NRL Report 7004

The Flight Performance of the NRL Mark III Omega Aircraft Navigation Set

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CONTENTS

Abstract	ii
Problem Status	iii
Authorization	iii
INTRODUCTION	1
LONG RANGE FLIGHT TESTS	2
North Atlantic Flight Tests	2
Trans-Continental and Pacific Flight Tests	4
Caribbean Flight Tests	7
DEMONSTRATION FLIGHTS AND LOCAL TEST FLIGHTS	9
RADAR RANGE FLIGHTS	9
GROUND MONITORING	11
Difference Frequency Accuracy	11
Differential Omega Tests	12
ADDITIONAL TESTS	12
CONCLUSIONS AND RECOMMENDATIONS	13
ACKNOWLEDGEMENTS	14
REFERENCES	15
TABLES 1 THROUGH 21	16-44
FIGURES 1 THROUGH 12	45-55
Appendix A - ACCEPTANCE TESTS OF THE MARK III	56
Appendix B - METHODS OF COMPUTING STATISTICAL ACCURACY	71

ABSTRACT

The Naval Research Laboratory has developed the Mark III aircraft receiver for use with Omega, a very low frequency radio navigation system characterized by a worldwide capability and an accuracy with respect to earth coordinates of one to two miles.

The Mark III equipment, which is the third Omega aircraft system designed and developed by NRL, consists of a crossed-loop antenna system, a receiver, a timing system and a navigation computer which generates continuous outputs including latitude-longitude, bearing and distance to a destination, and cross track error.

Evaluation flights of the Mark III were made in an NRL EC121K aircraft over the continental United States, the North Atlantic, the Pacific, and the Caribbean. Omega was used as the primary navigation mode on overwater portions of the flights with a Course Deviation Indicator providing continuous steering information to the pilots. In the 10.2 kHz carrier mode, the system provided RMS in-flight accuracies of approximately one mile during daylight and better than two miles during night and transition periods. In the 1133-1/3 Hz, wide lane, carrier difference mode the system provided RMS in-flight accuracies of better than 10 miles without utilizing corrections for shift in propagation.

At landfall after six long overwater flights the average deviation of the Omega fixes from short range, shore based navigation system fixes was 1.4 miles in range and one degree in bearing.

The ability of the system to provide continuous navigation under heavy precipitation static conditions by utilizing a crossed-loop antenna was confirmed by the uninterrupted Omega tracking during a three-hour flight through a North Atlantic storm when other radio navigation and communications systems failed.

At the termination of the NRL evaluation flights the Mark III had operated over 1700 hours with only one disabling component failure.

PROBLEM STATUS

This is the final report on the development of Omega aircraft receivers by NRL. A subsequent report concerning precipitation effects on Omega aircraft equipment will terminate this project at NRL.

AUTHORIZATION

NRL Problem R04-13
PME-119 Project XS 161-001-6161

INTRODUCTION

The Naval Research Laboratory has developed the Mark III aircraft receiver for use with Omega, a worldwide, very low frequency radio navigation system. The Omega system and early NRL aircraft receiver development are fully described in references (a), (b), (c), and (d).

Design and development data for the Mark III equipment (Fig. 1) is fully described in references (d), (e), and (f).

The Mark III equipment consists of a crossed-loop antenna system, a receiver, a timing system and a navigation computer which generates continuous outputs including latitude-longitude, bearing and distance to go, and cross track error.

The Mark III can be operated in a single frequency hyperbolic mode using either the 10.2 or 11-1/3 kHz carrier or in a difference frequency hyperbolic mode using the difference between the 10.2 and 11-1/3 kHz carriers. The receiver can also utilize a stable oscillator and operate in a circular coordinate mode rather than hyperbolic. In the 10.2 kHz hyperbolic mode the basic lane is approximately 8 miles wide; in the 1133-1/3 Hz difference frequency mode the lanes are approximately 72 miles wide at the cost of reduced accuracy. The circular coordinate mode increases the lane widths by a factor of two.

From July 1968 until February 1969, the Mark III was subjected to both long range and local flight tests to determine operational performance and capability. The objectives of the Mark III flight tests were as follows:

1. To demonstrate the in-flight navigation capabilities of Omega with the basic 10.2 kHz carrier frequency (1 to 2 mile accuracy).

2. To demonstrate the in-flight navigation capabilities of Omega with the 1133-1/3 Hz difference frequency (accuracy on the order of 10 miles)(ref (g)).

3. To demonstrate the ability of Omega to operate under adverse weather conditions utilizing a crossed-loop antenna with automatic directivity pattern switching (refs (b) and (d)).

4. To demonstrate the ability of Omega to tie into short-range shore based navigational facilities after long overwater flights.

5. To demonstrate the in-flight accuracy of Omega as compared with other enroute aids such as LORAN A, LORAN C and radar tracking on a real-time basis.

Certain cautions are advised in interpreting the statistical data in this report concerning Omega versus terminal navigational aid facilities (TACAN, VOR, DME, RADIO RANGE). Siting locations of European and Caribbean facilities are listed only to the nearest minute in latitude and longitude. U. S. terminal navigational aid facilities are listed, in general, to the nearest second of latitude and longitude. Additionally, survey references of islands, e.g., Hawaii and Bermuda, may have considerable offsets with respect to references in the Continental U. S. On the Atlantic flight LORAN A data was plotted by the navigator on standard GLC charts and the overall expected accuracy was only 5-10 miles. Therefore, no statistical reduction of Omega vs. LORAN data was made. However, LORAN A data is recorded in the tables.

Appendix B includes the mathematical methods of computing Omega position errors.

LONG RANGE FLIGHT TESTS

North Atlantic Flight Tests

The North Atlantic flight tests of the Mark III in an EC121K aircraft were completed in October 1968. The flight route was selected by representatives of the Federal Aviation Agency. It extended over 8,000 miles with a proportional mixture of day, night, and transition periods to obtain information regarding the potential of Omega for civil as well as military air use. Two LORAN C shipboard receivers were provided by the U. S. Coast Guard for comparison studies. Conventional LORAN A, TACAN, VOR, ADF and other navigational aids are standard equipment on the NRL EC121K aircraft. Omega was used as the primary navigation system on all overwater portions of the flight with the pilots following steering directions from the Mark III actuated Course Deviation Indicator (see Appendix A). An antenna phasing and switching unit

(Appendix A) was installed to allow Omega operation with either the crossed-loop antenna or the 24-inch polyethylene insulated rod antenna (ref (b)) without interrupting normal system operation. The LORAN C equipment was provided with an 8-foot vertical whip antenna in the upper radome of the aircraft. FAA and Coast Guard observers were on board for the flight.

The flight route was from NAS Patuxent River, Maryland, to Argentia Naval Air Station, Newfoundland; Mildenhall Air Force Base, England; Torrejon Air Force Base, Spain; Lajes Air Force Base, Azores; Kindley Air Force Base, Bermuda and return (Fig. 2). The flights were a complete success. At least three Omega signals were tracked over the entire flight route. On the flight from Newfoundland to England and on the flight from Spain to the Azores, LORAN A, LORAN C, and communications signals were obliterated by severe rain and icing conditions for approximately 3 hours on the former flight and 20 minutes on the latter (see Fig. 2). The Mark III Omega navigation set tracked consistently through both periods of precipitation static using the crossed-loop antenna (Omega signals from the polyethylene rod antenna were obliterated). This was a conspicuous illustration of the effectiveness of the crossed-loop antenna with Omega aircraft receivers and also indicated the possibilities for use of the crossed-loop with other VLF and LF navigation and communications systems. Pilot and navigator reaction to the course deviation indicator and to the Omega system in general was extremely favorable.

The data collected during the North Atlantic flight tests is illustrated in Tables 1 through 8. Table 8 illustrates the ability of the Mark III to tie in with shore based short range navigation systems after long overwater flights. The average deviation of the Omega distance and bearing readouts from VOR/DME/TACAN distance and bearing readouts at the maximum range of this shore station was 1.4 miles and 1 degree. Tables 1 through 6 indicate the data collected comparing Omega with LORAN A, LORAN C, and short range navigational aids. The RMS deviation of Omega from LORAN C (in good LORAN C groundwave coverage areas) was 1.06 miles during daylight periods and 1.43 miles during nighttime and transition periods. The RMS errors compared with short range terminal

aids, except for those in the United Kingdom were 2.05 miles during daylight and 1.95 miles during nighttime and transition periods. These errors would have been smaller had a Naval Oceanographic Office change notice of 30 December for Norway phase corrections been received before the flight. Note the 4.00 mile daytime error when using the Norway signal at Bermuda. Unusual propagation conditions for the Norway signal in the United Kingdom area caused a mean offset of 4.23 miles at 126 degrees with an RMS deviation of 1.20 miles around the offset during daylight and a mean offset of 7.18 miles at 143 degrees and an RMS deviation of 2.07 miles during nighttime and transition periods (see Fig. 3 and Table 7). New propagation predictions are under investigation for correction of this offset, which has also been noted by Omega shipboard receivers operating in the area and by British Omega monitors at Farnborough.

Transcontinental and Pacific Flight Tests

A test flight of the Mark III Omega Aircraft Navigation Set from NAS Patuxent River, Maryland to Los Angeles, California; Barbers Point, Hawaii; Tucson, Arizona; and return to NAS Patuxent River, took place from 9-14 December 1968 in the NRL EC121K aircraft (see Fig. 4). With the exception of an area within 120 miles of Hawaii at about 2400 local time, where the very strong Hawaii signal was unsatisfactory apparently due to modal interference, the flight was fully as successful as the European flight in October (with an 8 station system signals will not be used within 600 miles of the transmitter). Flying time was fairly well distributed between daytime and nighttime hours. However, the times for flying to and from Hawaii from the Western United States were selected to optimize signal strength from the New York and Trinidad Omega stations.

Predicted phase corrections for the entire flight path were provided by the Naval Electronics Laboratory Center, San Diego, California. From Patuxent to Los Angeles the Mark III performed in the 10.2 kHz mode on the Trinidad-Hawaii and Trinidad-New York lines of position and the Omega cross track error indicator (CDI) was flown by the pilots on a great circle course from Richmond, Virginia, to Long

Beach, California. The Omega error before take-off was 0.65 miles at 320 degrees. All four Omega signals were tracked at the beginning of the flight until the Norway signal was lost near Charleston, West Virginia due to blocking of the signal by the Greenland shadow.

This leg of the flight proved satisfactory for enroute navigation, but the exact degree of accuracy on this great circle route could not be determined since no precise enroute checkpoints were available. At landing the position error was 2 miles at 245 degrees with respect to the actual field position at Los Angeles.

Take-off from Los Angeles was on 10 December 1968 at 2250 GMT in order to take advantage of the night path from the Trinidad and New York Omega stations to the aircraft and assure adequate signal amplitude for the flight. The equipment was flown in the 10.2 kHz mode using the Trinidad-Hawaii and Hawaii-New York lines of position. Possibly due to an extremely weak Trinidad signal and high noise on the ground, the error before take-off was approximately four miles. After take-off and before leaving the west coast, the Trinidad signal was stronger, and the error at Ventura was 1.4 miles. Omega was then used as the primary navigation mode, with the pilots flying the CDI from Gateway to Tuna, near Molokai, Hawaii. Track of the Norway signal was picked up (near the edge of the Greenland shadow) at 0500 GMT about 1100 miles from Oahu. Track of the New York signal was lost at 0930 GMT about 200 miles from Oahu, and the Lines of Position were changed to Norway-Hawaii and Trinidad-Hawaii with no loss of position. At 0950 GMT, about 120 miles out of Honolulu, the Hawaii lost-signal light on the Mark III came on, and the extremely strong Hawaii signal would not track on the five-minute time constant servos. Since the NRL Mark III receiver operated satisfactorily on several previous flights in the Hawaii area, and a Tracor receiver on board the aircraft for this trip experienced no apparent loss of the Hawaii signal during this period, the problem would appear to be caused by modal interference causing rapid phase changes in the signal which could not be followed by the five-minute time constant servo.

Take-off from Hawaii was on 13 December 1968 at 0440 GMT with the Mark III in the difference frequency (1133-1/3 Hz) mode using the Norway-Hawaii and Trinidad-Hawaii lines of position (the New York signal was too weak to track). It appeared that there was considerable trouble with resolution of the difference frequency due to proximity to the Hawaii station and resultant modal interference. The receiver was switched to the 10.2 kHz mode and updated to the navigator's position at 0540 GMT and again at 0700 GMT when a more accurate LORAN position was available. The navigator provided primary navigation with LORAN A and Dead Reckoning on this flight, and positions with respect to Omega were compared. At 0830 GMT the New York Omega signal was tracking steadily and the Mark III was switched to the Trinidad-Hawaii and Hawaii-New York lines of position. From 0840 to 1000 GMT the aircraft encountered heavy precipitation, and operations of the TRACOR Omega Receiver (using an 8-foot vertical wire antenna in the upper radome of the aircraft), the LORAN A receiver and HF communications were disrupted. The Mark III tracked all signals except Norway, which was blocked by the Greenland shadow during this period, although the very weak New York signal lost track several times for periods of 10 to 50 seconds. Omega position was good throughout this period. Upon lock-on on the VOR-DME at Santa Catalina, the difference between Omega and the VOR-DME was 1 mile and 3 degrees at 117 miles. At landfall (Oceanside TACAN) the Omega error was 1.97 miles at 117 degrees. Trinidad lost track after landfall (due to weak signal and high noise) for intermittent periods of up to two minutes, but the automatic dead reckoning circuits in the Mark III held the indicated position without lane loss. At Yuma, the Mark III was changed in-flight to the difference frequency mode of operation for the last 2 position fixes and the average error was 7 miles at 340 degrees. Upon landing at Tucson the error on the difference frequency was 6.03 miles at 339 degrees.

The flight leg from Tucson to Patuxent was made on the airways with the Mark III in the difference frequency mode on the Trinidad-Hawaii and Trinidad-New York lines of position without phase corrections. The Omega position was compared with all TACAN and VOR overpasses enroute. The RMS

Omega position error during daylight hours was 2.08 miles about a mean offset of 2.65 miles at 336 degrees (Fig. 5). During transition and nightfall, the RMS error was 6.37 miles about a mean offset of 3.83 miles at 28 degrees (Fig. 6). Detailed data for the flight tests are illustrated in Tables 9 through 12.

Present on this trip were representatives of the Army Materiel Command, Fort Monmouth, New Jersey; and of the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Caribbean Flight Tests

The primary purpose of the Caribbean flight tests was to complete NRL commitments to FAA and to fly in the vicinity of the Trinidad Omega station in order to duplicate conditions found in the Hawaii area and isolate the cause of the actuation of the "lost signal" circuit experienced in the Hawaii area. In addition to the above objectives, an excellent check of Omega enroute navigation in the Caribbean area was accomplished (see Fig. 7).

The first leg of the flight was from Patuxent to San Juan, Puerto Rico on 4 January 1969. The Mark III was flown in the 10.2 kHz mode using the Norway-Hawaii and Trinidad-New York lines of position and published phase corrections (with recently published offsets for the Norway signal). Position error at Patuxent was 0.36 miles at 21 degrees and upon leaving the U. S. coast at Elizabeth City, North Carolina, was 0.88 miles at 317 degrees. Omega was used as the primary navigation mode to San Juan (great circle route). Omega position difference with respect to VOR-DME 122 miles from San Juan was 0.4 miles and 1 degree. However, after landing, position difference with respect to estimated field position was approximately 3 miles at 70 degrees.

The round-trip to Trinidad was taken late at night on 5 January 1969 in order to duplicate the conditions on the Hawaii trip. The 10.2 kHz mode using the Norway-Hawaii and Trinidad-New York lines of position was used. Omega provided satisfactory enroute navigation all the way into the Piarco,

Trinidad radio beacon. The error at take-off was approximately 0.8 miles at 0 degrees at San Juan and no tracking trouble was experienced going into Trinidad in spite of the fact that the aircraft passed within 8 miles of the Trinidad Omega station.

On the return leg from Trinidad to San Juan no trouble was experienced with tracking of the Trinidad signal until the aircraft was 320 miles from the station. At this point the Trinidad servo appeared to drift away from track, and eventually the "lost signal" circuit of the Trinidad signal channel was actuated. Recycling the Mark III computer to a servo with a shorter time constant (2 minute time constant as opposed to 5 minutes) recovered track of the signal, however, one Trinidad-New York lane was lost in the process. After updating the lost lane, the error upon landing at San Juan was approximately 0.6 miles at 130 degrees. The error with the lost lane would have been slightly over 8 miles.

On 7 January 1969, the aircraft took off at 1246 GMT for Andrews Air Force Base from San Juan using Omega as the prime navigation mode. The Mark III was in the 10.2 kHz mode using the Norway-Hawaii and Trinidad-New York lines of position until the New York Omega station went off the air for unscheduled maintenance at 1405 GMT. After five minutes of dead reckoning on the New York channel the Mark III was changed to the Norway-Hawaii and Trinidad-Hawaii lines of position without lane loss and these lines of position were used for the rest of the trip. Upon lock-on of the Elizabeth City VOR 125 miles out, the Omega vs. VOR difference was 4 degrees. The error over the VOR was 0.5 miles at 152 degrees and upon landing at Andrews AFB was approximately 0.9 miles at 6 degrees. Detailed data from the flight tests are illustrated in Tables 13 through 15. The RMS error of Omega vs. short range terminal navigational aids on overland portions of the flight was 1.35 miles during daylight and 1.87 miles during night and transition periods. Captain J. C. Matheson, USN, Director of NRL and Captain G. Leggit, USAF, SAC, Offutt AFB, Nebraska, were aboard the flight as observers.

DEMONSTRATION FLIGHTS AND LOCAL TEST FLIGHTS

Demonstration flights of the Mark III were performed in the Washington area for personnel of other agencies with an interest in the use of Omega in aircraft. Representatives on the demonstration flights included personnel from Naval Air Systems Command, Naval Air Development Center, Naval Oceanographic Office, Naval Electronic Systems Command, Omega Project Office, Federal Aviation Agency, U. S. Air Force, Department of Defense, National Aeronautics and Space Agency, and U. S. Coast Guard.

Ten demonstration flights and nine local test flights were performed in the months of July, August, and September 1968. The flights were about equally divided between daylight and transition periods on the Omega signal paths. Difference frequency (1133-1/3 Hz) data was obtained on three of the demonstration flights and four of the test flights. The local test flights were performed primarily for the purpose of testing the Course Deviation Indicator and Antenna Switching and Phasing Unit (see Appendix A) and to check the operation of the crossed-loop antenna system in precipitation. A local flight test on 10 September 1968 was performed under both light and heavy rain and hail. No perceptible deterioration of the signal from the crossed-loop antenna was experienced in the rain and hail and the Mark III operated satisfactorily throughout. A summary of demonstration and local flight tests is given in Tables 16 and 17.

The RMS accuracy of Omega for all the local flight tests and demonstration flights in the 10.2 kHz carrier mode of operation was 1.15 miles during daylight and 1.36 miles during nighttime and transition periods. In the difference frequency mode of operation the RMS error was 3.82 miles during daylight and 4.39 miles about a mean offset of 4.67 miles at 83 degrees during transition periods. No night-time flight data was collected.

