being remoted to the cockpit has, in fact, an error introduced. This is to simulate a real life case of indecision. It will be up to the pilot to determine if, in fact, the Loran has a cycle slip or not. Possibly two or more subject pilots can be used.

Post-flight data analysis will provide accurate measurements of station passage transmitted signal characteristics at several typical NAVAIDS, and as a limited demonstration, indicate whether such station passages would be usable for an OIC in the Atlantic City Loran environment. Station passage measurements could also be applied to other areas with the same type of NAVAIDS in use, providing that the Loran C position error which would be generated by cycle slip is known.

DATA ANALYSIS

The results of the simulator tests will be presented as statistics representing the percent of successful acquisitions for a given SNR. At least two different

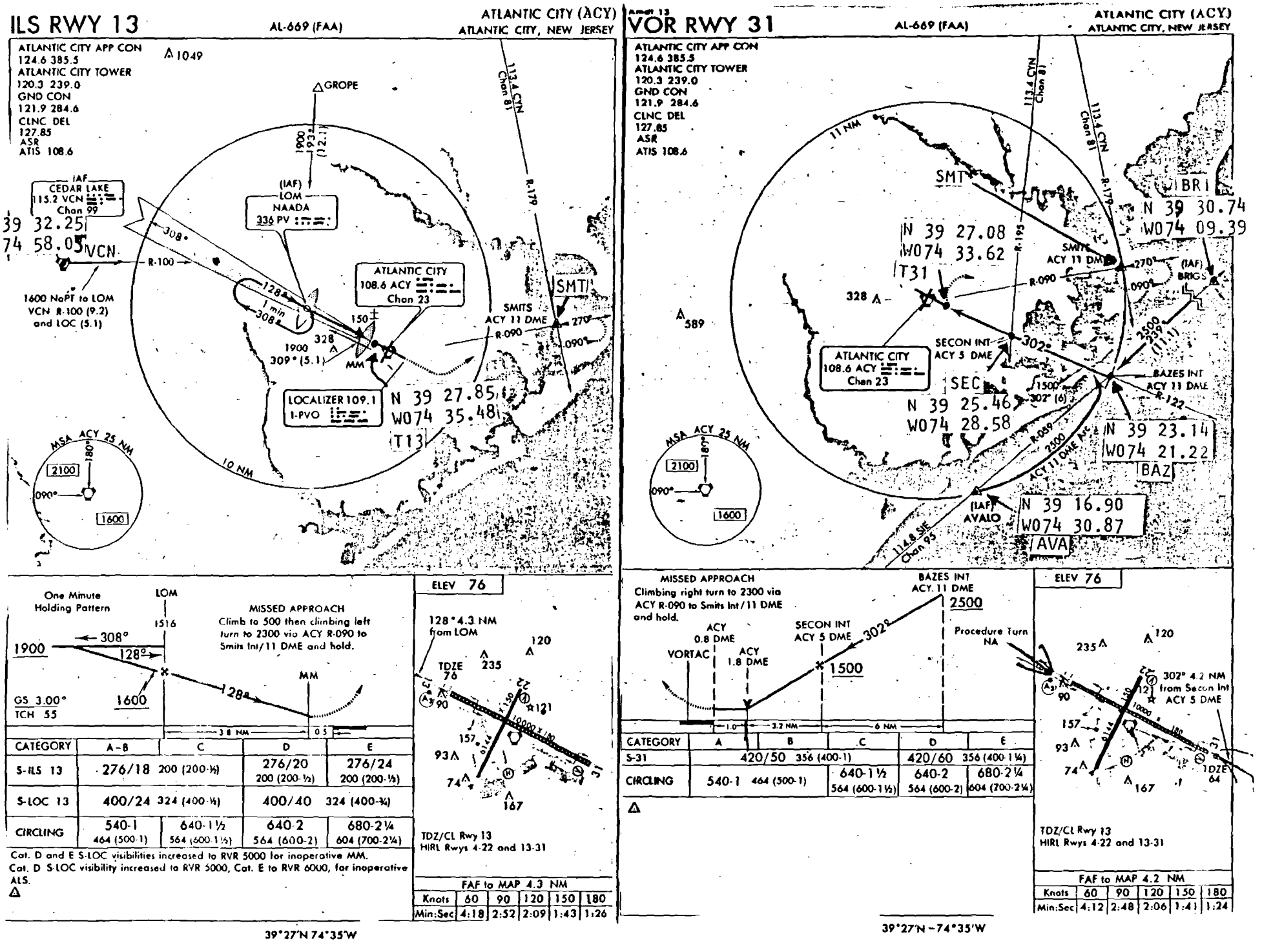
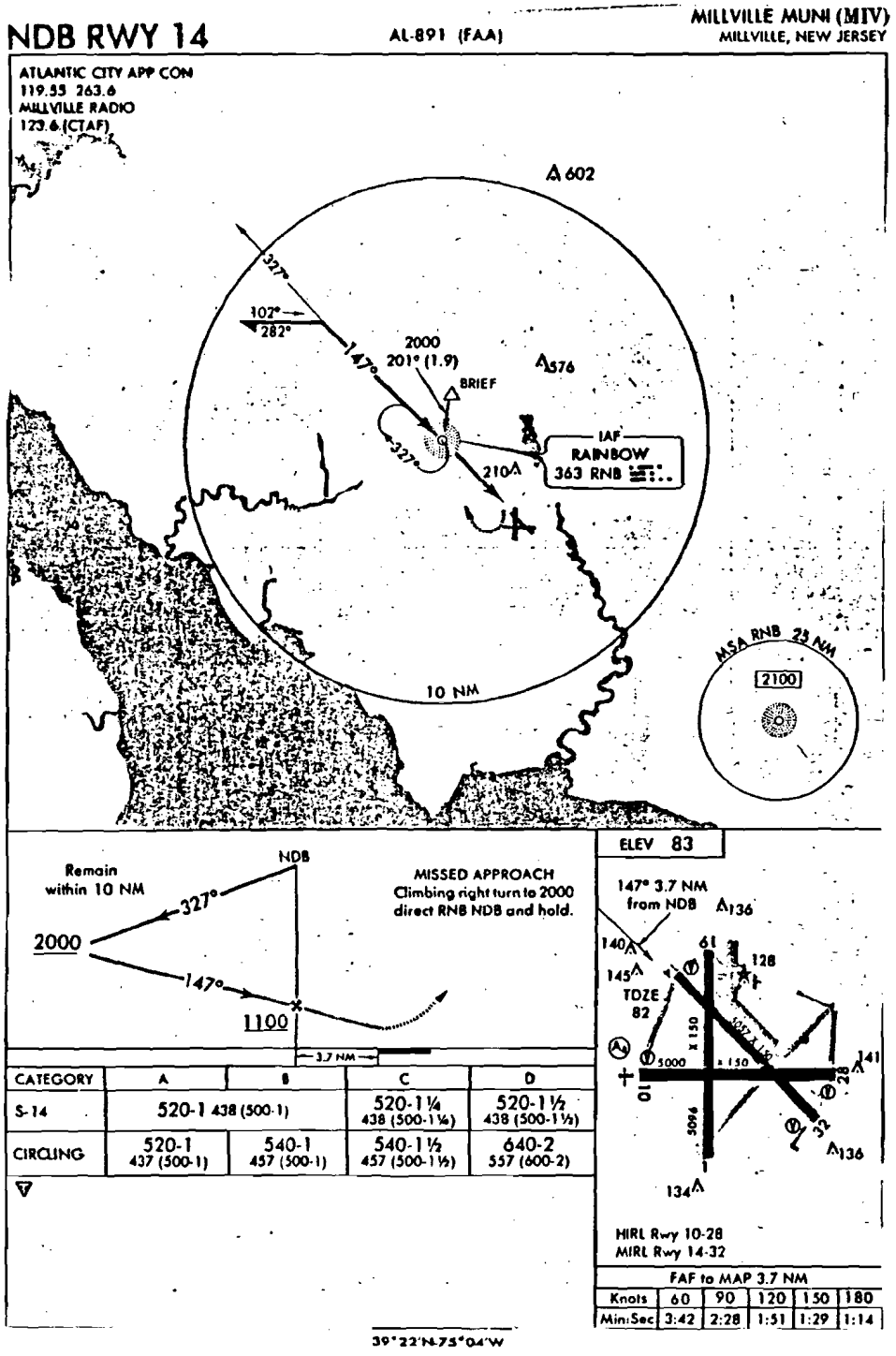
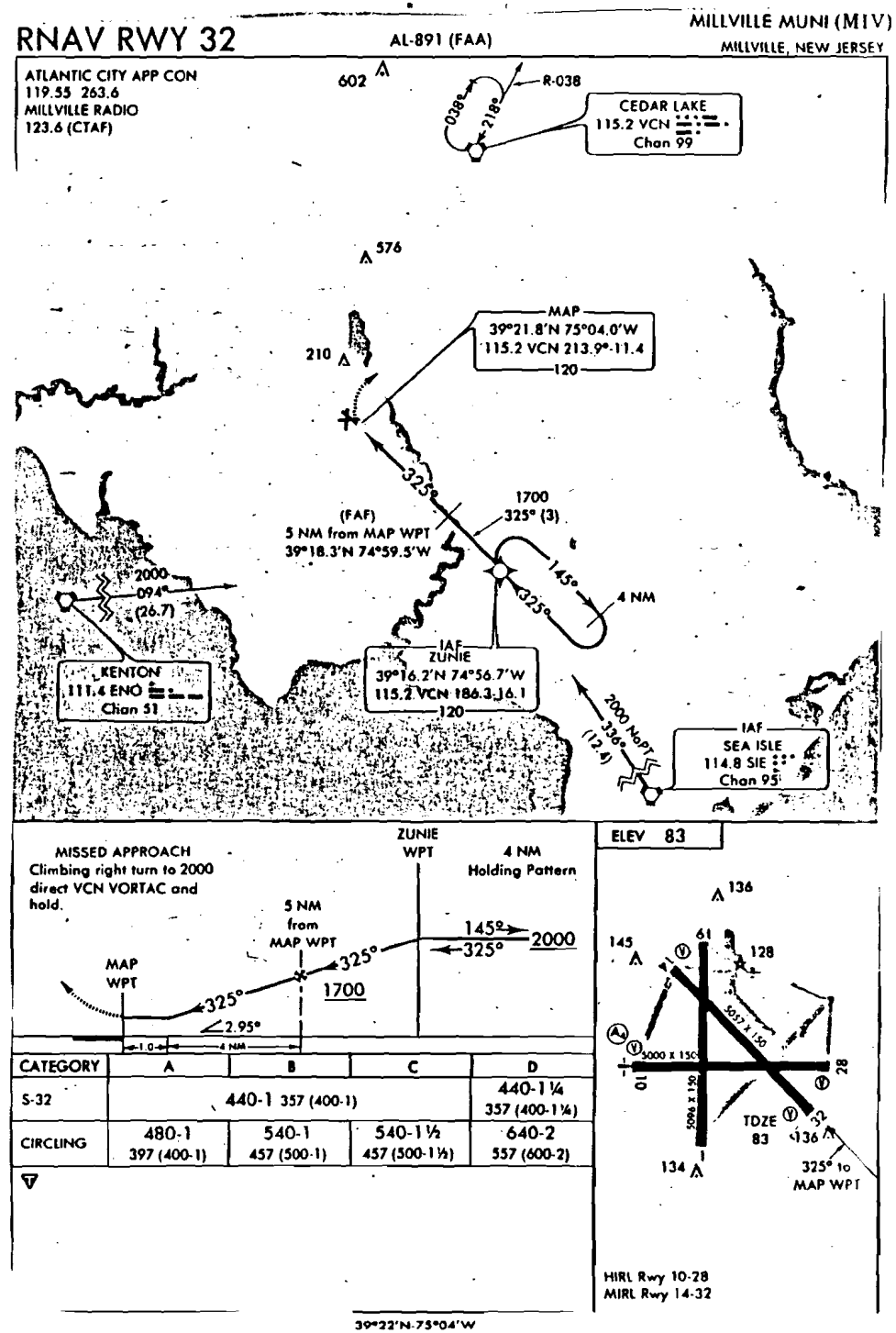


FIGURE 2. APPROACHES, ATLANTIC CITY INTERNATIONAL AIRPORT



CATEGORY	A	B	C	D
S-14	520-1 438 (500-1)		520-1¼ 438 (500-1¼)	520-1½ 438 (500-1½)
CIRCLING	520-1 437 (500-1)	540-1 457 (500-1)	540-1½ 457 (500-1½)	640-2 557 (600-2)



CATEGORY	A	B	C	D
S-32	440-1 357 (400-1)			440-1¼ 357 (400-1¼)
CIRCLING	480-1 397 (400-1)	540-1 457 (500-1)	540-1½ 457 (500-1½)	640-2 557 (600-2)

FIGURE 3. APPROACHES, MILLVILLE AIRPORT

state-of-the-art receivers approved for the limited implementation program will be tested.

The responses from the questionnaire wil be summarized. The combination of results from the simulation tests and the questionnaire are expected to result in the selection of Loran C signal-in-space conditions where minimum Loran C nonprecision approaches can be approved without the requirement of an operational integrity check.

It is anticipated that users will request nonprecision approach approval in locations where the signal-in-space conditions are below the conditions recommended for use without an OIC.

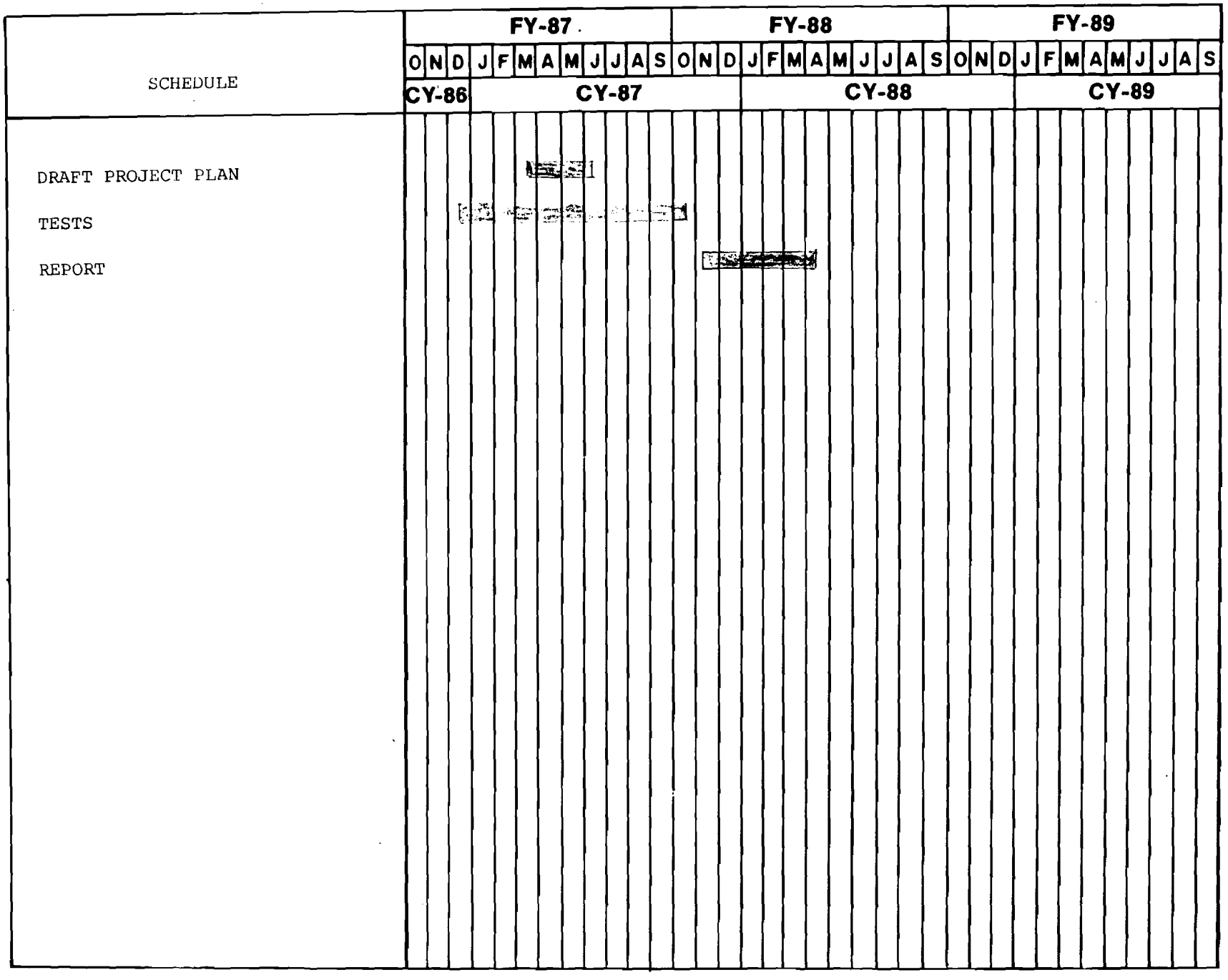
The data collection in the flight test phase will be used to demonstrate how to use several different NAVAIDS (VOR, NDB, and marker beacons) as an OIC. Since the tests will be conducted at Atlantic City where GDOP is low, the results will be conservative when applied to areas with higher GDOP's.

COORDINATION - AREAS OF RESPONSIBILITY

APS-420 will be responsible for subprogram management and allocation of project funding.

ACT-140 will conduct the simulator tests, the flight tests; perform data reduction and analysis; prepare and distribute the questionnaire; and prepare the required reports.