RADAR RANGE FLIGHTS

During late July 1968, the NRL aircraft was flown to Patrick Air Force Base, Florida, for comparison of Omega position data with precision radar position data at the Air

Force Eastern Test Range. The Mark III utilized the Trinidad-Hawaii and Trinidad-New York lines of position, the 5-minute time constant servos, and the crossed-loop antenna. Provisions were made for recording Mark III and radar data of aircraft position on magnetic tapes for reduction and comparison. The flight route for radar tracking is shown in Figure 8. Radar tapes recorded latitude and longitude of the aircraft every 0.1 seconds for approximately 2 minutes before the aircraft made each pass at the "Polaris" checkpoint and for 30 seconds after each pass. The Mark III tapes recorded aircraft latitude and longitude every 11.25 seconds during the entire flight period. Two 2-hour flights were performed on 29 July using the 10.2 kHz carrier mode of operation and published Omega phase corrections. The first was performed in the morning during day-night transition on the Hawaii signal path and the second in the afternoon during the stable daytime period on all Omega signals. A third flight was performed during the afternoon of 30 July using the carrier difference frequency (1133-1/3 Hz) mode of operation without phase corrections. No tapes were recorded on the third flight, however, and only "miss" distances and directions were relayed from the radar observers via UHF radio.

Table 18 shows detailed data from the morning flight. Note that on the North-South path (latitude), primarily dependent on the Trinidad-New York line-of-position, the errors were within expected accuracy for daytime propagation. On the east-west path (longitude), primarily dependent on the Trinidad-Hawaii line-of-position, the errors were more on the order of nighttime accuracy due to day-night transition on the Hawaii signal path. During the afternoon flight (Table 19) when all signal paths were in daylight, accuracies were well within the predicted one-mile accuracy. Omega difference frequency (1133-1/3 Hz) data obtained via the UHF radio link on the afternoon flight of 30 July 1968 is shown in Table 20. The accuracy shown is much better than predicted, but it must be noted that this data was taken during the stable propagation period for all three Omega stations and only over a period of slightly more than one hour. RMS errors were 2.30 miles for the morning flight (10.2 kHz), 0.49 miles for the afternoon flight (10.2 kHz), and 2.03 miles for the difference frequency flight.

A flight test was performed in the Bermuda area on 12 September 1968 to test the use of the Mark III in a differential Omega (ref (h)) experiment with the U. S. Coast Guard Omega monitor station and the Bermuda NASA radar tracking station. Primarily due to inadequate radio communications between the aircraft and the Coast Guard monitor station, the flight test mission was not successful. However, the Omega actuated Course Deviation Indicator was used by the pilots for enroute navigation over water to and from Bermuda and proved to be a success in demonstrating the use of Omega as a primary enroute navigational aid.

GROUND MONITORING

Difference Frequency Accuracy

Because of a greater interest in the 10.2 kHz single frequency mode of operation and because of a restricted flight schedule, the flight data obtained on the difference frequency mode of operation (1133-1/3 Hz) was limited. However, during a period of aircraft downtime in November 1968 a reasonable amount of difference frequency data was obtained by ground monitoring at NRL with the Mark III. The data which was recorded in both hyperbolic and circular coordinate modes was obtained by photographing the Range and Bearing readouts with a time lapse camera at approximately 6-minute intervals. The Range and Bearing with respect to the actual location of the equipment, which was inserted into the computer "destination" register is a measure of the magnitude and direction of the Omega position error.

The objective of these tests was to determine the fix accuracy in the difference frequency mode of operation without phase corrections and to determine the ability of the 1133-1/3 Hz difference frequency to resolve 3.4 kHz Omega lines-of-position in future 3 frequency Omega receivers. The data collected at NRL is shown in Figures 9 through 11. Using the worst-case criterion of less than 12 miles absolute error for accomplishment of 3.4 kHz lane resolution in hyperbolic mode and 24 miles absolute error in rho-rho mode, there were only 4 data points out of approximately

2500 recorded that could not accomplish 3.4 kHz lane resolution. Further references to this mode of operation and to work still in progress may be found in ref (g). For enroute navigational accuracy the data indicates 5.88 miles RMS accuracy during daylight and 5.62 miles RMS accuracy during transition and nighttime operation in the hyperbolic mode, and 3.51 miles RMS accuracy during daylight and 4.43 miles RMS accuracy during transition and nighttime operation in the circular coordinate mode.* Further research is certainly needed in the future to confirm whether these accuracies would be available on a worldwide basis under full Omega system implementation.

Differential Omega Tests

A differential Omega ground test was perfomed prior to the Bermuda flight test. The Mark III was operated with the aircraft at a surveyed point at Patuxent Naval Air Test Center. Differential phase corrections were relayed from the NRL Omega monitor station, 45 miles away, via UHF link, approximately every 5 minutes. The Trinidad-Hawaii and Trinidad-New York lines-of-position and 5-minute time constant servos were used on the Mark III and position fixes recorded for one hour. The data is shown in Table 21 and Figure 12, and shows a mean offset of 0.32 miles at 212° and an RMS variation about the offset of 0.18 mile.

ADDITIONAL TESTS

The Army Materiel Command, Fort Monmouth, New Jersey sponsored tests of the Mark III on an Army Helicopter during February and March 1969. The Strategic Air Command is currently investigating Omega applications using the Mark III in an operational aircraft. Details of the Mark III laboratory tests at Lear-Siegler, Inc., the shakedown flights at Grand Rapids, Michigan, and additional hardware developed after publication of reference (d) are included in Appendix A.

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*See Appendix B for more detailed data on circular coordinate calculations. The above are better than the expected overall navigational accuracies for the circular coordinate mode. Day-night transition offsets are not included in the data.

CONCLUSIONS AND RECOMMENDATIONS

Various conclusions and recommendations were drawn up during flight tests of the Mark III and communicated to the agencies involved in Omega aircraft receiver development. Among the most significant are the following:

1. The Receiver-Navigation-Computer approach to Omega appears to be the optimum in providing for current and future requirements for aircraft Omega equipment.

2. At this time a crossed-loop antenna system appears to be essential in meeting all-weather operational requirements for Omega aircraft equipment. However, future research into aircraft antennas (also precipitation static dischargers) for use at VLF frequencies is recommended in order to determine alternate solutions to problems resulting from precipitation effects. The use of crossed-loop antennas for other VLF/LF avionics equipment should be investigated.

The Mark III at the end of the NRL flight tests had accumulated over 1700 operating hours with only one disabling component failure, indicating that Omega aircraft receivers should be reliable.

4. The difference frequency mode of the Mark III may provide an enroute navigational aid of reasonable accuracy. Further flight testing of this mode is indicated.

5. The validity of the restrictions on the use of Omega signals when within several hundred miles of the transmitter was confirmed during flight tests near Hawaii and Trinidad.

The actuation of the "lost signal" light close to the Hawaii and Trinidad station should not be considered a malfunction of the receiver. System instructions point out that signals are not to be used closer than 600 miles from the transmitter. At the time of the "lost signal" indication the oscilloscope showed a very strong signal at the output of the I.F. amplifier. A reasonable interpretation would appear to be that the time constant of the signal amplitude

servo which is actuated by a phase sensitive detector with a 5-minute time constant cannot follow the rapid phase change at a modal interference point.

6. Omega has proved itself as a reliable long-range, all-weather navigational aid for aircraft with one to two mile RMS accuracy in the 10.2 kHz mode.

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(b) NRL Memorandum Report No. 1810, "Interim Report of Precipitation Effects on Omega Aircraft Receivers," 10 August 1967 by R. L. Eisenberg and M. F. Williams.

(c) NRL Memorandum Report No. 1683, "Summary of the Flight Performance of the NRL Mark I and Mark II Omega Aircraft Receivers," 23 February 1966 by E. L. Kline, A. F. Thornhill and M. F. Williams.

(d) NRL Memorandum Report No. 1886, "NRL Mark III Aircraft Omega Receiver," 29 May 1968 by R. L. Eisenberg, E. L. Kline, and A. F. Thornhill.

(e) "Omega 226-2/3 Hz Receiver-Navigation Set," Interim Report on Contract N00173-67-C-0726, Lear Siegler, Inc., Instrument Division, Grand Rapids, Michigan, dated January 1968.

(f) "Omega 226-2/3 Hz Receiver-Navigation Set," Final Report on Contract N00173-67-C-0726, Lear Siegler, Inc., Instrument Division, Grand Rapids, Michigan, dated October 1968.

(g) NRL Memorandum Report No. 1876, "Interim Report Number 2 - Lane Identification in the Omega System," 2 May 1968 by J. W. Brogden and K. Luken.

(h) NRL Memcrandum Report No. 1716, "Differential Omega," 8 August 1966 by J. W. Brogden and K. O. Luken.

Table 1
PATUXENT TO ARGENTIA, 7 OCTOBER 1968

		OMEGA		LORAN C		OMEGA VS. LORAN C			NAVIGATOR			OMEGA		TERMINAL		AID	
	TIME(Z)	LAT.	LONG.	LAT.	LONG.	ERROR(NMI)	BRG °	NOTES	LAT.	LONG.	NOTES	RANGE(NMI)	BRG °	RANGE(NMI)	BRG °	TYPE	NOTES
1	1345	° '	° '	° '	° '												
2	1414	38 19.38	75 32.76	38 21.12	75 32.18	1.80	015					0.34	001	0	0	AT STATION	PAX
3	1430	39 07.54	74 45.83									2.15	056	0	0	TACAN	SBY
4	1440	39 31.94	74 07.57									2.54	227	0	0	TACAN	SIE
5	1443			39 20.41	73 55.33							40.88	238	39	240	TACAN	SIE
6	1450	39 56.59	73 28.77	39 56.45	73 30.47	1.31	264										
7	1500	40 26.90	72 49.80	40 26.28	72 50.46	0.80	219					79.05	052	80	056	TACAN	HTO
8	1510	40 56.00	72 18.50	40 55.54	72 17.97	0.40	098					36.64	050	40	053	TACAN	HTO
9	1520	41 00.21	71 27.10	40 59.81	71 27.51	0.51	217					0.96	218	0	0	TACAN	HTO
10	1530	41 09.28	70 38.80	41 8.31	70 38.88	0.97	183					39.65	276	39	276	TACAN	HTO
11	1538	41 18.02	70 00.60	41 16.57	70 00.93	1.08	203					29.00	091	29.5	090	TACAN	ACK
12	1550	41 47.13	69 16.84									1.36	231	0	0	TACAN	ACK
13	1600	42 12.44	68 38.17	42 3.91	68 33.11			LORAN C ERROR				45.60	244	45	242	TACAN	ACK
14	1610	42 37.81	68 00.41	42 34.55	67 57.05			"				83.21	244	82.5	243	TACAN	ACK
15	1620	43 02.91	67 19.22	43 1.31	67 17.36	2.09	140										
16	1630	43 27.99	66 39.71	43 26.39	66 38.71	1.76	155										
17	1641	43 48.79	66 16.45	43 55.98	65 59.20			OMEGA OP ERROR				8.32	101	0	0	RADIO RNG	YAR-MOUTH
18	1714	44 54.31	63 28.44									2.25	250	0	0	VOR	HZ
19	1734	45 23.28	61 57.38									0.39	161	0	0	RADIO RNG	VW
20	1800	46 09.91	60 03.37									0.26	105	0	0	TACAN	QY
21	1810	46 21.45	59 11.51									37.50	280	38.5	278	TACAN	QY
22	1820	46 30.91	58 19.57									74.64	281	75.5	279	TACAN	QY
23	1830	46 41.00	58 24.91														
24	1850	47 01.55	55 40.68									70.64	103	72	103	TACAN	NWP
25	TOUCHDOWN											2.27	256	0	0	AT STATION	ARGENTIA
26																	
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	

Table 2
ARGENTIA TO MILDENHALL, 8 OCTOBER 1968

	TIME (Z)	OMEGA LAT.	OMEGA LONG.	LORAN C LAT.	LORAN C LONG.	OMEGA VS. LORAN C ERROR (NMI)	OMEGA VS. LORAN C BRG °	NOTES	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES	OMEGA RANGE (NMI)	OMEGA BRG °	TERMINAL RANGE (NMI)	TERMINAL BRG	AID TYPE	NOTES
1	1010	47°17.75'	53°56.64'	47°15.33'	53°57.04'	2.44	186		° '	° '		1.72	313	0	0	AT STATION	ARGENTIA
2	1045			47 18.01	52 44.98												
3	1052	47 30.22	52 49.62	47 27.48	52 48.13	2.92	160										
4	1100	47 40.63	52 30.30														
5	1110	47 58.30	51 52.73														
6	1120	48 16.58	51 14.99	48 16.99	51 21.48			LORAN C ERROR									
7	1130	48 30.92	50 34.44	48 24.38	51 5.18			"									
8	1140	48 44.47	49 53.64	48 45.92	49 54.74	1.62	297										
9	1150	48 56.89	49 12.44	48 57.97	49 16.88			LORAN C ERROR	48 57	49 20	LORAN A						
10	1200	49 09.61	48 30.95						49 10	48 36	LORAN A						
11	1210	49 21.48	47 49.81						49 20	47 53	LORAN A						
12	1220	49 32.71	47 10.80	49 31.49	47 10.51	1.23	171		49 32	47 17	LORAN A						
13	1230	49 42.46	46 31.22	49 41.27	46 30.53	1.27	159		49 42	46 34	LORAN A						
14	1240	49 52.92	45 53.59						49 53	45 58	LORAN A						
15	1250	50 03.07	45 16.17			1.67	208		50 04	45 20	LORAN A						
16	1300	50 12.14	44 37.15	50 11.60	44 36.90	0.56	163		50 12	44 40	LORAN A						
17	1310	50 20.70	43 58.22	50 20.64	43 57.92	0.20	107		50 23	43 52	LORAN A						
18	1320	50 29.90	43 17.05														
19	1330	50 40.32	42 31.97	50 39.62	42 29.67	1.61	116		50 37	42 35	LORAN A						
20	1340	50 48.71	41 51.20	50 48.28	41 49.46	1.18	111		50 46	41 40	LORAN A						
21	1350	50 57.41	41 04.69	50 54.30	40 58.44			LORAN C ERROR	50 58	41 04	LORAN A						
22	1400	51 07.82	40 16.13	51 07.55	40 13.01	1.98	098		51 07	40 11	LORAN A						
23	1410	51 18.05	39 27.65	51 19.59	39 28.33	1.60	345										
24	1420	51 28.10	38 37.60	51 28.22	38 34.76	1.77	087		51 27	38 23	LORAN A						
25	1430	51 33.51	37 45.42	51 32.94	37 42.83	1.59	111										
26	1440	51 41.75	36 54.46	51 41.52	36 55.01	0.23	188		51 46	37 05	LORAN A						
27	1450	51 50.47	36 00.85	51 50.28	31 01.26	0.32	233										
28	1500	51 57.21	35 07.93						52 11	35 16	LORAN A + PLOP						
29	1510	52 05.91	34 13.35	52 05.07	34 10.68	1.84	117				"P"STATIC						
30	1520	52 13.80	33 17.57	52 07.98	32 58.16			"P"STATIC									
31	1530	52 19.68	32 22.42	52 18.21	32 18.98			"									
32	1540	52 26.33	31 24.53	52 25.57	31 21.28			"									
33	1550	52 33.10	30 26.80	52 31.40	30 18.94			"									
34	1600	52 37.80	29 25.63					"									
35	1610	52 42.81	28 28.26	52 38.67	28 11.27			"									

Table 2 (Continued)

	TIME (Z)	OMEGA LAT.	OMEGA LONG.	LORAN C LAT.	LORAN C LONG.	OMEGA VS ERROR(NMI)	LORAN C BRG °	NOTES	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES	OMEGA RANGE(NMI)	OMEGA BRG°	TERMINAL RANGE(NMI)	TERMINAL BRG °	AID TYPE	NOTES
1	1620	52°48.00'	27°30.44'	° '	° '			"P"STATIC									
2	1630	52 50.96	26 35.82					"									
3	1640	52 55.23	25 40.09					"									
4	1650	52 58.72	24 42.98					"									
5	1700	53 00.67	23 42.91					"									
6	1710	53 02.95	22 45.31					"									
7	1720	53 04.91	21 49.11					"									
8	1730	53 05.41	20 52.45					"									
9	1740	53 06.89	19 54.80					"									
10	1750	53 04.67	18 56.73					"									
11	1800	53 07.77	17 57.44					"									
12	1810	53 07.55	16 54.33					"									
13	1820	53 06.89	15 53.44					"									
14	1830	53 05.09	14 50.11					"									
15	1840	53 02.74	13 49.17					"									
16	1850	52 59.41	12 49.73					"									
17	1900	52 56.91	11 50.25					"									
18	1910	52 53.47	10 51.30					"									
19	1918							"				45.00	113	42	111	VOR/DME	SHANNON
20	1930							"				4.97	165	0	0	"	"
21	1945	53 17.11	07 36.39														
22	1950			53 10.46	7 09.24												
23	1958	53 35.44	06 24.15									6.58	156	0	0	VOR	DUBLIN
24	2010			53 26.27	5 01.28												
25	2015	53 31.15	04 40.99	53 24.43	4 35.09												
26	2020			53 28.27	3 57.76												
27	2029	53 30.04	03 16.54									7.90	150	0	0	VOR	WALLASEY
28	2045	53 38.00	01 45.81														
29	2055			53 51.25	0 24.13												
30	2100	53 46.71	00 25.00														
31		53 48.13	00 17.05					OTTRINGHAM				9.71	147	DOUBTFUL		VOR	OTTRINGHAM
32	2156	52 27.20	-00 18.34					MILDENHALL				7.74	135			AT FIELD	MILDENHALL
33																	
34																	
35																	

Table 3
FARNBOROUGH TO TORREJON, 11 OCTOBER 1968

	TIME (Z)	OMEGA LAT.	OMEGA LONG.	LORAN C LAT.	LORAN C LONG.	OMEGA VS LORAN C ERROR(NMI)	OMEGA VS LORAN C BRG °	NOTES	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES	OMEGA RANGE(NMI)	OMEGA BRG °	TERMINAL RANGE(NMI)	TERMINAL BRG °	AID TYPE	NOTES
1	1200	51°04.37'	01°29.41'	51°16.27'	0°45.58'			LORAN C									
2	1210	50 45. 7	02 14.71					EQUIP-									
3	1220	50 46 83	2 52.25					MENT FAILURE:									
4	1230	50 39.77	3 31.81					NO DATA									
5	1240	50 28.84	4 07.64														
6	1250	50 18.63	4 45.97														
7	1303	50 02.71	5 38.44									5.30	012	0	0	TACAN	LANDS END
8	1320	49 37.69	6 35.56	50 3.19	6 23.61												
9	1330	49 20.39	7 03.81														
10	1340	49 04.85	7 06.19														
11	1350	48 43.03	7 56.36	48 33.38	8 02.83												
12	1400	48 15.59	7 59.53	48 1.83	8 06.98												
13	1410	47 46.06	7 57.96	47 14.12	7 53.97												
14	1420	47 16.07	7 59.50	47 5.05	8 00.66												
15	1430	46 43.91	8 00.32	46 39.60	8 03.95												
16	1440	46 14.85	7 59.38	46 10.62	8 02.88												
17	1450	45 41.75	8 00.71	45 39.23	7 58.90												
18	1500	45 08.46	7 59.61	44 56.17	8 03.07												
19	1510	44 35.19	8 05.14	44 31.18	8 03.70												
20	1520	44 02.00	8 12.06	43 52.83	8 08.78												
21	1541	42 56.17	8 26.41	42 1.83	8 23.53							0.32	126	0	0	VOR	SANTIAGO
22	1550	42 36.30	7 45.03	42 37.98	7 33.61												
23	1600	42 15.40	7 02.62														
24	1610	41 53.67	6 19.53	41 4.95	6 21.63												
25	1620	41 32.41	5 41.42	41 19.17	5 42.51							2.62	111	0	0	VOR	Zamora
26	1630	41 03.25	5 03.57														
27	1650	40 14.07	3 52.80														
28	1659											2.90	117	0	0	AT STATION	TORREJON
29																	
30																	
31																	
32																	
33																	
34																	
35																	