ACT-600 will provide the aircraft and flight crew and EAIR facility.


SCHEDULE
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FY-88
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CY-86
CY-87
CY-88
CY-89
DRAFT PROJECT PLAN
TESTS
REPORT

APPENDIX A

LORAN C SIMULATOR

The ANI 2500 Loran C signal generator is a state-of-the-art test device that provides a stable reference based Loran C signal for a wide variety of static and dynamic test conditions. Each setup allows the selection of master and secondaries with individually set signal levels noise levels and ECD bias.

The Loran C signal generator consists of:

Description	Quantity
Loran C Generator - ANI Model 2500	1
Consisting of:	
Rockland Synthesizer Model/5110-06 (2 MHz)	1
Rockland Synthesizer Model/5110-06-13 (3 MHz)	1
Model 2044 Loran C Simulator	1
IBM-CRT	1
IBM Personnal Computer	1
Printer	1
Joy Stick	1

The Loran C ANI model 2500 signal generator system consists of two major subassemblies, a Loran C simulator unit and the IBM computer. Both units have monochrome displays and are interfaced by an RS-232 data bus.

The model 2044 Loran C simulator can simulate four chains with up to six secondary stations per chain along with ground wave and skywave component signals.

The Loran C signal structure is in conformance with the U.S. Coast Guard publication "Specifications of the Transmitted Loran C Signal," COMDTINST M165624, July 1981. Individual adjustment is provided for station field strength, signal-to-noise ratio, and envelope-to-cycle deviation. Continuous wave interference (CWI) is provided by two Rockland synthesizers operable over a range of 0 to 3 MHz. Gaussian/atmospheric noise simulation is internally provided.

APPENDIX B

LORAN C IMPLEMENTATION QUESTIONNAIRE

OBJECTIVE

The objective of this questionnaire is to solicit an input from receiver manufacturers to determine in their opinion if an operational integrity check is necessary before beginning a Loran C nonprecision approach.

BACKGROUND

The FAA has made a commitment to implement Loran C as an interim supplemental air navigation system. Once implemented, Loran C will be approved as a supplemental navigation system that can be used in controlled airspace of the NAS until at least the year 2003.

Loran C expansion will be supported by installing four Loran C transmitters to fill the mid continent gap. Loran C nonprecision approaches will be supported by installing 102 monitors to provide an integrity check of the local Loran C signal in space and to provide local area bias corrections on a routine basis for the airborne receivers.

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There is a concern over the ability of a Loran C receiver to reliably acquire and track the Loran C signal on the proper cycle. If Loran C is to gain wide acceptance and approval in the NAS this issue must be resolved in the receiver design and by limiting operation to areas where wrong cycle acquisition is improbable. The MOPS addressed this issue by requiring receivers to detect or correct a cycle slip with 90% probability within 10 minutes in the en route and terminal mode and within 3 minutes in the approach mode. The MOPS did not specify the probability associated with the approach mode, however, the test section of the MOPS requires the receiver under test to detect a cycle slip in 20 out of 20 test cycles. In addition, the MOPS requires the receivers to

properly acquire and track with an ECD of 0 to -2.4 microseconds at SNRs from -6 to -16 dB and ECDs of -2.4 to +3.0 microseconds at SNRs above -6 dB.

It has been suggested that an inflight operational integrity check (OIC) before beginning an approach is a necessary requirement to insure the receiver is tracking on the proper cycle. This could be accomplished by overflying a VOR or NDB or comparing position with another navaid. The addition of an OIC to a Loran C nonprecision approach procedure is undesirable because it complicates the procedure and adds another task for the pilot when he is entering a high work load phase. In addition, the advantage to fly point to point with Loran C may be severely compromised in areas where it is not possible or convenient to crosscheck against another navaid. Mandating an OIC for every approach could seriously affect widespread acceptance and approval of Loran C in the NAS for nonprecision approach use.

An alternative to an OIC is to provide a ground check point (GCP) at an airport and require the pilot to compare his Loran C system against the coordinates of the GCP. Additional receiver software would be required to insure the receiver did not experience a cycle slip after completing a GCP validation. The minimum Loran C GDOP that users can experience is approximately 480 feet/microsecond. Hence, the minimum error for wrong cycle acquisition or track would never be less than 4800 feet. As GDOP increases the position error caused by a cycle slip increases. This error could easily be detected at a GCP. The Loran receiver would require software to insure the position coordinates never change suddenly in flight to a value greater than or equal to a cycle slip even when acquiring new stations. An OIC would be required only after inflight receiver initialization or when a new Loran C chain is selected.

QUESTIONS

1. Is it possible to design a receiver that will acquire and track on the proper cycle with nearly 100% probability?

2. If the answer to question 1 is yes, is it ecomonically feasible to manufacture a receiver that will nearly always acquire and track on the proper cycle?

3. In your opinion, have you resolved the cycle slip issue with proprietary software or hardware?

4. If operation is restricted to geographical areas with good signal in space coverage, i.e., SNR and ECD above some minimum value, to what probability can you guarantee proper cycle acquisition and track? Specify the SNR, ECD and other criteria to meet that probability.

5. What improvements, if any, would you recommend to the MOPS or a TSO to increase confidence in proper cycle acquisition or track?

6. What undetectable receiver failure modes if any could cause wrong cycle acquisition or detection?

7. In your opinion is an OIC necessary?

8. Can a GCP be used in place of an OIC?

9. Do you have any other comments or suggestions to resolve the cycle slip issue?