Table 4
TORREJON TO LAJES, 14 OCTOBER 1968

	TIME(Z)	OMEGA LAT.	OMEGA LONG.	LORAN C LAT.	LORAN C LONG.	OMEGA VS ERROR(NMI)	LORAN C BRG °	NOTES	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES	OMEGA RANGE(NMI)	OMEGA BRG°	TERMINAL RANGE(NMI)	TERMINAL BRG°	AID TYPE	NOTES
1	1505	40°30.41'	03°30.32'	° '	° '			LORAN C	° '	° '		2.26	136	0	0	AT FIELD	TORREJON
2	1534	40 23.57	04 20.25					EQUIPMENT				4.30	119	0	0	RADIO RNG	NAVES DEL RAY
3	1550	39 58.75	05 17.40					FAILURE:									
4	1609	39 32.53	06 29.79					NO DATA				2.98	109	0	0	VOR	CACERAS
5	1623	39 11.28	07 15.55														
6	1630	39 00.30	07 45.06														
7	1645	38 40.94	08 40.74									3.06	117	0	0	RADIO RNG	MARA-TECA
8	1700	38 35.35	09 42.53														
9	1710	38 31.65	10 18.28						38 39	10 15	LORAN A						
10	1720	38 43.94	10 55.22	39 21.26	10 20.19				38 44	10 54	LORAN A						
11	1730	38 48.12	11 32.77	38 58.10	11 40.94				38 47	11 30	LORAN A						
12	1740	38 52.66	12 11.88	39 27.00	12 8.00				38 50	12 11	LORAN A						
13	1750	38 54.36	12 49.82						38 54	12 51	LORAN A						
14	1800	38 57.00	13 30.58	38 25.13	13 47.50				38 57	13 32	LORAN A						
15	1810	38 58.97	14 10.79	38 49.42	14 22.87												
16	1820	39 00.10	14 51.73	38 58.22	15 2.87				38 57	14 55	LORAN A						
17	1830	39 00.65	15 32.58	38 58.92	15 43.85												
18	1840	39 01.13	16 13.82	38 57.29	16 26.63				39 00	16 17	LORAN A						
19	1850	39 01.81	16 57.17	38 48.54	17 1.65												
20	1900	39 02.41	17 40.06						39 00	17 42	LORAN A						
21	1910	39 01.62	18 23.18	38 44.17	18 45.32												
22	1920	39 00.16	19 06.74	39 0.49	19 13.98				39 00	19 10	LORAN A						
23	1930	39 00.16	19 51.52	39 2.03	19 57.68												
24	1940	39 00.30	20 36.92	39 1.91	20 42.15				38 57	20 42	LORAN A						
25	1951	38 59.45	21 26.10								"P"STATIC						
26	2000	38 58.23	22 08.45								"						
27	2010	38 57.52	22 52.51								"						
28	2020	38 56.61	23 37.56						39 02	23 37	LAJES TACAN						
29	2030	38 55.18	24 23.07														
30	2040	38 50.81	25 07.88						38 50	25 01	LORAN A + D.R.						
31	2050	38 49.72	25 51.34									59.66	281	59.75	280	TACAN	LAJES
32	2100	38 50.09	26 40.86														
33	2102			51 53.48	27 21.77												
34	2105			38 47.12	27 1.40												
35	2110			38 45.98	27 10.62												

Table 4 (Continued)

TIME(Z)	OMEGA LAT.	OMEGA LONG.	LORAN C LAT.	LORAN C LONG.	OMEGA VS. LORAN C ERROR(NMI)	OMEGA VS. LORAN C BRG°	NOTES	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES	OMEGA RANGE(NMI)	OMEGA BRG°	TERMINAL RANGE(NMI)	TERMINAL BRG°	AID TYPE	NOTES
2115	38°45.15'	27°03.16'	38°44.97'	27°05.05'							1.44	282	0	0	AI FIELD	LAJES

Table 5
LAJES TO KINDLEY, 16 OCTOBER 1968

	TIME(Z)	OMEGA LAT.	OMEGA LONG.	LORAN C LAT.	LORAN C LONG.	OMEGA VS LORAN C ERROR(NMI)	OMEGA VS LORAN C BRG °	NOTES	NAVIGATOR LAT. ° '	NAVIGATOR LONG. ° '	NOTES	OMEGA RANGE(NMI)	OMEGA BRG °	TERMINAL RANGE(NMI)	TERMINAL BRG °	AID TYPE	NOTES
1	0220	38°45.66'	27°04.93'	38°43.95'	27° 4.17'			LORAN C				1.18	208	0	0	AT STATION	LAJES
2	0300			37 52.50	27 43.52			EQUIPMENT									
3	0302	37 52.55	27 42.75					FAILURE:									
4	0315	38 04.49	28 34.68	38 3.05	28 33.38			NO DATA									
5	0330	38 07.32	29 35.59						38 07	29 41	LORAN A						
6	0345	38 08.23	30 38.95						38 09	30 50	LORAN A						
7	0400	38 09.62	31 45.38						38 12	31 51	LORAN A						
8	0415	38 09.93	32 54.89	38 26.40	32 53.85												
9	0418								38 13	33 10	LORAN A						
10	0430	38 10.31	33 57.67	38 39.50	34 06.37				38 11	34 06	LORAN A						
11	0445	38 10.05	34 57.93						38 10	35 00	LORAN A						
12	0500	38 08.30	36 00.39	38 17.18	36 01.58				38 07	36 13	LORAN A						
13	0515	38 06.86	37 00.85														
14	0530	38 05.01	38 01.12						38 02	38 12	LORAN A+D.R.						
15	0535			38 10.98	38 24.75												
16	0545	38 01.88	38 59.70	37 54.53	38 54.78				38 00	39 07	LORAN A+D.R.						
17	0600	37 58.03	39 56.64	36 30.92	39 07.10				37 55	40 24	LORAN A (POOR CROSS)						
18	0615	37 53.97	40 51.98	37 45.68	40 47.73												
19	0630	37 49.12	41 48.53	37 48.27	41 49.50												
20	0645	37 43.28	42 48.79														
21	0650			37 34.00	43 11.15												
22	0700	37 37.54	43 49.82	37 30.50	43 52.93				37 32	43 58	LORAN A+D.R.						
23	0715	37 30.34	44 54.42	38 31.18	45 17.90												
24	0730	37 21.95	45 53.52														
25	0745	37 12.66	46 51.30						37 11	47 05	LORAN A						
26	0800	37 03.04	47 59.51														
27	0815	36 52.82	49 03.11	36 48.72	48 57.32												
28	0830	36 40.99	50 09.45														
29	0845	36 28.47	51 15.01	36 23.07	51 07.53				36 27	51 21	LORAN A						
30	0900	36 14.83	52 21.94														
31	0915	36 00.45	53 22.79	36 05.65	53 29.65												
32	0930	35 46.40	54 23.71	35 50.98	54 31.35				35 57	54 42	LORAN A						
33	0945	35 30.80	55 26.25	35 35.42	55 35.35												
34	1000	35 14.76	56 28.77	35 24.23	56 43.92				35 15	56 40	LORAN A						
35	1015	34 58.00	57 30.14						34 51	57 58	LORAN A						

Table 5 (Continued)

	TIME(Z)	OMEGA LAT.	OMEGA LONG.	LORAN C LAT.	LORAN C LONG.	OMEGA VS LORAN C ERROR(NMI)	OMEGA VS LORAN C BRG °	NOTES	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES	OMEGA RANGE(NMI)	OMEGA BRG °	TERMINAL RANGE(NMI)	TERMINAL BRG °	AID TYPE	NOTES
1	1030	34°21.82'	59°33.50'	34°47.82'	58°45.73'												
2	1045	34 21.82	59 33.50	34 28.07	59 49.72												
3	1100	34 01.91	60 35.00	34 10.53	60 52.65												
4	1115	33 42.07	61 37.15	33 47.62	61 51.48												
5	1127											131.98	258	129.5	254	VOR/DME	KINDLEY
6	1130			33 14.30	62 46.12												
7	1139											91.37	260	88	255	TACAN	KINDLEY
8	1145											64.06	259	62	256	TACAN	KINDLEY
9	1150											48.00	257	45	256	TACAN	KINDLEY
10	1155											28.63	259	26	256	TACAN	KINDLEY
11	1208											4.00	262	0	0	ON STATION	KINDLEY
12																	
13																	
14																	
15																	
16																	
17																	
18																	
19																	
20																	
21																	
22																	
23																	
24																	
25																	
26																	
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	

Table 6

KINDLEY TO PATUXENT, 17 OCTOBER 1968

	TIME(Z)	OMEGA LAT.	OMEGA LONG.	LORAN C LAT.	LORAN C LONG.	OMEGA VS. LORAN C ERROR(NMI)	LORAN C BRG°	NOTES	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES	OMEGA RANGE(NMI)	OMEGA BRG°	TERMINAL RANGE(NMI)	TERMINAL BRG°	AID TYPE	NOTES
1	1345	32°21.58'	64°39.97'	32°21.75'	64°40.16'	0.23	317		° '	° '		0.96	312	0	0	ON STATION	KINDLEY
2	1410	32 39.18	65 01.58	32 39.77	65 1.75	0.60	347										
3	1420	33 04.62	65 28.37	33 05.07	65 28.62	0.50	335										
4	1430	33 31.55	65 57.50	33 31.80	65 57.78	0.34	317		33 34	66 02	LORAN A	100	151	100	151	RADAR	KINDLEY
5	1450	33 59.70	67 19.21	33 59.43	67 20.50	1.10	256		34 05	67 27	LORAN A						
6	1500	34 26.20	67 50.29	34 26.12	67 52.17	1.55	267		34 27	67 56	LORAN A						
7	1510	34 50.59	68 26.74	34 50.77	68 28.37	1.35	278										
8	1520	35 14.76	69 03.85	35 15.05	69 05.03	1.01	287		35 17	69 07	LORAN A						
9	1530	35 38.45	69 40.82	35 38.78	69 41.47	0.62	302										
10	1540	36 01.43	70 17.94	36 01.43	70 19.63	1.37	270		36 06	70 22	LORAN A						
11	1550	36 25.60	70 55.86														
12	1600	36 49.63	71 33.03	36 49.87	71 35.12	1.69	298		36 54	71 39	LORAN A						
13	1610	37 14.85	72 11.95	37 14.98	72 12.48	0.44	288										
14	1620	37 38.06	72 52.06	37 38.27	72 51.47	0.51	066										
15	1630	38 04.91	73 28.18						38 05	73 28	LORAN A						
16	1637											76.73	267	76.5	268	TACAN	SNOW HILL
17	1650			38 8.95	74 57.77							27.91	265	30	264	TACAN	SNOW HILL
18	1656	38 02.57	75 28.82	38 03.28	75 26.82	1.73	066					1.11	050	0	0	TACAN	SNOW HILL
19	1731	38 16.76	76 24.44									0.38	196	0	0	ON STATION	SNOW HILL
20																	
21																	
22																	
23																	
24																	
25																	
26																	
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	

Table 7
RAE DEMONSTRATION FLIGHTS, 9 OCTOBER 1968
OMEGA 10.2 kHz OPERATION

FACILITY	TIME (Z)	RANGE ERROR (NMI)	BEARING (DEGREES)
FARNBOROUGH	1103	6.98	129
FARNBOROUGH	1420	3.88	121
BOSCOMBE DOWNS	1437	5.53	133
BRIZE NORTON	1448	3.68	111
UPPER HEYFORD	1452	3.24	104
UPPER HEYFORD	1458	4.30	128
BOSCOMBE DOWNS	1515	5.01	133
FARNBOROUGH	1541	4.56	131

Table 8

AIRCRAFT APPROACHING	AFTER A FLIGHT LENGTH OF		OMEGA DISTANCE AND HEADING DIFFERENCE vs. TACAN or VOR and DME		DISTANCE FROM DESTINATION
	Nautical Miles	Hours	Nautical Miles	Degrees	Nautical Miles
Argentia	1,200	6	1.4	0	72
Shannon	1,700	10	3.0	3	45
Madrid	500	2.5		0	
Azores	1,000	5	0.75	0	128
Bermuda	1,800	9	2.5	3	132
Patuxent	600	3	0.25	1	76

Table 9

PATUXENT TO LOS ANGELES (GREAT CIRCLE), 9 DECEMBER 1968

	TIME(Z)	OMEGA LAT.	OMEGA LONG.	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES		OMEGA RANGE(NMI)	OMEGA BRG °	TERMINAL RANGE(NMI)	TERMINAL BRG °	AID TYPE	NOTES				
1	1400	38°15.94'	76°23.93'					0.65	320	0	0	ON STATION	PATUXENT				
2	1430	38 03.38	76 21.23														
3	1440	37 57.28	76 50.94														
4	1450	37 30.31	77 17.32					1.52	270	CLOSE	CLOSE	TACAN	RICHMOND				
5	1500	37 34.70	77 57.43														
6	1510	37 39.42	78 39.46														
7	1520	37 43.74	79 18.96														
8	1530	37 47.29	79 57.78														
9	1540	37 51.06	80 37.41														
10	1550	37 55.32	81 21.49														
11	1600	37 57.52	81 57.00														
12	1610	38 00.76	82 37.68														
13	1620	38 02.94	83 19.71														
14	1630	38 04.97	84 02.76														
15	1640	38 06.41	84 44.83														
16	1650	38 08.53	85 25.77														
17	1700	38 09.73	86 08.07														
18	1710	38 11.14	86 50.92														
19	1720	38 11.17	87 34.04														
20	1730	38 11.40	88 18.88														
21	1740	38 12.76	89 01.94														
22	1750	38 11.36	89 45.19														
23	1800	38 10.38	90 27.46														
24	1810	38 09.34	91 09.09														
25	1820	38 07.85	91 49.99														
26	1830	38 06.84	92 30.52														
27	1840	38 04.81	93 10.57														
28	1850	38 02.84	93 49.71														
29	1900	38 00.66	94 29.17														
30	1910	37 58.42	95 09.93														
31	1920	37 55.99	95 50.89														
32	1930	37 52.43	96 33.66														
33	1940	37 48.08	97 16.65														
34	1950	37 44.04	97 58.89														
35																	

Table 9 (Continued)

	TIME(Z)	OMEGA LAT.	OMEGA LONG.	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES		OMEGA RANGE(NMI)	OMEGA BRG °	TERMINAL RANGE(NMI)	TERMINAL BRG °	AID TYPE	NOTES				
1	2000	37°39.69'	98°41.77														
2	2010	37 34.14	99 26.87														
3	2020	37 28.47	100 00.00			OP ERROR: IN DOUBT	LONG.										
4	2030	37 23.54	100 53.03														
5	2040	37 17.41	101 35.43														
6	2050	37 11.42	102 16.39														
7	2100	37 05.45	102 58.74														
8	2110	36 57.97	103 42.59														
9	2120	36 50.57	104 27.35														
10	2130	36 42.98	105 08.12														
11	2140	36 35.85	105 51.28														
12	2150	36 27.18	106 33.34														
13	2200	36 18.22	107 15.75														
14	2210	36 09.27	107 58.30														
15	2220	36 00.70	108 40.28														
16	2230	35 50.68	109 21.57														
17	2240	35 41.06	110 03.48														
18	2250	35 30.93	110 44.99														
19	2300	35 20.37	111 26.06														
20	2310	35 10.01	112 07.19														
21	2320	34 58.56	112 46.65														
22	2330	34 46.58	113 26.18														
23	2340	34 35.66	114 05.86														
24	2350	34 23.95	114 45.10														
25	0000	34 11.96	115 25.11			10 DEC Z											
26	0010	34 00.15	116 04.87														
27	0016					PALM SPRINGS							NO MARK				
28	0020	33 55.25	116 47.82														
29	0030	33 56.54	117 30.11														
30						LA INTL.											
31	0046	33 56.92	118 21.17			TD		4.00	241	2.00	251	ON STATION	FIELD POSITION TO				
32													TACAN				
33																	
34																	
35																	

Table 10

LOS ANGELES TO BARBERS POINT, HAWAII - 10, 11 DECEMBER 1968

	TIME(Z)	OMEGA LAT.	OMEGA LONG.	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES		OMEGA RANGE(NMI)	OMEGA BRG °	TERMINAL RANGE(NMI)	TERMINAL BRG °	AID TYPE	NOTES				
1	2210	34°01.75'	118°26.26'	° '	° '												
2	2215					TRINIDAD	VERY	4.11	335	2.5	260	ON STATION	FIELD POSITION TO TACAN				
3						WEAK		21.67	302	22	300	TACAN	SANTA BARBARA				
4	2304	34 08.23	119 04.12	34 06.90	119 02.92					0	0	TACAN	VENTURA				
5	2315	34 15.73	119 46.15														
6																	
7	2330	34 13.06	120 41.80														
8	2345	33 56.32	121 31.98														
9	0000	33 40.62	122 19.11			11 DEC											
10	0015	33 22.30	123 04.63														
11	0030	33 13.07	123 52.90	33 13	123 46	LORAN A											
12	0045					COMPUTER	MALFUNCTION										
13	0100	32 50.68	125 28.43	32 47	125 25	LORAN A											
14	0115	32 41.06	126 16.67	32 46	125 54	LORAN A											
15	0130	32 30.27	127 05.33	32 30	127 01	LORAN A											
16	0145	32 17.61	127 51.98	32 15	127 54	LORAN A											
17	0202	32 04.47	128 48.53	32 00	128 46	LORAN A											
18	0215	31 54.51	129 31.33	31 47	129 47	LORAN A											
19	0230	31 40.30	130 21.28	31 30	130 37	LORAN A											
20	0245	31 26.25	131 12.55	31 17	131 22	LORAN A											
21	0300	31 11.66	132 04.16	31 04	132 08	LORAN A											
22	0315	30 55.72	132 58.30														
23	0330	30 39.18	133 53.17	30 28	134 09	LORAN A											
24	0345	30 22.07	134 48.68														
25	0400	30 04.73	135 44.44	29 52	135 53	LORAN A											
26	0415	29 46.65	136 39.78														
27	0430	29 27.96	137 35.73	29 22	137 46	LORAN A											
28	0445	29 08.68	138 30.78														
29	0500	28 49.85	139 26.67	28 52	139 37	OCEAN STATION											
30	0515	28 30.14	140 20.72														
31	0530	28 10.12	141 14.18	28 07	141 24	LORAN A/CONSOLAN											
32	0545	27 50.37	142 05.43														
33	0600	27 30.04	142 57.19	27 20	143 06	D.R.											
34	0615	27 09.34	143 49.98														
35	0630	26 47.78	144 40.83														

Table 10 (Continued)

	TIME(Z)	OMEGA LAT.	OMEGA LONG.	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES		OMEGA RANGE(NMI)	OMEGA BRG °	TERMINAL RANGE(NMI)	TERMINAL BRG°	AID TYPE	NOTES				
1	0645	26°26.02'	145°34.20'	° '	° '												
2	0700	26 04.08	146 27.33	26 04	146 22	LORAN A											
3	0715	25 40.17	147 22.43														
4	0730	25 19.78	148 12.12	25 25	147 55	LORAN A											
5	0749	24 48.34	149 17.93														
6	0800	24 32.36	149 56.67	24 37	149 27	LORAN A											
7	0815	24 07.67	150 47.15														
8	0830	23 43.85	151 37.65	23 44	151 23	LORAN A											
9	0845	23 20.04	152 28.25														
10	0900	22 56.17	153 15.99	22 55	153 10	LORAN A											
11	0915	22 32.17	154 02.81														
12	0928	22 15.44	154 46.61														
13	0930			22 04	154 55	LORAN A											
14	0941			21 44	155 44	MOLOKAI VOR											
15	0945	21 43.43	155 38.97			IN DOUBT											
16						HAWAII IN DOUBT											
17																	
18	1030					TD											
19																	
20																	
21																	
22																	
23																	
24																	
25																	
26																	
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	

Table 11

BARBERS POINT, HAWAII TO TUCSON - 13 DECEMBER 1968

	TIME(Z)	OMEGA LAT.	OMEGA LONG.	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES	OMEGA RANGE(NMI)	OMEGA BRG°	TERMINAL RANGE(NMI)	TERMINAL BRG °	AID TYPE	NOTES
1	0445	21°59.24'	156°48.28'	° '	° '							
2	0500					HAWAII IN DOUBT						
3	0520	22 35.51	154 37.88	22 42	154 31	LORAN A						
4	0540					NO FIX						
5	0600	23 23.16	152 12.03									
6	0620	24 02.88	150 50.26									
7	0625	24 08.59	150 30.36									
8	0640											
9	0700	24 38.91	148 02.18									
10	0720	25 05.26	146 43.44	25 09	146 38	LORAN A						
11	0743	25 40.53	145 07.91	25 45	145 27	NAV AT 0740 Z						
12	0800	26 08.30	143 55.84	26 18	143 55	LORAN A						
13	0820	26 35.54	142 24.37			PRECIP						
14	0843	27 04.66	140 34.92			"						
15						"						
16	0900	27 31.02	139 10.86			"						
17	0920	28 03.70	137 39.32			"						
18	0941	28 33.04	136 11.50			"						
19	1000	29 03.35	134 53.11	29 00	134 55	LORAN A						
20	1020	29 28.10	133 29.58	29 32	133 25	LORAN A						
21	1040	29 47.00	132 01.18	29 45	132 06	LORAN A						
22	1100	30 05.95	130 30.51	30 00	130 25	LORAN A						
23	1120	30 24.13	129 01.24									
24	1140	30 43.12	127 31.61									
25	1200			30 53	126 00	LORAN A						
26	1201	31 02.85	125 54.73									
27	1220			31 08	124 32	LORAN A						
28	1221	31 19.81	124 25.05									
29	1240	31 37.05	123 02.07	31 23	123 05	LORAN A						
30	1300	31 51.71	121 29.15	31 45	121 27	LORAN A						
31	1312						116	036	117	033	TACAN	LONG BEACH
32	1320	32 17.89	120 08.55									
33	1330						95.90	022	97.5	019	TACAN	LONG BEACH
34												
35												

Table 11 (Continued)

TIME(Z)	OMEGA LAT.	OMEGA LONG.	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES		OMEGA RANGE(NMI)	OMEGA BRG °	TERMINAL RANGE(NMI)	TERMINAL BRG °	AID TYPE	NOTES
1350	33°26.12'	118°27.28'										
							4.19	135	IN DOUBT		VOR	SANTA CATALINA
1403	33 15.71	117 26.81					1.97	117	0	0	TACAN	OCEANSIDE
1415							2.67	134	0	0	TACAN	JULIAN
							3.07	152	0	0	TACAN	YUMA
	32 49.53	112 39.36			DIFFERENCE	FREQ.	7.84	340	0	0	TACAN	GBN
1540					"	"	6.03	339	0	0	ON STATION	TUCSON

Table 12

TUCSON TO PATUXENT, 1.333-1/3 kHz - 14, 15 DECEMBER 1968

TIME(Z)	OMEGA LAT.	OMEGA LONG.	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES	OMEGA RANGE(NMI)	OMEGA BRG °	TERMINAL RANGE(NMI)	TERMINAL BRG°	AID TYPE	NOTES
1806	32°08.29'	110°56.03'			ΔΔ	1.72	191	0	0	ON STATION	TUCSON
1831	31 57.62	109 45.63			ΔΔ	4.36	349	0	0	TACAN OR VOR	COCHISE
1839	32 14.84	109 16.90			"	1.62	024	0	0	"	SAN SIMON
1901	32 14.27	107 33.99			"	2.27	345	0	0	"	DEMING
1919	31 51.51	106 14.76			"	5.72	334	0	0	"	NEWMAN
1936	32 27.09	105 17.48			"	4.69	339	0	0	"	PINON
1952	33 15.88	104 35.14			"	4.69	325	0	0	"	ROSWELL
2026	33 41.13	101 54.26			"	1.25	328	0	0	"	LUBBOCK
2048	34 21.30	100 16.27			"	1.20	303	0	0	"	CHILDRESS
2105	34 52.24	99 01.30			"	2.05	252	0	0	"	HOBART
2123	35 22.73	97 44.73			"	4.02	332	0	0	"	OKLAHÓMA CITY
2210	36 11.36	94 07.10			"	3.41	350	0	0	"	FAYETTEVILLE
2232	36 58.90	92 52.75			"	2.49	355	0	0	"	DOGWOOD
2250	37 36.71	91 46.02			TRANSITION	1.63	211	0	0	"	MAPLES
2310	37 41.08	90 10.15			"	3.14	252	0	0	"	FARMINGTON
2325	37 49.28	88 56.67			"	5.13	215	0	0	"	MARION
2341	37 47.96	87 49.84			SUNDOWN	8.37	020	0	0	"	EVANSVILLE
0010	37 58.36	85 33.66			15 DEC	7.87	353	0	0	"	LOUISVILLE
0022	37 50.41	84 30.94			ΔΔ	7.82	016	0	0	"	LEXINGTON
0032	37 59.06	82 55.86			"	10.46	009	IN DOUBT		"	NEWCOMBE
0058	38 12.12	81 51.07			"	9.87	026	0	0		CHARLESTON
					"						
0153					"	9.40	098	0	0	"	BROOKE
					"						
0218					TD	5.48	097	0	0	ON STATION	PATUXENT

Table 13
PATUXENT TO SAN JUAN - 4 JANUARY 1969

	TIME (Z)	OMEGA LAT.	OMEGA LONG.	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES		OMEGA RANGE(Mi)	OMEGA BRG °	TERMINAL RANGE(Mi)	TERMINAL BRG °	AID TYPE	NOTES				
1	1420	38°16.02'	76°24.66'	° '	° '			0.36	21	0	0	ON STATION	PATUXENT				
2	1533	36 53.40	76 12.08					0.10	30	0	0	TACAN	NORFOLK				
3	1544	36 14.90	76 09.69					0.88	317	0	0	VOR	ELIZ. CITY				
4	1600	35 31.54	75 12.87	35 31	75 11	D.R.											
5	1611	35 04.91	74 39.74														
6	1620	34 42.15	74 10.60	34 38	74 10	LORAN A											
7	1630	34 15.13	73 44.46														
8	1640	33 45.12	73 31.55	33 44	73 25	LORAN A											
9	1650	33 15.53	73 15.20														
10	1700	32 43.98	73 00.08	32 43	73 01	LORAN A											
11	1710	32 12.56	72 44.28														
12	1720	31 41.92	72 29.71	31 40	72 28	LORAN A											
13	1730	31 12.60	72 15.23														
14	1740	30 41.57	72 01.03	30 35	71 58	LORAN A											
15	1750	30 10.58	71 46.01														
16	1800	29 39.75	71 31.97	29 41	71 31	LORAN A											
17	1810	29 08.95	71 17.34														
18	1820	28 39.48	71 04.64	28 37	71 00	LORAN A											
19	1830	28 11.43	70 50.52														
20	1840	27 42.42	70 35.90	27 43	70 35	LORAN A											
21	1850	27 09.39	70 23.01														
22	1900	26 42.84	70 06.63	26 33	70 02	LORAN A											
23	1910	26 11.64	69 53.12														
24	1920	25 41.15	69 37.26	25 37	69 35	LORAN A											
25	1930	25 09.33	69 24.78														
26	1940	24 38.16	69 08.26	24 36	69 05	LORAN A											
27	1950	24 06.06	68 53.90														
28	2000	23 33.22	68 38.38	23 33	68 36	LORAN A											
29	2010	23 00.59	68 23.87														
30	2020	22 26.18	68 08.65	22 22	68 07	LORAN A											
31	2030	21 54.08	67 55.38														
32	2040	21 21.20	67 39.49	21 14	67 36	LORAN A											
33	2050	20 48.17	67 25.85														
34	2100	20 14.93	67 11.97	20 12	67 11	LORAN A	DME										
35	2102							121.6	154	122	153	VOR-DME	SAN JUAN				

DATA PAPER (17 COLUMN)—NDW-GEN-5900-4

GPO 931-476

Table 13 (Continued)

TIME(Z)	OMEGA LAT. ° '	OMEGA LONG. ° '	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES		OMEGA RANGE(Mi)	OMEGA BRG °	TERMINAL RANGE(Mi)	TERMINAL BRG°	AID TYPE	NOTES				
2110							92.3	150	91	151	VOR-DME	SAN JUAN				
2120							59.9	142	57.5	146	VOR-DME	SAN JUAN				
2142	18 25.00	66 04.06					3.2	75	0	0	ON STATION	SAN JUAN				

Table 14

SAN JUAN TO TRINIDAD AND RETURN - 6 JANUARY 1969

	TIME(Z)	OMEGA LAT.	OMEGA LONG	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES		OMEGA RANGE(Mi)	OMEGA BRG °	TERMINAL RANGE(Mi)	TERMINAL BRG °	AID TYPE	NOTES				
1	0109	18°25.37'	65°59.08'					2.5	290	0	0	ON STATION	SAN JUAN				
2	0115	18 05.16	65 56.24														
3	0130	17 16.58	65 41.66														
4	0145	16 31.71	65 09.77														
5	0200	15 45.87	64 40.79														
6	0215	15 03.17	64 13.81														
7	0230	14 19.65	63 46.04														
8	0245	13 35.57	63 16.13														
9	0300	12 53.54	62 48.80														
10	0315	12 08.77	62 24.29														
11	0330	11 25.42	61 57.01														
12	0345																
13	0401	11 11.84	61 29.66														
14	0415																
15	0430	12 11.07	62 31.29														
16	0445	13 03.63	62 56.23														
17	0500	13 50.89	63 25.75														
18	0515	14 36.95	63 57.05														
19	0527					LOST ONE LANE ON TRINIDAD DUE TO MODAL INTERFERENCE CAUSING SERVO UN-LOCK ON NARROW-BAND SERVOS.											
20	0545	16 07.41	64 53.63														
21	0600	16 55.40	65 25.53														
22	0615	17 42.89	65 54.40														
23	0629					TD		8.07	0	0	0	ON STATION	SAN JUAN				
24	0630							0.5	180	0	0	ON STATION	AFTER UPDATE OF LOST LANE				
25																	
26																	
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	

DATA PAPER (17 COLUMN)-NDW-GEN-5900-4

GPC 931-476

Table 15
SAN JUAN TO PATUXENT - 7 JANUARY 1969

	TIME(Z)	OMEGA LAT.	OMEGA LONG.	NAVIGATOR LAT.	NAVIGATOR LONG.	NOTES		OMEGA RANGE(Mi)	OMEGA BRG °	TERMINAL RANGE(Mi)	TERMINAL BRG °	AID TYPE	NOTES				
1	1246	18°27.01'	65°58.42'	° '	° '			2.5	80	0	0	ON STATION	SAN JUAN				
2	1315	18 53.28	66 13.28														
3	1330	19 38.32	66 41.39	19 37	66 47	LORAN A-TACAN											
4	1345	20 19.00	67 16.96														
5	1400	21 11.56	67 35.48	21 11	67 35	LORAN A-ADF											
6	1415																
7	1430	22 54.56	68 22.33	22 53	68 21	LORAN A											
8	1445	23 46.11	68 43.72														
9	1500	24 36.21	69 07.05	24 36	69 08	LORAN A											
10	1515	25 27.86	69 30.11														
11	1530	26 18.11	69 55.19	26 16	69 54	LORAN A											
12	1545	27 08.63	70 18.24														
13	1600	27 58.29	70 42.21	28 01	70 45	LORAN A											
14	1615	28 48.50	71 06.53														
15	1630	29 38.44	71 30.03	29 38	71 28	LORAN A											
16	1645	30 27.83	71 54.02														
17	1700	31 18.16	72 15.80	31 20	72 18	LORAN A											
18	1715	32 07.50	72 40.89														
19	1730	32 58.72	73 06.08	33 04	73 07	LORAN A											
20	1745	33 45.10	73 30.62														
21	1802	34 37.94	74 00.72	34 39	73 56	LORAN A 1800 Z											
22	1815	35 05.64	74 33.64														
23	1848							0.5	152	0	0	VOR	ELIZABETH CITY				
24	1859	36 51.87	76 13.15					1.85	35	0	0	TACAN	NORFOLK				
25	1930							0.86	6	0	0	ON STATION	ANDREWS				
26																	
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	

Table 16

DEMONSTRATION AND LOCAL FLIGHTS

- 10.2 kHz OMEGA ERROR

FACILITY	DATE	TIME (Z)	RANGE ERROR (NMI)	BEARING (DEGREES)
OTT	7/17/68	1413	0.56	266
BAL	7/17/68	1425	2.79	272
OTT	7/17/68	1435	1.22	255
ADW	7/17/68	1440	2.13	300
OTT	7/17/68	1503	1.25	255
NHK	7/17/68	1520	1.26	270
RIC	7/17/68	1539	1.44	231
GVE	7/17/68	1555	1.45	284
NHK	7/18/68	1420	0.93	316
SBY	7/18/68	1505	0.92	318
ATR	7/18/68	1514	2.22	280
ENO	7/18/68	1522	1.66	287
OTT	7/18/68	1544	0.76	258
NHK	7/18/68	1555	0.75	068
OTT	7/18/68	1652	0.79	047
NHK	7/18/68	1701	1.68	060
LDN	7/23/68	1354	NO FIX	
ESL	7/23/68	1407	0.73	077
MGW	7/23/68	1417	1.45	275
SWL	7/24/68	1510	0.67	324
SBV	7/24/68	1516	2.53	276
ATR	7/24/68	1525	1.34	309
SIE	7/24/68	1532	0.63	019
ENO	7/24/68	1543	1.20	278
OTT	7/24/68	1602	0.90	287
NHK	7/24/68	1610	0.57	057
JWL	7/24/68	1624	0.38	357
JBY	7/24/68	1631	1.49	320
ATR	7/24/68	1640	1.17	342
OTT	7/25/68	1437	2.76	263
OTT	7/25/68	1515	1.40	276
NHK	7/25/68	1523	0.47	299
SWL	7/25/68	1537	1.79	268
SBY	7/25/68	1543	1.55	274
ATR	7/25/68	1552	1.18	277
ENO	7/25/68	1600	0.79	303
NHK	7/25/68	1709	0.16	031
NHK	8/1/68	1300	1.52	314
OTT	8/1/68	1347	1.85	293
ADW	8/1/68	1405	0.92	281

Table 16 (Continued)

FACILITY	DATE	TIME (Z)	RANGE ERROR (NMI)	BEARING (DEGREES)
OTT	8/1/68	1418	0.97	279
BRK	8/1/68	1431	1.38	242
GVE	8/1/68	1443	1.25	231
RIC	8/1/68	1457	1.19	276
NHK	8/1/68	1514	1.08	337
OTT	8/1/68	1523	1.43	260
ADW	8/1/68	1528	1.52	282
ADW	8/1/68	1540	1.40	283
OTT	8/1/68	1547	0.73	302
BRK	8/1/68	1559	1.03	237
GVE	8/1/68	1611	0.95	243
RIC	8/1/68	1626	0.49	353
NHK	8/1/68	1644	1.13	010
OTT	8/1/68	1653	1.19	274
ADW	8/1/68	1701	0.54	318
OTT	8/2/68	1555	0.81	304
BRK	8/2/68	1606	1.10	236
BRK	8/2/68	1612	1.12	292
OTT	8/2/68	1624	1.92	292
ADW	8/2/68	1630	0.21	025
ADW	8/2/68	1700	0.82	292
OTT	8/2/68	1706	0.45	008
BRK	8/2/68	1717	0.19	272
GVE	8/2/68	1736	0.23	262
ADW	8/2/68	1925	0.93	275
ENO	8/22/68	1429	0.82	308
ARD	8/22/68	1450	1.16	284
NJP	8/22/68	1530	0.87	328
NJP	8/22/68		0.94	356
ARD	8/22/68	1608	1.81	033
ACY	8/22/68	1622	1.49	107
SIE	8/22/68	1628	1.84	099
ENO	8/22/68	1639	0.32	059
EWT	8/22/68	1648	0.94	005
PTW	8/22/68	1659	1.99	016
ARD	8/22/68	1708	2.48	017
NJP	8/22/68		1.47	353
NWT	8/22/68		2.10	182
ENO	8/22/68		1.55	138
NHK	8/22/68		1.57	053
OTT	8/27/68	1431	2.44	270

Table 16 (Continued)

FACILITY	DATE	TIME (Z)	RANGE ERROR (NMI)	BEARING (DEGREES)
OTT	8/27/68	1513	0.25	330
NHK	8/27/68	1521	1.34	089
RIC	8/27/68	1540	0.98	224
GVE	8/27/68	1555	1.58	301
BRK	8/27/68	1608	0.69	341
OTT	8/27/68	1620	0.77	351
ADW	8/27/68	1626	0.70	044
ADW	9/4/68	1505	1.01	311
OTT	9/4/68	1523	0.55	044
NHK	9/4/68	1532	2.13	070
RIC	9/4/68	1557	0.66	188
GVE	9/4/68	1607	1.09	301
BRK	9/4/68	1621	1.05	342
OTT	9/4/68	1631	1.15	006
ADW	9/4/68	1640	0.93	012
ACY	9/5/68		1.11	106
NHK	9/5/68	1750	0.61	059
HPW	9/10/68	1522	0.92	245
LVL	9/10/68	1535	1.76	195
SBV	9/10/68	1550	0.69	267
NHK	9/10/68	1642	1.10	193
NHK	10/1/68	1430	2.37	276
SWL	10/1/68	1504	1.27	064
ATR	10/1/68	1522	1.49	066
SIE	10/1/68	1530	1.07	013
ENO	10/1/68	1541	1.00	081
OTT	10/1/68	1601	1.58	066
SWL	10/1/68	1623	0.46	095
NHK	10/1/68	1648	0.70	008
NHK	10/24/68	1417	0.24	273
ATL	10/24/68	1454	1.12	317
SIE	10/24/68	1502	1.33	293
RIC	12/5/68	16	0.38	353
GVE	12/5/68		1.15	269
BRK	12/5/68		1.60	280
OTT	12/5/68		1.65	292

Table 17
DEMONSTRATION AND LOCAL FLIGHTS - 1.333-1/3 kHz OMEGA ERROR (WITHOUT PHASE CORRECTIONS)

FACILITY	DATE	TIME (Z)	RANGE ERROR (NMI)	BEARING (DEGREES)
HLG	7/23/68	1434	4.75	110
BSV	7/23/68	1448	4.80	088
BSV	7/23/68	1503	5.30	021
HLG	7/23/68	1515	4.72	079
MGW	7/23/68	1529	4.43	086
ESL	7/23/68	1540	4.27	089
LDN	7/23/68	1546	5.36	175
CSN	7/23/68	1556	5.37	171
BRV	7/23/68	1603	4.81	160
NHK	7/24/68	1700	4.01	088
SWL	7/24/68	1714	3.56	090
SBY	7/24/68	1720	3.47	077
ATL	7/24/68	1728	4.78	067
OTT	7/24/68	1749	3.31	081
OTT	7/25/68	1617	6.55	087
ADW	7/25/68	1631	6.05	068
ADW	7/25/68	1645	3.44	086
ADW	8/1/68	1705	6.15	074
OTT	8/1/68	1716	5.37	076
NHK	8/1/68	1729	6.40	087
NHK	8/2/68	1400	7.00	070
OTT	8/2/68		3.50	050
NHK	8/2/68	1805	4.47	071
OTT	8/2/68	1816	4.88	085
ADW	8/2/68		4.89	073
NHK	10/1/68	1644	3.29	061
SIE	10/24/68	1502	8.70	064
SBY	10/24/68	1638	8.10	064
SWL	10/24/68	1643	7.57	061
CCV	10/24/68	1652	4.48	067
HCM	10/24/68	1707	4.66	071
NHK	10/24/68	1728	0.82	032

Table 18
PATRICK RANGE RUN #1 7/29/68 BC-BD

TIME (Z)	OMEGA LAT.	OMEGA LONG.	RADAR LAT.	RADAR LONG.	OMEGA - RADAR LAT.(Min.)	OMEGA - RADAR LONG(Min.)
133014	28° 09.0'	80° 01.9'	28° 08.0'	80° 04.5'	+ 1.0	- 2.6
133025	28 09.5	80 02.5	28 08.6	80 05.1	+ 0.9	- 2.6
133036	28 10.1	80 03.0	28 09.1	80 05.6	+ 1.0	- 2.6
133047	28 10.6	80 03.5	28 09.6	80 06.1	+ 1.0	- 2.6
133058	28 11.1	80 04.0	28 10.1	80 06.6	+ 1.0	- 2.6
133110	28 11.6	80 04.6	28 10.6	80 07.2	+ 1.0	- 2.6
133121	28 12.0	80 05.3	28 11.0	80 07.8	+ 1.0	- 2.5
133132	28 12.2	80 06.0	28 11.1	80 08.5	+ 1.1	- 2.5
133143	28 12.4	80 06.8	28 11.4	80 09.3	+ 1.0	- 2.5
133155	28 12.6	80 07.6	28 11.6	80 10.0	+ 1.0	- 2.4
133206	28 12.8	80 08.3	28 11.7	80 10.8	+ 1.1	- 2.5
134514	28° 11.4'	80° 16.4'	28° 10.8'	80° 18.2'	+ 0.6	- 1.8
134525	28 11.7	80 15.7	28 11.1	80 17.5	+ 0.6	- 1.8
134536	28 11.9	80 15.1	28 11.4	80 16.8	+ 0.5	- 1.7
134547	28 12.3	80 14.4	28 11.7	80 16.1	+ 0.6	- 1.7
134558	28 12.6	80 13.7	28 12.1	80 15.5	+ 0.5	- 1.8
134610	28 12.9	80 13.1	28 12.4	80 14.8	+ 0.5	- 1.7
134621	28 13.2	80 12.4	28 12.7	80 14.2	+ 0.5	- 1.8
134632	28 13.6	80 11.7	28 13.0	80 13.5	+ 0.6	- 1.8
134643	28 13.8	80 11.0	28 13.3	80 12.8	+ 0.5	- 1.8
134655	28 14.1	80 10.4	28 13.6	80 12.1	+ 0.5	- 1.7
134706	28 14.4	80 09.6	28 13.9	80 11.4	+ 0.5	- 1.8
134717	28 14.8	80 09.0	28 14.3	80 10.8	+ 0.5	- 1.8
141847	28° 09.4'	80° 10.6'	28° 09.1'	80° 11.3'	+ 0.3	- 0.7
141858	28 10.1	80 10.5	28 09.7	80 11.2	+ 0.4	- 0.7
141910	28 10.8	80 10.5	28 10.4	80 11.1	+ 0.4	- 0.6
141921	28 11.4	80 10.4	28 11.1	80 11.0	+ 0.3	- 0.6
141932	28 12.1	80 10.2	28 11.8	80 10.9	+ 0.3	- 0.7
141943	28 12.8	80 10.2	28 12.4	80 10.8	+ 0.4	- 0.6
141955	28 13.5	80 10.1	28 13.2	80 10.7	+ 0.3	- 0.6
142006	28 14.2	80 10.0	28 13.8	80 10.6	+ 0.4	- 0.6
142017	28 14.8	80 09.9	28 14.5	80 10.4	+ 0.3	- 0.5
143754	28° 11.6'	80° 12.5'	28° 10.7'	80° 15.6'	+ 0.9	- 3.1
143805	28 12.2	80 12.0	28 11.2	80 15.1	+ 1.0	- 3.1
143816	28 12.8	80 11.4	28 11.7	80 14.6	+ 1.1	- 3.2

Table 18 (Continued)

TIME (Z)	OMEGA LAT.	OMEGA LONG.	RADAR LAT.	RADAR LONG.	OMEGA - RADAR LAT.(Min.)	OMEGA - RADAR LONG(Min.)
143828	28° 13.3'	80° 11.0'	28° 12.3'	80° 14.1'	+ 1.0	- 3.1
143839	28 13.8	80 10.5	28 12.8	80 13.6	+ 1.0	- 3.1
143850	28 14.3	80 10.0	28 13.3	80 13.1	+ 1.0	- 3.1
143902	28 14.8	80 09.5	28 13.8	80 12.5	+ 1.0	- 3.0
145243	28° 09.8'	80° 07.4'	28° 08.5'	80° 10.7'	+ 1.3	- 3.3
145254	28 10.5	80 08.0	28 09.2	80 11.2	+ 1.3	- 3.2
145305	28 11.2	80 08.5	28 09.9	80 11.7	+ 1.3	- 3.2
145317	28 11.9	80 08.9	28 10.6	80 12.2	+ 1.3	- 3.3
145328	28 12.6	80 09.3	28 11.3	80 12.6	+ 1.3	- 3.3
145339	28 13.3	80 09.7	28 12.0	80 12.9	+ 1.3	- 3.2
145350	28 14.1	80 10.0	28 12.8	80 13.2	+ 1.3	- 3.2
145402	28 14.8	80 10.3	28 13.5	80 13.5	+ 1.3	- 3.2
145413	28 15.5	80 10.7	28 14.2	80 14.0	+ 1.3	- 3.3

Table 19
PATRICK RANGE RUN #2 7/29/68 BC-BD

TIME (Z)	OMEGA LAT.	OMEGA LONG.	RADAR LAT.	RADAR LONG.	OMEGA - RADAR LAT.(Min.)	OMEGA - RADAR LONG(Min)
182626	28° 10.8'	80° 07.3'	28° 10.3'	80° 07.7'	+ 0.5	- 0.4
182637	28 11.4	80 07.7	28 10.9	80 08.2	+ 0.5	- 0.5
182649	28 11.9	80 08.2	28 11.5	80 08.7	+ 0.4	- 0.5
182700	28 12.5	80 08.7	28 12.1	80 09.1	+ 0.4	- 0.4
182711	28 13.1	80 09.2	28 12.6	80 09.5	+ 0.5	- 0.3
182722	28 13.6	80 09.6	28 13.2	80 10.0	+ 0.4	- 0.4
182734	28 14.3	80 10.0	28 13.8	80 10.3	+ 0.5	- 0.3
182745	28 14.9	80 10.4	28 14.4	80 10.8	+ 0.5	- 0.4
182756	28 15.5	80 10.8	28 15.0	80 11.2	+ 0.5	- 0.4
182807	28 16.1	80 11.2	28 15.6	80 11.6	+ 0.5	- 0.4
182819	28 16.6	80 11.6	28 16.2	80 12.0	+ 0.4	- 0.4
182830	28 17.2	80 12.1	28 16.8	80 12.4	+ 0.4	- 0.3
182841	28 17.7	80 12.6	28 17.4	80 12.9	+ 0.3	- 0.3
182852	28 18.2	80 13.2	28 17.9	80 13.4	+ 0.3	- 0.2
182904	28 18.6	80 13.8	28 18.3	80 14.0	+ 0.3	- 0.2

Table 19 (Continued)

TIME (Z)	OMEGA LAT.	OMEGA LONG.	RADAR LAT.	RADAR LONG.	OMEGA - RADAR LAT.(Min.)	OMEGA - RADAR LONG(Min)
184115	28° 10.5'	80° 13.8'	28° 10.4'	80° 14.1'	+ 0.1	- 0.3
184126	28 11.0	80 13.3	28 10.9	80 13.5	+ 0.1	- 0.2
184137	28 11.5	80 12.7	28 11.4	80 13.0	+ 0.1	- 0.3
184149	28 12.0	80 12.3	28 11.9	80 12.5	+ 0.1	- 0.2
184200	28 12.6	80 11.7	28 12.4	80 12.0	+ 0.2	- 0.3
184211	28 13.1	80 11.2	28 13.0	80 11.5	+ 0.1	- 0.3
184222	28 13.6	80 10.7	28 13.5	80 11.0	+ 0.1	- 0.3
184234	28 14.1	80 10.2	28 14.1	80 10.5	+ 0.0	- 0.3
184245	28 14.6	80 09.7	28 14.6	80 10.0	+ 0.0	- 0.3
184256	28 15.0	80 09.1	28 15.0	80 09.4	+ 0.0	- 0.3
190900	28° 10.9'	80° 06.2'	28° 10.3'	80° 06.3'	+ 0.6	- 0.1
190911	28 11.4	80 06.6	28 10.9	80 06.8	+ 0.5	- 0.2
190922	28 11.9	80 07.2	28 11.3	80 07.3	+ 0.6	- 0.1
190934	28 12.4	80 07.7	28 11.8	80 07.9	+ 0.6	- 0.2
190945	28 12.8	80 08.3	28 12.2	80 08.5	+ 0.6	- 0.2
190956	28 13.3	80 08.9	28 12.7	80 09.1	+ 0.6	- 0.2
191007	28 13.7	80 09.5	28 13.1	80 09.7	+ 0.6	- 0.2
191019	28 14.1	80 10.1	28 13.5	80 10.3	+ 0.6	- 0.2
191030	28 14.6	80 10.6	28 14.0	80 10.8	+ 0.6	- 0.2
191041	28 15.1	80 11.1	28 14.5	80 11.3	+ 0.6	- 0.2
192348	28° 10.5'	80° 13.8'	28° 10.3'	80° 14.4'	+ 0.2	- 0.6
192400	28 10.9	80 13.3	28 10.8	80 13.9	+ 0.1	- 0.6
192411	28 11.4	80 12.7	28 11.4	80 13.3	+ 0.0	- 0.6
192422	28 11.9	80 12.3	28 11.8	80 12.9	+ 0.1	- 0.6
192433	28 12.5	80 11.7	28 12.4	80 12.3	+ 0.1	- 0.6
192445	28 13.0	80 11.2	28 12.9	80 11.8	+ 0.1	- 0.6
192456	28 13.5	80 10.7	28 13.4	80 11.3	+ 0.1	- 0.6
192507	28 14.0	80 10.3	28 13.9	80 10.8	+ 0.1	- 0.5
192518	28 14.5	80 09.8	28 14.4	80 10.3	+ 0.1	- 0.5
192530	28 15.0	80 09.3	28 14.9	80 09.7	+ 0.1	- 0.4
192541	28 15.6	80 08.7	28 15.4	80 09.2	+ 0.2	- 0.5
195026	28° 08.7'	80° 05.0'	28° 08.2'	80° 04.6'	+ 0.5	+ 0.4
195038	28 09.2	80 05.4	28 08.8	80 05.1	+ 0.4	+ 0.3
195049	28 09.7	80 06.0	28 09.4	80 05.6	+ 0.3	+ 0.4
195100	28 10.3	80 06.5	28 09.9	80 06.1	+ 0.4	+ 0.4
195111	28 10.8	80 06.9	28 10.5	80 06.5	+ 0.3	+ 0.4

Table 19 - (Continued)

TIME (Z)	OMEGA LAT.	OMEGA LONG.	RADAR LAT.	RADAR LONG.	OMEGA - RADAR LAT.(Min)	OMEGA - RADAR LONG(Min)
195123	28° 11.4'	80° 07.4'	28° 11.0'	80° 07.0'	+ 0.4	+ 0.4
195134	28 11.9	80 07.9	28 11.6	80 07.5	+ 0.3	+ 0.4
195145	28 12.4	80 08.3	28 12.2	80 08.0	+ 0.2	+ 0.3
195156	28 13.0	80 08.7	28 12.7	80 08.4	+ 0.3	+ 0.3
195208	28 13.5	80 09.2	28 13.3	80 08.9	+ 0.2	+ 0.3
195219	28 14.0	80 09.8	28 13.8	80 09.5	+ 0.2	+ 0.3
195230	28 14.4	80 10.5	28 14.2	80 10.1	+ 0.2	+ 0.4
195241	28 14.8	80 11.1	28 14.6	80 10.7	+ 0.2	+ 0.4
195353	28 15.0	80 11.7	28 14.9	80 11.3	+ 0.1	+ 0.4

Table 20
PATRICK RANGE RUN #3 1.133-1/3 kHz 7/30/68

TIME (Z)	RANGE ERROR (NMI)	BEARING (DEGREES)
1829	2.9	254
1850	2.6	072
1920	1.3	011
1936	1.9	233
1948	0.4	020

Table 21
DIFFERENTIAL OMEGA MONITORING, 10.2 kHz
LOP's BC & BD, 20 AUGUST 1968

TIME (Z)	RANGE ERROR (NMI)	BEARING (DEGREES)
1650	0.31	208° 22'
1655	0.37	098 35
1700	0.33	210 35
1707	0.52	217 55
1709	0.39	218 41
1713	0.28	206 43
1716	0.48	227 36
1722	0.42	211 29
1728	0.45	217 14
1735	0.37	221 01
1741	0.29	201 00
1748	0.30	220 37
1753	0.34	221 22
1758	0.22	217 32

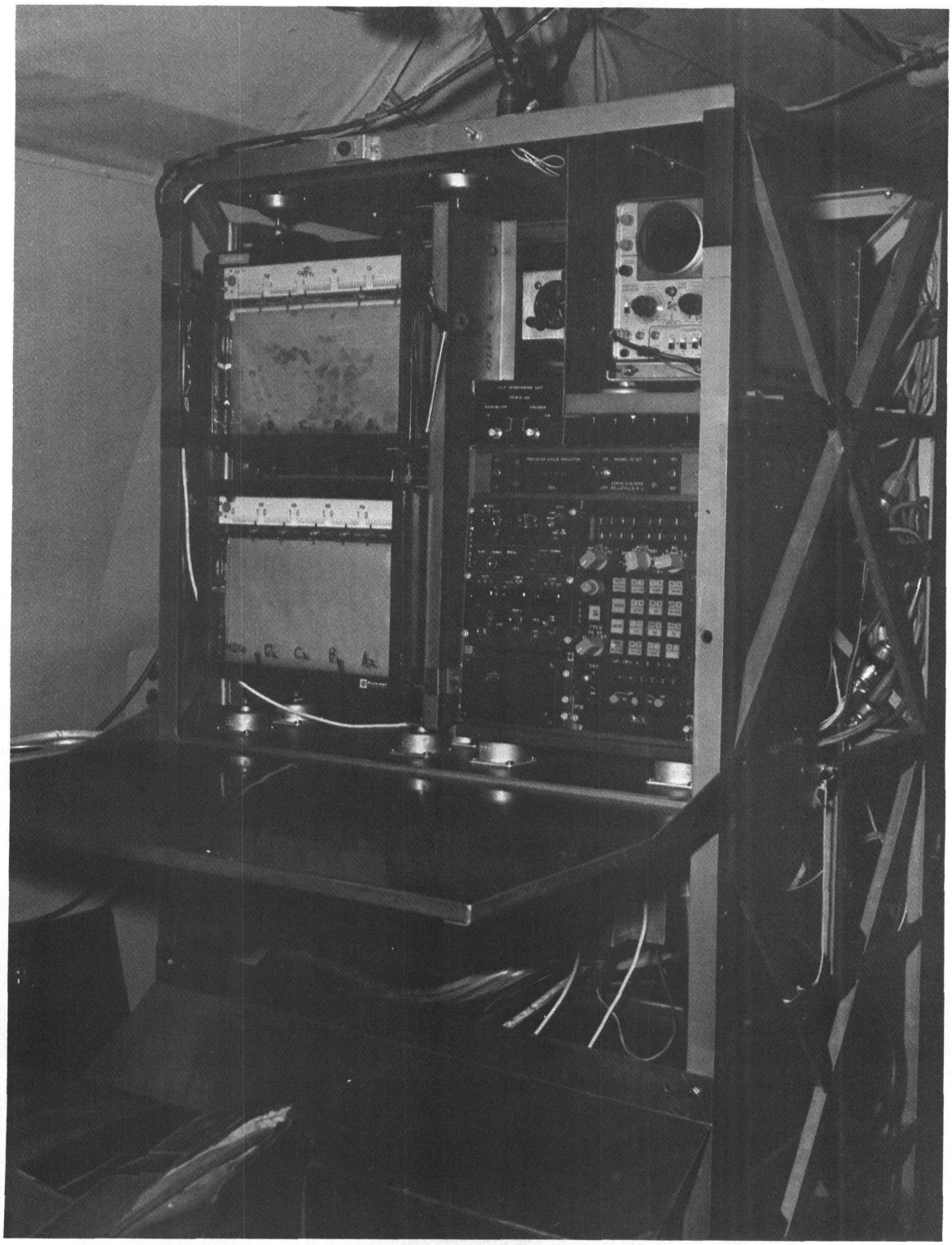


Fig. 1 - Mark III Installation in NRL EC121K Aircraft

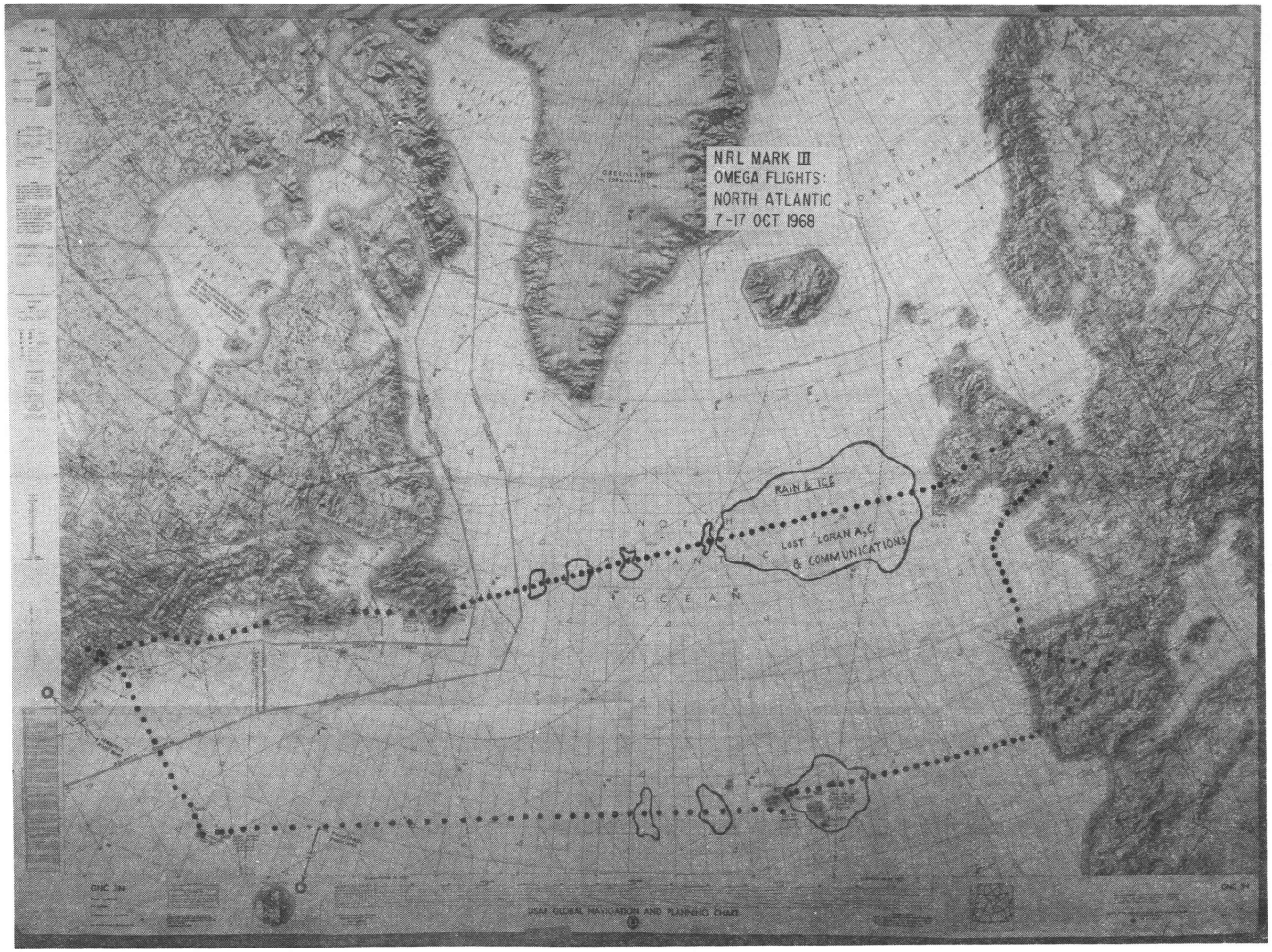


Fig. 2 - North Atlantic Flight Test Route

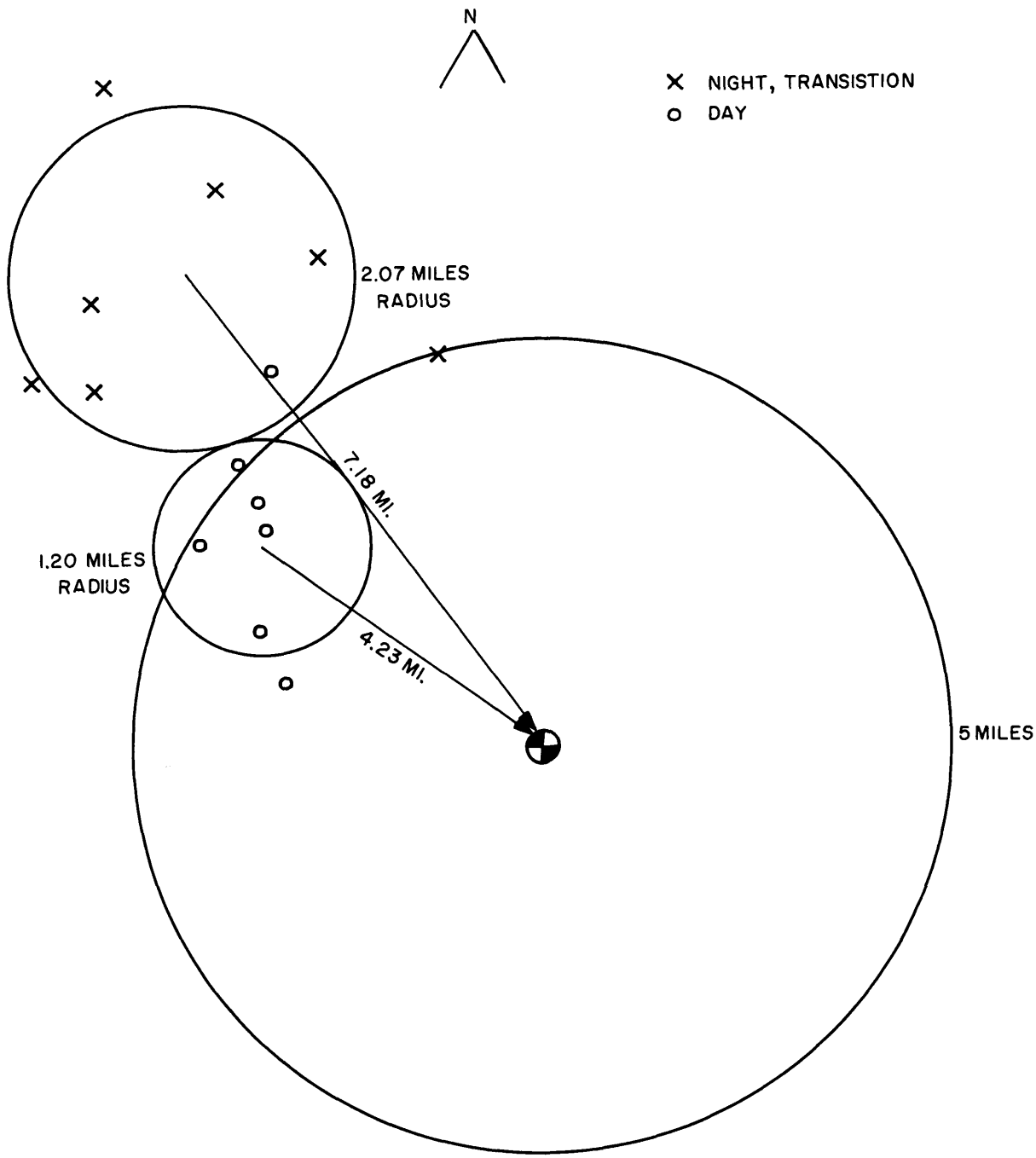


Fig. 3 - Omega Errors, United Kingdom Area

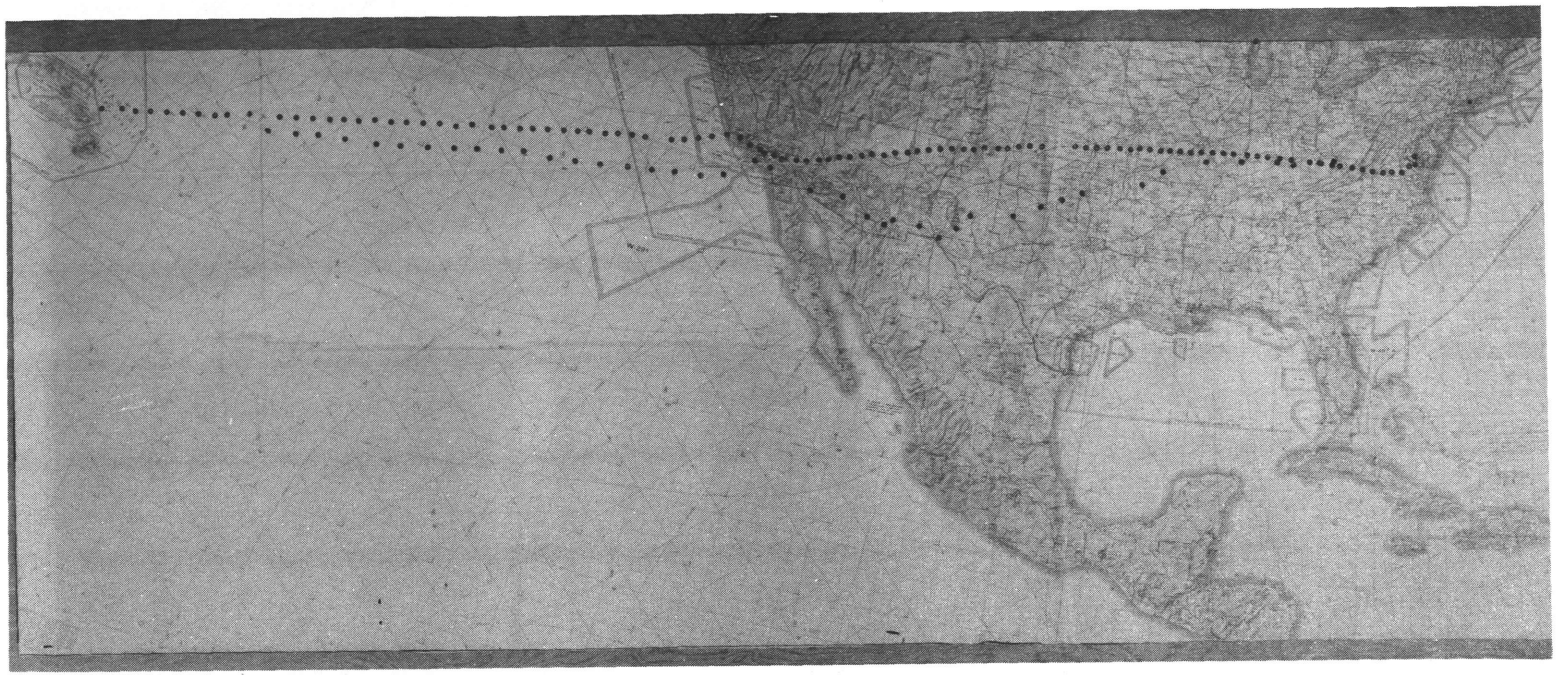
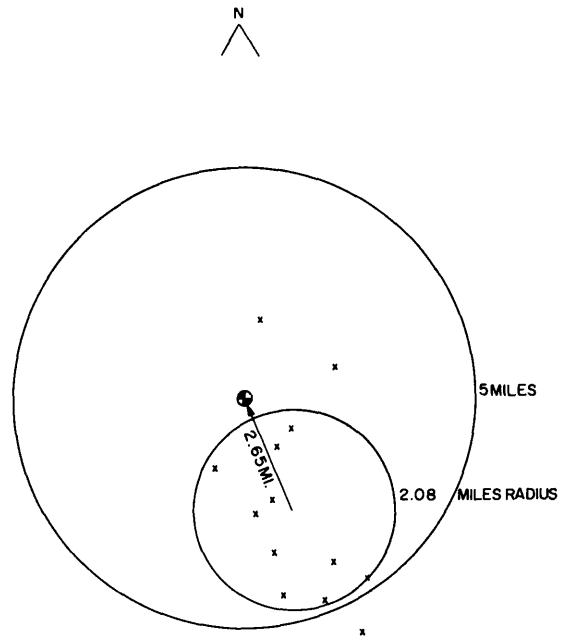


Fig. 4 - Cross Country and Hawaii Flight Test Route

Fig. 5 - Omega Difference Frequency Errors, Trans-U.S., Daytime



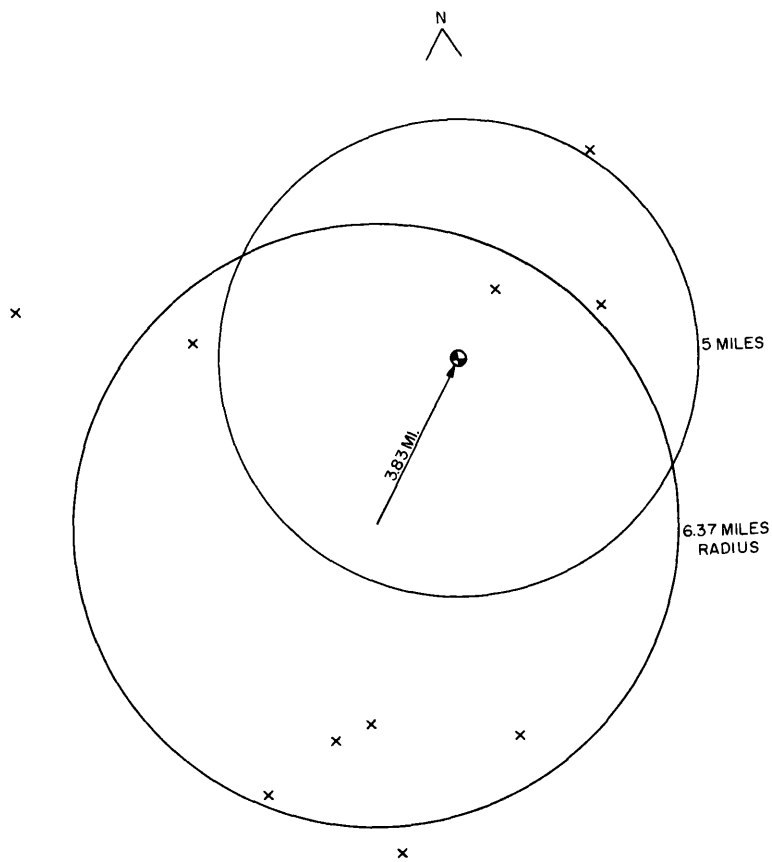


Fig. 6 - Omega Difference Frequency Errors, Trans-U.S., Nighttime and Transition

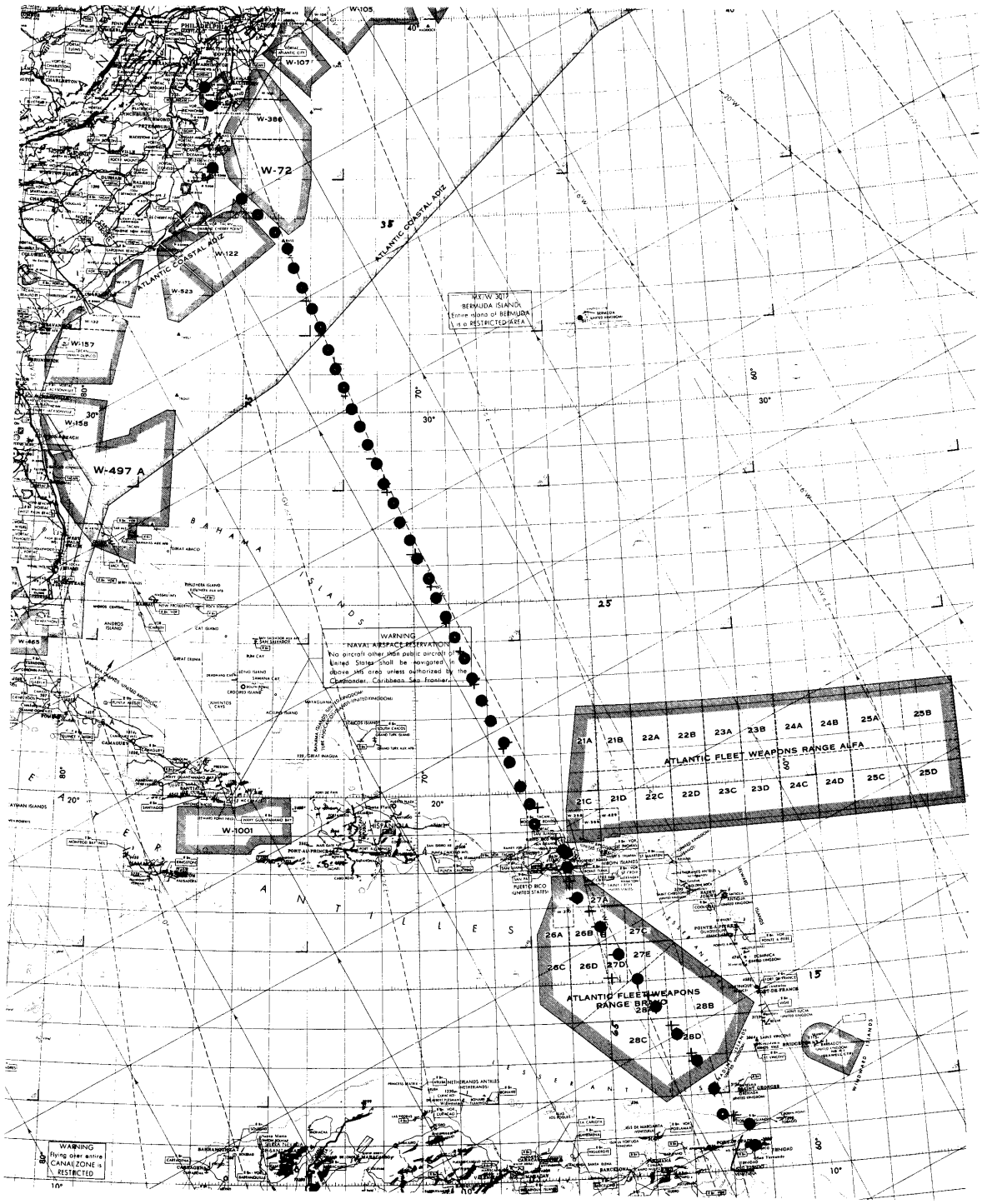


Fig. 7 - Caribbean Flight Test Route

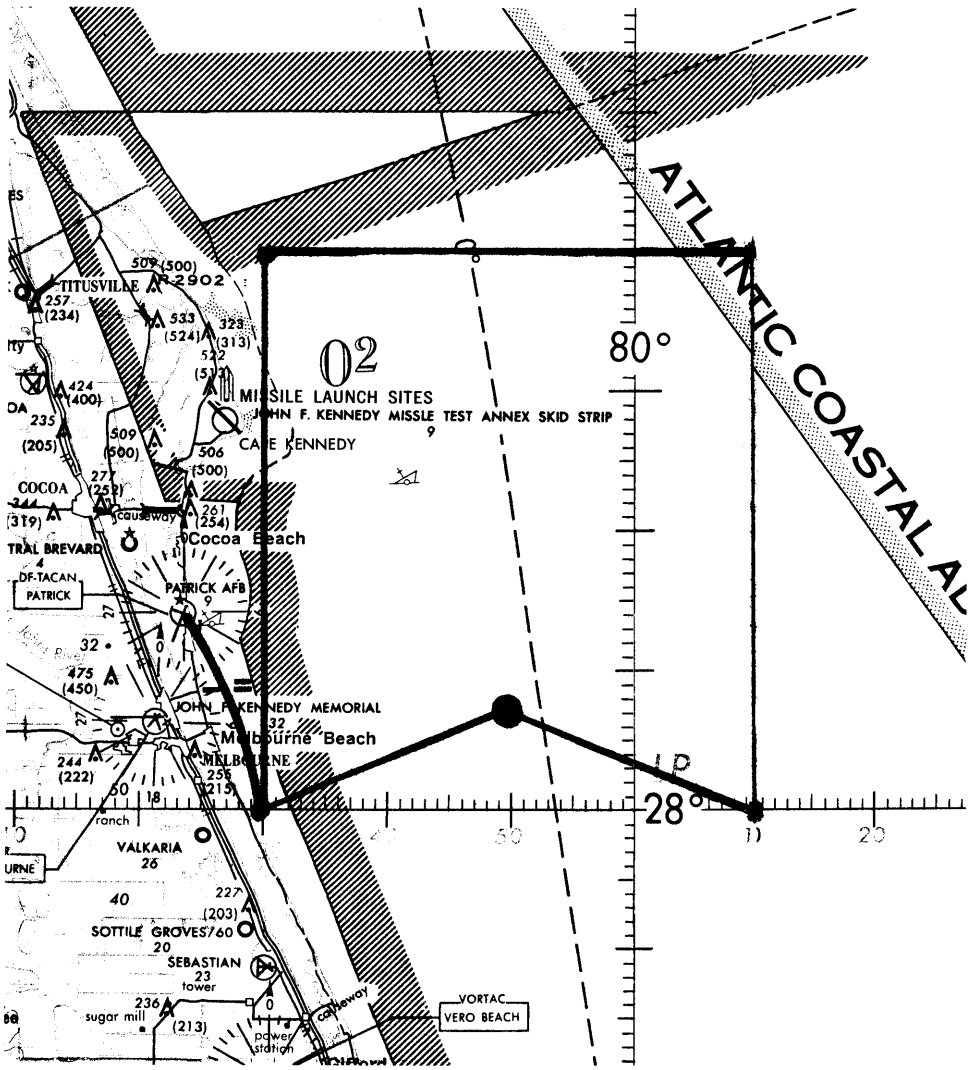


Fig. 8 - Atlantic Missile Range Radar Flight Test Route

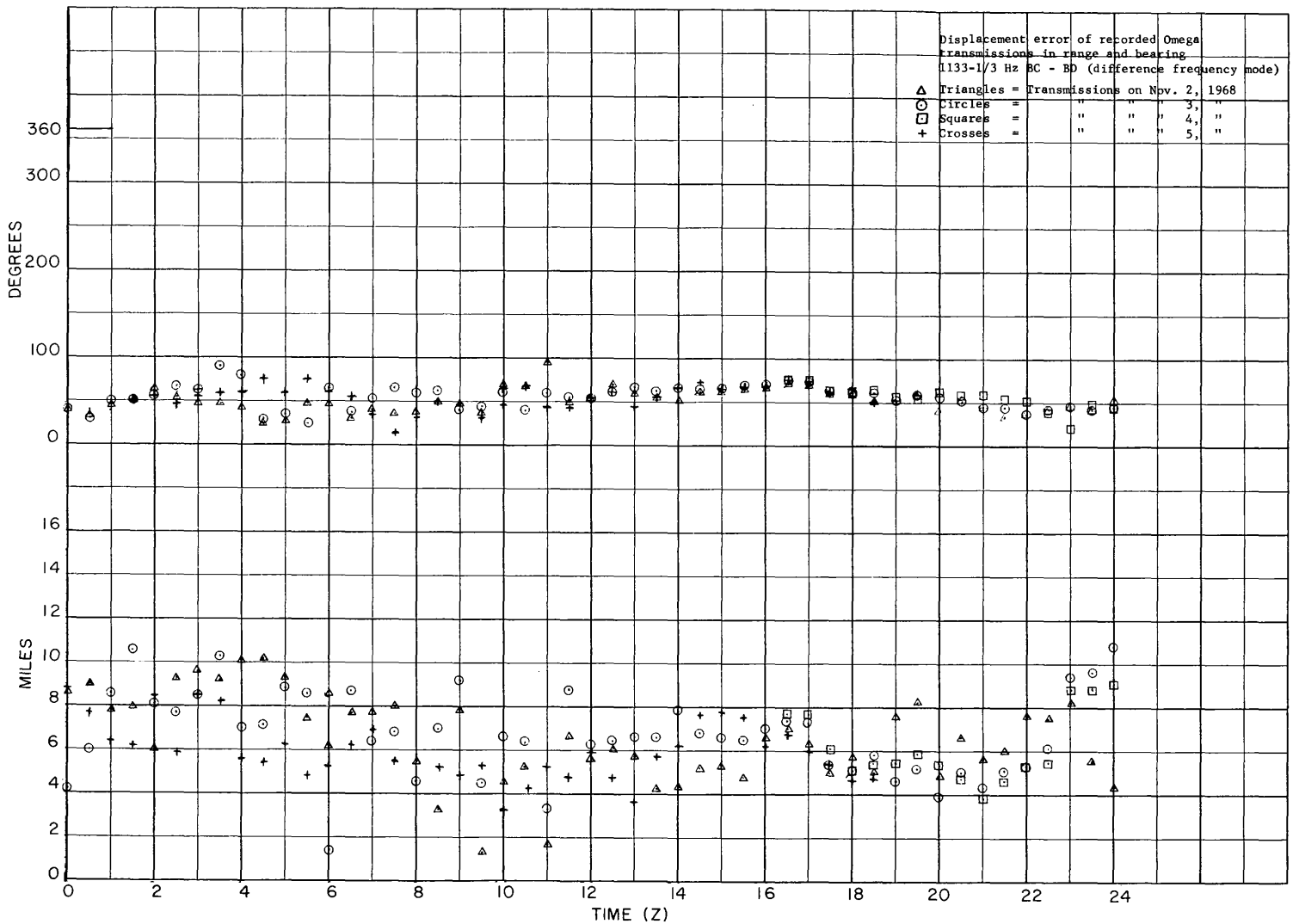

Displacement error of recorded Omega transmissions in range and bearing
1133-1/3 Hz BC - BD (difference frequency mode)
Triangles = Transmissions on Nov. 2, 1968
Circles = " " " 3, "
Squares = " " " 4, "
Crosses = " " " 5, "
DEGREES
360
300
200
100
0
MILES
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (Z)

Figure 9

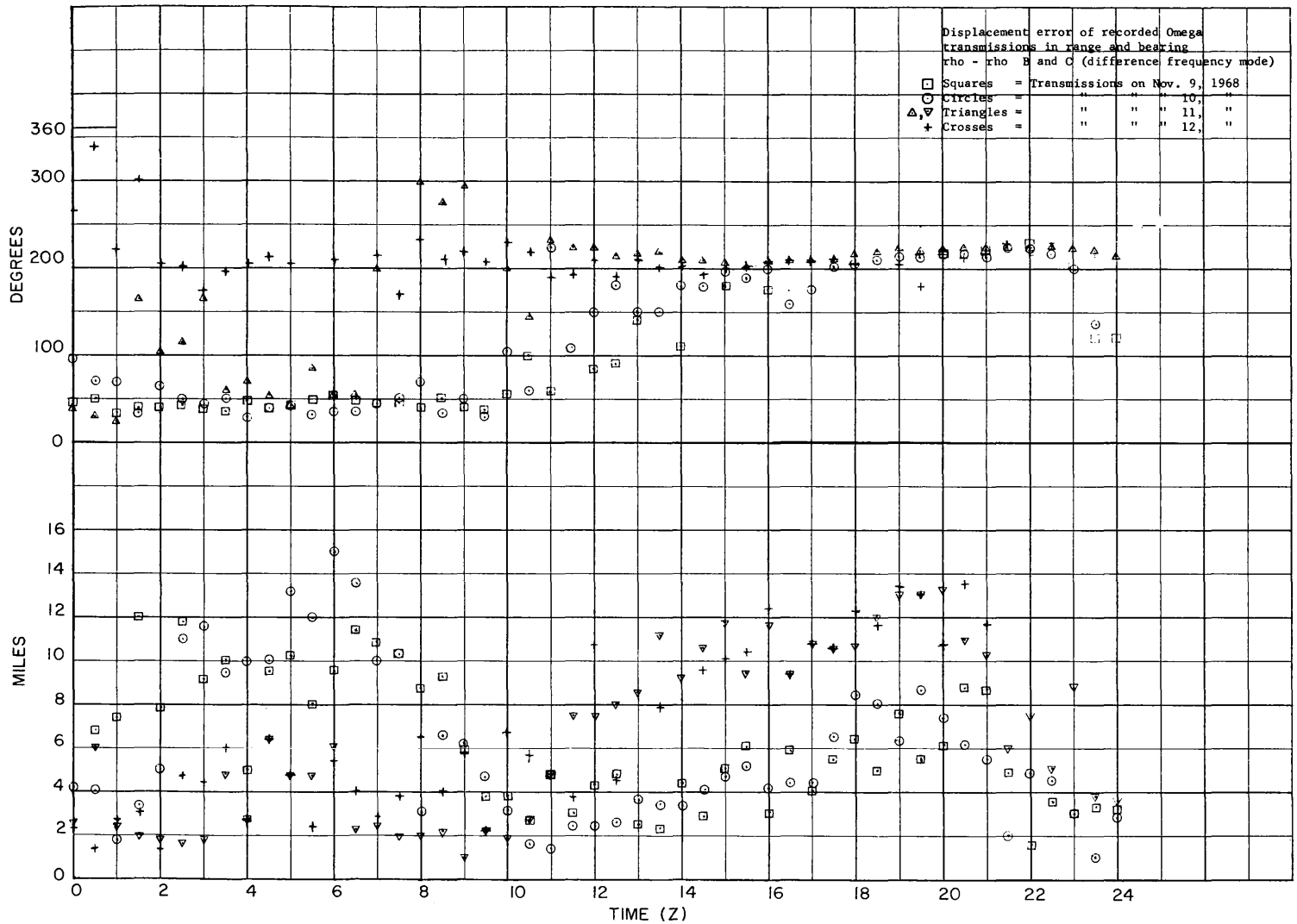

Displacement error of recorded Omega transmissions in range and bearing
rho - rho B and C (difference frequency mode)
Squares = Transmissions on Nov. 9, 1968
Circles = " " " 10, "
Triangles = " " " 11, "
Crosses = " " " 12, "
DEGREES
360
300
200
100
0
MILES
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (Z)

Figure 10

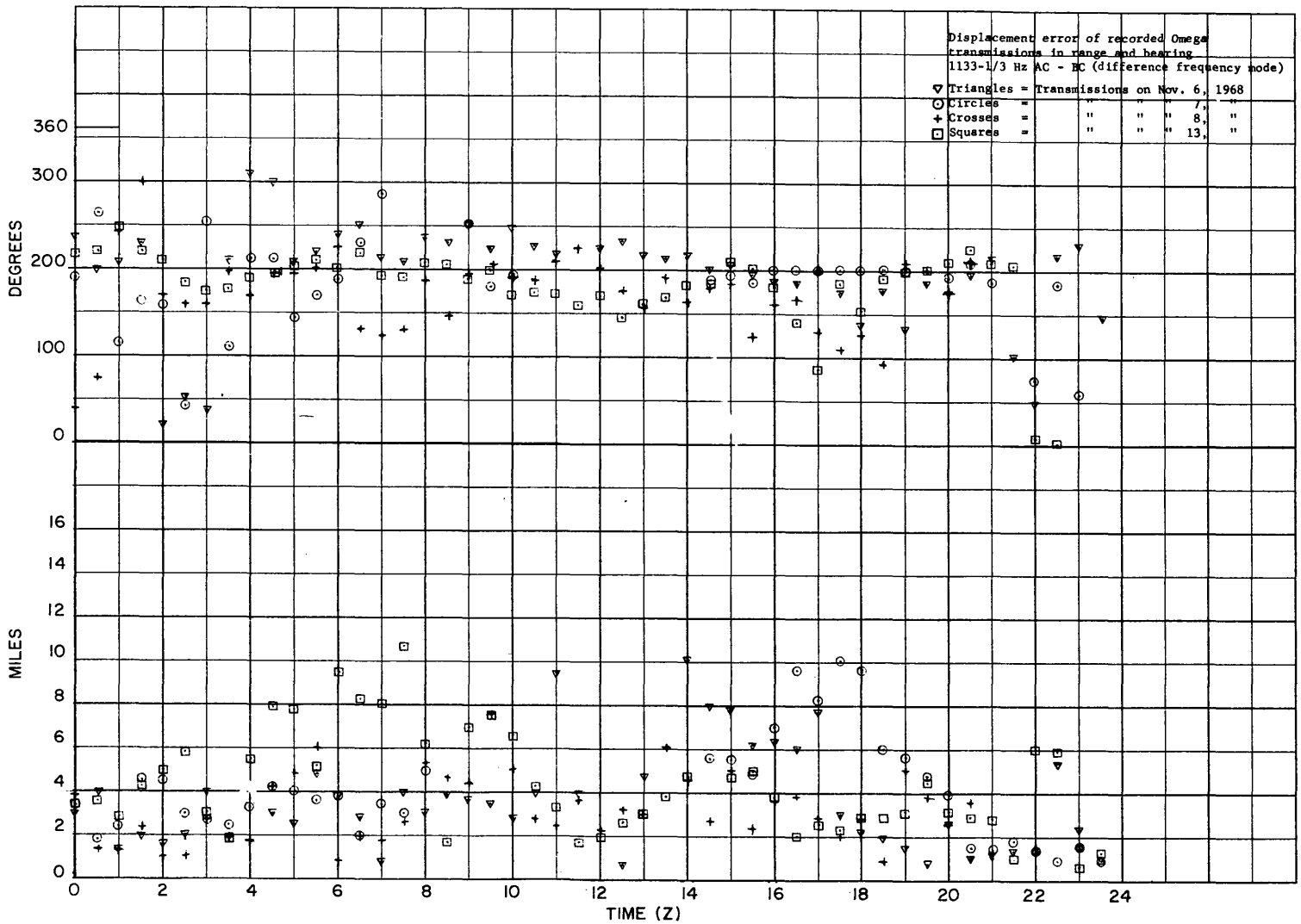

Displacement error of recorded Omega transmissions in range and bearing
1133-1/3 Hz AC - BC (difference frequency mode)
Triangles = Transmissions on Nov. 6, 1968
Circles = " " " 7, "
Crosses = " " " 8, "
Squares = " " " 13, "
DEGREES
360
300
200
100
0
MILES
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (Z)

Figure 11

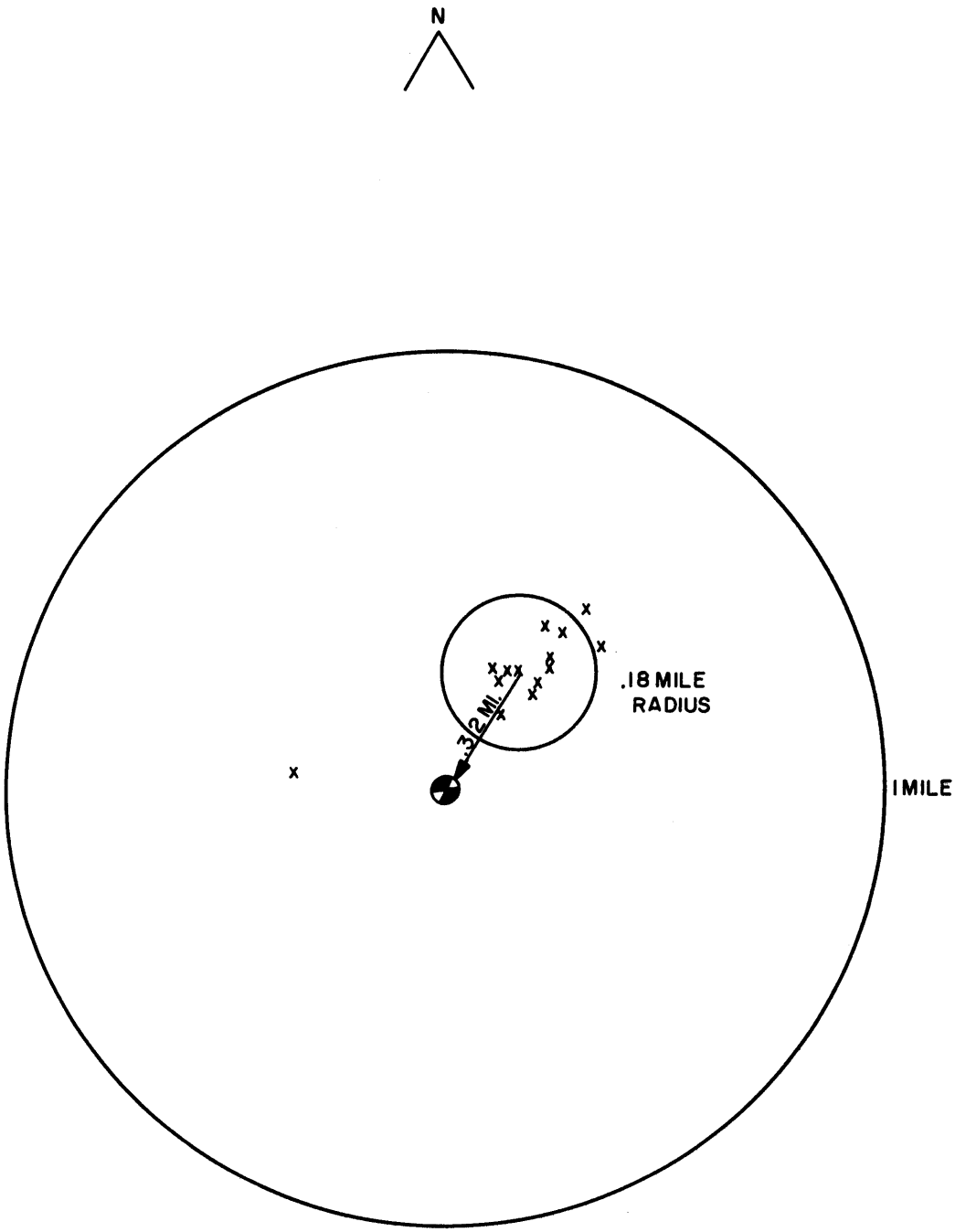


Fig. 12 - Differential Omega Errors, 20 August 1968

APPENDIX A

ACCEPTANCE TESTS OF THE MARK III

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LABORATORY TESTS

Laboratory tests of the NRL Mark III receiver were conducted at NRL previous to shipping the receiver to Lear-Siegler, Inc. for use in the testing of the Lear-Siegler Navigation Computer.

Testing of the Navigation Computer began in early June 1968. Laboratory tests included an engineering evaluation of the navigation computer, dynamic testing of the NRL Mark III receiver-computer package, environmental testing of the computer, and EMI-RFI testing of the complete receiver-computer package.

Engineering evaluation of the navigation computer yielded the following results in the laboratory using simulated rf signals and/or off-the-air signals.

1. 10.2 kHz Reception, No Noise, Circular Coordinate Mode: Phase measurement accuracy was better than $\pm$ 1 centicycle and latitude-longitude accuracy better than $\pm$ 2 minutes using the 2-minute time constant, type II digital servos.

2. 11-1/3 kHz Reception, No Noise, Circular Coordinate Mode: Phase measurement accuracy was better than $\pm$ 1 centilane (10.2) and latitude-longitude accuracy better than $\pm$ 0.2 minutes using the 2-minute time constant, type II digital servos.

3. Difference Frequency (1133-1/3 Hz) Reception, No Noise, Circular Coordinate Mode: Phase measurement accuracy was better than $\pm$ 10 centilanes (10.2) and latitude-longitude accuracy better than $\pm$ 1 minute using the 2-minute time constant, type II digital servos.

4. Dynamic Reception, No Noise, Circular Coordinate Mode: The 2-minute time constant, type II digital servos tracked within ± 1 centicycle with an 80 knot velocity aid input.

5. 10.2 kHz Reception, No Noise, Hyperbolic Mode: The hyperbolic LOP readouts were accurate to within ± 1 centilane using the direct digital measurement mode (very short bandwidth). Circular Coordinate outputs were accurate to within ± 1 centilane using the direct digital measurement mode.

6. 10.2 and 11-1/3 kHz reception, 0db S/N in a 1 Hz Bandwidth, Circular Coordinate Mode: The latitude-longitude accuracy was within ± 0.3 minutes using the type I digital servos.

7. 10.2 and 11-1/3 kHz reception, -20 db S/N in a 1 Hz Bandwidth, Circular Coordinate Mode: The latitude-longitude accuracy was within ± 1.0 minutes using the type I digital servos.

8. Dead Reckoning Ambiguity Light: The equipment was allowed to dead reckon on simulated avionics inputs. When the dead reckoning position disagreed with the Omega position by 3.5 miles, the DR AMBIG light came on.

9. Automatic Dead Reckoning Accuracy: The equipment was allowed to dead reckon on one LOP using simulated True Air Speed and Magnetic Heading inputs. After 10 minutes of operation the accuracy was better than ± 0.5% for both 10.2 kHz and difference frequency (1133-1/3 Hz) operation.

10. Autopilot Output: The autopilot voltages for indicated cross track errors on the computer were within ± 5% above 1 mile cross track error and ± 0.1 miles (0.0075 volts into 333 Ω load) below 1 mile cross track error.

11. Track Angle and Ground Speed: Ground Speed was computed to an accuracy of $\pm$ 4 knots and Track Angle to $\pm$ 1 degree using keyboard inserted inputs of True Air Speed, Wind Velocity, Wind Direction, Magnetic Heading and Magnetic Variation in the Dead Reckoning mode of computer operation.

12. True Air Speed - Magnetic Heading Positioning Accuracy: The computer was operated in the TAS mode of operation with externally simulated avionics inputs and the same accuracies as in (11) above were obtained.

13. Doppler Positioning Accuracy: Similar accuracies to (11) and (12) above were obtained using simulated Doppler signals with the computer in the DOP mode of operation.

14. Inertial Positioning Accuracy: Results similar to (11) above were obtained using simulated inertial signals with the computer in the INT mode of operation. Track Angle Conversion in this mode was precise to within input accuracy limitations.

15. Auxiliary Navigation Parameters: Range, Bearing, Cross Track Error and Course were checked for given insertions of Position Fix, Initial Position and Destination. Range at 80 miles was accurate to within $\pm$ 0.5 nautical miles. Bearing was accurate to within $\pm$ 0.5 minutes, Cross Track Error was accurate to within $\pm$ 0.25 nautical miles and Course was accurate to within $\pm$ 0.25 minutes.

16. True Air Speed Conversion: True air speed analogue to digital conversion accuracy was within $\pm$ 2 knots using simulated TAS inputs.

17. Loop Antenna Switching: Utilizing the self-test on the NRL Mark III loop antenna coupler, the antenna switching outputs of the computer were tested for proper station bearing outputs at several different simulated locations.

18. Self Test: The computer self test yielded the proper outputs under all tests performed; no failures in arithmetic operations occurred during tests.

19. Off-the-Air Operation: The Receiver-Computer operated satisfactorily with off-the-air signals on a 24 hour test. Analogue recorder outputs of the computer were checked for proper operation during this test. The Trinidad, Hawaii and New York signals all showed proper phase tracking.

20. Related Functions: All other "go" "no-go" type functions of the computer were checked for proper operation.

Environmental testing of the navigation computer yielded the following results.

1. Power Consumption: Power consumption of the computer and controller was measured to be less than 400 watts.

2. Power Variation: The computer and controller operated satisfactorily under conditions of voltage and frequency variation according to MIL-STD-704, Category C, transient limit 1.

3. High Temperature: The computer and controller operated satisfactorily during a heat soak of +55°C for 4 hours.

4. Low Temperature: The computer and controller were cold soaked at -54°C for 4 hours non-operating and met operational requirements after a 15-minute warm up. The glass on the controller readout cracked and was replaced. The computer and controller were cold soaked for 4 hours at -20°C and again at 0°C for 4 hours and met all operating requirements immediately after turn on.

5. Altitude: The computer and controller were subjected to pressures equivalent to altitudes of -1000 and 35,000 feet for 2 hours each and met operational requirements after these tests.

6. Vibration: The computer and controller were tested in accordance with MIL-E-5400 Class 1, Curve 1, Figure 5. The controller was hard mounted and the computer shock mounted. The controller was vibrated at .036" double amplitude from 5 to 500 cycles up to 2G. The computer was vibrated to 5G. The complete cycle (5-500-5) Hz required 15 minutes in each of 3 perpendicular planes. The navigation computer self test was continuously checked during the tests and the computer met operational requirements during and after the tests.

7. Humidity: The computer and controller were subjected to humidity per MIL-E-5422 for 3 days and at completion of the test met operational requirements.

8. Radio Noise Interference: Tests were conducted on the entire Mark III Receiver-Computer package in accordance with MIL-I-6181. The package itself met operational requirements during these tests but radiated excessive noise from the interconnecting cables which were made up at NRL. Shielding these cables would solve this problem if the radiation were found objectionable in a given aircraft.

SHAKEDOWN FLIGHT TESTS

The NRL EC121K flight test aircraft was flown to Kent County Airport, Grand Rapids, Michigan, for installation of the Mark III navigation set on 8 July 1968. Mounting racks and the crossed-loop and aft-lower-vertical antenna were installed previously. During the flight to Michigan the antennas were tested for proper reception and correct relative phasing with the NRL Mark II Omega receiver. Installation and aircraft equipment interfacing of the Mark III (Fig. 1) were completed during the morning of 9 July and the equipment was checked for proper operation on the ground during the evening of 9 July 1968. The equipment was interfaced with the T349/APA57B True Air Speed transmitter and N1 Magnetic Compass on board the aircraft for velocity aid information.

The shakedown flight test route (Fig. A1) was a closed route between the following short range, highly accurate navigational aids:

Facility	Type Navigational Aid
Kent County Airport	Survey (on ground)
Grand Rapids	VOR
Pullman	VORTAC
Kalamazoo	VOR
Battle Creek	VORTAC
Jackson	VOR
Lansing	VOR

The Mark III accuracy figures in Tables A1 through A3 tabulate the magnitude and directions of the radial offset indicated by the Mark III during visual overflights of the navigational aids.

The first shakedown flight was performed on 10 July 1968. During the first circuit of the course the computer was operated using the Trinidad-Hawaii and Trinidad-New York lines of position, the 10.2 kHz, single frequency, hyperbolic mode of operation, the 2-minute time constant servos (bandwidth "3") and the vertical antenna. Navigation was well within expected system accuracy; the Latitude-Longitude, Cross Track Error, True Air Speed, Magnetic Heading, and Range and Bearing outputs of the computer all operated satisfactorily.

During the second circuit the computer was operated in the difference frequency (1133-1/3 Hz) mode with the other computer settings the same. Diurnal shift corrections were not utilized. During the flight, the Hawaii signal went into automatic dead reckoning due to low signal-to-noise ratio. After 25 minutes the signal was recovered with no lane loss. All navigation was well within expected system accuracy (less than 10 miles in the difference frequency mode). However, after a refueling stop at Selfridge Air Force Base, the computer read-write memory lost several words during power switchover from ground power to aircraft power and no further data was collected on this flight.

During the afternoon of 10 July and morning of 11 July, Lear-Siegler installed computer power supply modifications to prevent loss of read-write memory during aircraft power variations as experienced on the previous flight. The modifications appeared to correct the malfunction.

The next shakedown flight was performed during the afternoon of 11 July. During this test, the 2-minute time constant servos (bandwidth "3"), the crossed loop antenna, and the circular mode of operation (Trinidad and Hawaii lines-of-position) were tested in both 10.2 kHz carrier and difference frequency modes of operation. All navigation was satisfactory. However, track of the Hawaii signal was again lost for several brief periods, apparently due to low signal-to-noise ratio.

July 12 was spent determining and inserting read-write-memory words in order to set the bandwidth "2" servo operation to a 5-minute time constant, type II servo with appropriate amplitude detector time constants and signal cut-out levels for more sensitive tracking of the Omega signals. The need for this was evidenced by the losses of the Hawaii signal during the first two shakedown flights.

On 13 July, a shakedown flight was performed utilizing the Modified Bandwidth "2" servos, the vertical antenna, and the hyperbolic 10.2 kHz carrier mode of operation. The servos performed with higher sensitivity and normal navigation was satisfactory. However, when the antenna was disconnected for automatic dead reckoning tests, the servos immediately went into a search rather than a dead reckoning mode. This was due to an error in the setting of one of the memory constants and was corrected at the end of the flight.

During the final shakedown flight on 14 July, the Bandwidth "2" and Bandwidth "3" servos were both tested for proper operation and the antenna was removed several times for automatic dead reckoning tests. All computer functions now appeared to be operating satisfactorily.

The NRL aircraft returned to Patuxent NAS on 15 July. The Mark III was operated with the crossed-loop antenna, the 10.2 kHz carrier frequency, and in the hyperbolic mode using

the Bandwidth "2" (5-minute time constant) servos. Omega Navigation was compared with enroute airways navigational aids over the entire flight and operated satisfactorily. The Norway signal was tracked after crossing the Appalachian Mountain chain.

Detailed results of the shakedown flights and return flight to Patuxent NAS are summarized in Tables A1 through A3. RMS Omega navigation errors were 1.04 nautical miles during daytime propagation of the Omega signals and 1.10 nautical miles during nighttime and transition periods in the 10.2 kHz carrier mode of operation using published phase corrections. RMS errors were 2.74 nautical miles (daytime) and 10.10 nautical miles (night and transition) in the carrier difference (1133-1/3 Hz) mode of operation without phase corrections.

The demonstration flights and local test flights during the months of August and September 1968 revealed the desirability of two additional devices to aid the Mark III operation and evaluation tests. A Course Deviation Indicator (CDI) displaying cross track error and steering direction was designed for cockpit display. This indicator processed the autopilot steering data from the computer for remote use by the NRL aircraft pilots. An illustration and schematic of the Omega CDI are shown in Figures A2 and A3. In addition, an antenna phasing and switching unit was designed and constructed in order that the crossed loop and vertical antenna inputs to the Omega receiver could be interchanged in flight without affecting the signal tracking of the servos. This proved a valuable aid in evaluating the relative performance of the vertical and loop antennas under precipitation conditions. An illustration and schematic of the antenna phasing and switching unit are shown in Figures A4 and A5.

Table A1
10.2 kHz OMEGA-SHAKEDOWN FLIGHT TESTS

FACILITY	DATE (JULY)/TIME	N-S ERROR (NMI)	E-W ERROR (NMI)	RADIAL ERROR(NMI)	MODE
GRR	10/1520 Z	0.51 S	0.56 E	0.76	Hyperbolic
"	10/1615 Z	1.01 S	0.54 E	1.15	"
"	10/1715 Z		NO FIX		"
"	11/2110 Z	1.08 S	0.50 W	1.19	Rho-Rho
"	11/	0.07 N	0.32 W	0.33	"
"	13/1525 Z	0.86 S	0.84 E	1.19	Hyperbolic
"	13/1904 Z	0.31 S	0.11 W	0.33	"
"	14/1505 Z	0.31 S	0.54 E	0.62	"
"	14/1559 Z	0.67 S	1.07 E	1.26	"
"	14/1651 Z	0.69 S	0.63 E	0.94	"
"	14/1743 Z	0.40 S	0.01 E	0.40	"
PMM	10/1530 Z	0.56 S	0.25 E	0.61	"
"	10/1627 Z	0.32 S	0.62 E	0.70	"
"	10/1727 Z	0.40 S	0.22 W	0.46	"
"	11/2100 Z	0.28 S	0.13 W	0.31	Rho-Rho
"	11/	1.44 N	0.47 E	1.51	"
"	13/1535 Z	0.57 S	0.48 E	0.74	Hyperbolic
"	13/1915 Z	0.61 S	0.59 E	0.85	"
"	14/1515 Z	0.59 S	1.21 E	1.33	"
AZO	10/1540 Z	0.35 S	0.30 W	0.46	"
"	10/1637 Z	0.74 S	0.06 W	0.74	"
"	11/	0.38 N	1.00 W	1.07	Rho-Rho
"	11/	0.86 N	0.85 W	1.21	"
"	13/1429 Z	0.06 N	0.39 W	0.40	Hyperbolic
"	13/1544 Z	0.04 S	0.88 W	0.97	"
"	13/1923 Z	0.82 N	1.79 W	1.96	"
"	14/1524 Z	0.22 S	0.87 W	0.90	"
"	14/1617 Z	0.21 S	0.33 W	0.38	"
"	14/1709 Z	0.32 N	0.67 W	0.74	"
BTL	10/1545 Z	0.60 S	0.13 W	0.61	"
"	10/1643 Z	0.65 S	0.25 E	0.70	"
"	11/	0.14 S	0.89 W	0.90	Rho-Rho
"	11/	1.28 N	0.50 W	1.37	"
"	13/1434 Z	0.93 S	0.58 W	1.10	Hyperbolic
"	13/1549 Z	0.69 S	1.03 W	1.24	"
"	13/1927 Z	0.43 S	2.32 W	2.36	"
"	14/1528 Z	1.09 S	0.95 W	1.68	"
"	14/1621 Z	0.58 S	0.35 E	0.68	"
"	14/1713 Z	0.84 S	0.63 W	1.05	"
JAX	10/1550 Z	0.01 N	0.18 W	0.18	"
"	11/	0.92 N	0.25 W	0.95	Rho-Rho
"	11/	1.83 N	0.64 W	1.94	"

Table A1 (Continued)

FACILITY	DATE (JULY)/TIME	N-S ERROR (NMI)	E-W ERROR (NMI)	RADIAL ERROR(NMI)	MODE
JAX	13/1443 Z	0.16 S	0.54 W	0.56	Hyperbolic
"	13/1507 Z	0.61 S	1.46 E	1.54	"
"	14/1538 Z	0.11 S	0.19 W	0.22	"
"	14/1630 Z	0.65 N	0.01 E	0.65	"
"	14/1723 Z	0.54 N	0.16 W	0.58	"
LAN	10/	0.01 S	0.14 W	0.14	"
"	10/1705 Z	0.54 S	0.17 E	0.57	"
"	11/	0.01 S	0.18 E	0.18	Rho-Rho
"	11/	1.01 S	0.46 E	1.11	"
"	13/1515 Z	1.64 S	0.97 E	1.90	Hyperbolic
"	13/1607 Z	0.67 S	0.03 E	0.67	"
"	13/1853 Z	0.37 S	0.18 E	0.41	"
"	14/1548 Z	1.16 S	1.24 E	1.70	"
"	14/1640 Z	0.77 S	0.86 E	1.16	"
"	14/1732 Z	0.54 S	0.48 E	0.72	"

Table A2
RETURN FLIGHT GRAND RAPIDS - PAX RIVER NATC 10.2
kHz HYPERBOLIC OMEGA ERRORS, 15 JULY 1968

FACILITY	TIME (Z)	RANGE ERROR (NMI)	BEARING (DEGREES)
LANSING	1534	0.32	236.6
JACKSON		NO FIX	
WATERVILLE	1556	2.03	126.0
ATTICA	1605	1.88	118.0
MANSFIELD	1611	1.05	136.5
BRIGGS	1624	1.36	066.5
WHEELING	1636	2.23	092.1
GRANTSVILLE	1651	NO FIX	
FRONT ROYAL	1710	1.72	327.6
LINDEN	1714	0.38	139.0
BROOKE	1728	0.24	305.8

Table A3
1.133-1/3 kHz OMEGA (NO PHASE CORRECTIONS) -
SHAKEDOWN FLIGHT TESTS

FACILITY	DATE (JULY)/TIME	N-S ERROR (NMI)	E-W ERROR (NMI)	RADIAL ERROR (NMI)	MODE
GRR	10/1810 Z	1.20 S	3.90 E	4.07	Hyperbolic
"	11/	5.93 S	7.56 W	9.55	Rho-Rho
"	11/	7.65 N	0.67 E	7.65	"
"	12/0125 Z	2.02 N	0.06 W	2.02	"
PMM	10/1819 Z	0.50 S	6.50 E	6.50	Hyperbolic
"	11/	1.29 S	2.09 W	2.45	Rho-Rho
"	12/0100 Z	8.25 S	2.66 W	8.65	"
AZO	10/1735 Z	2.30 N	1.26 W	2.62	Hyperbolic
"	10/1829 Z	3.20 N	1.12 E	3.38	"
"	11/	9.56 S	8.82 W	13.00	Rho-Rho
"	12/	8.85 S	2.94 W	9.30	"
BTL	10/1738 Z	0.90 N	2.00 W	2.18	Hyperbolic
"	10/1833 Z	3.20 N	2.16 E	3.86	"
"	11/	6.73 S	7.07 W	9.76	Rho-Rho
"	12/	14.18 S	5.69 W	15.25	"
JAX	10/1729 Z	0.30 N	0.52 W	0.60	Hyperbolic
"	10/1844 Z	3.40 N	0.52 W	3.44	"
"	11/	4.33 S	3.42 W	5.52	Rho-Rho
"	12/	7.57 S	6.93 W	10.30	"

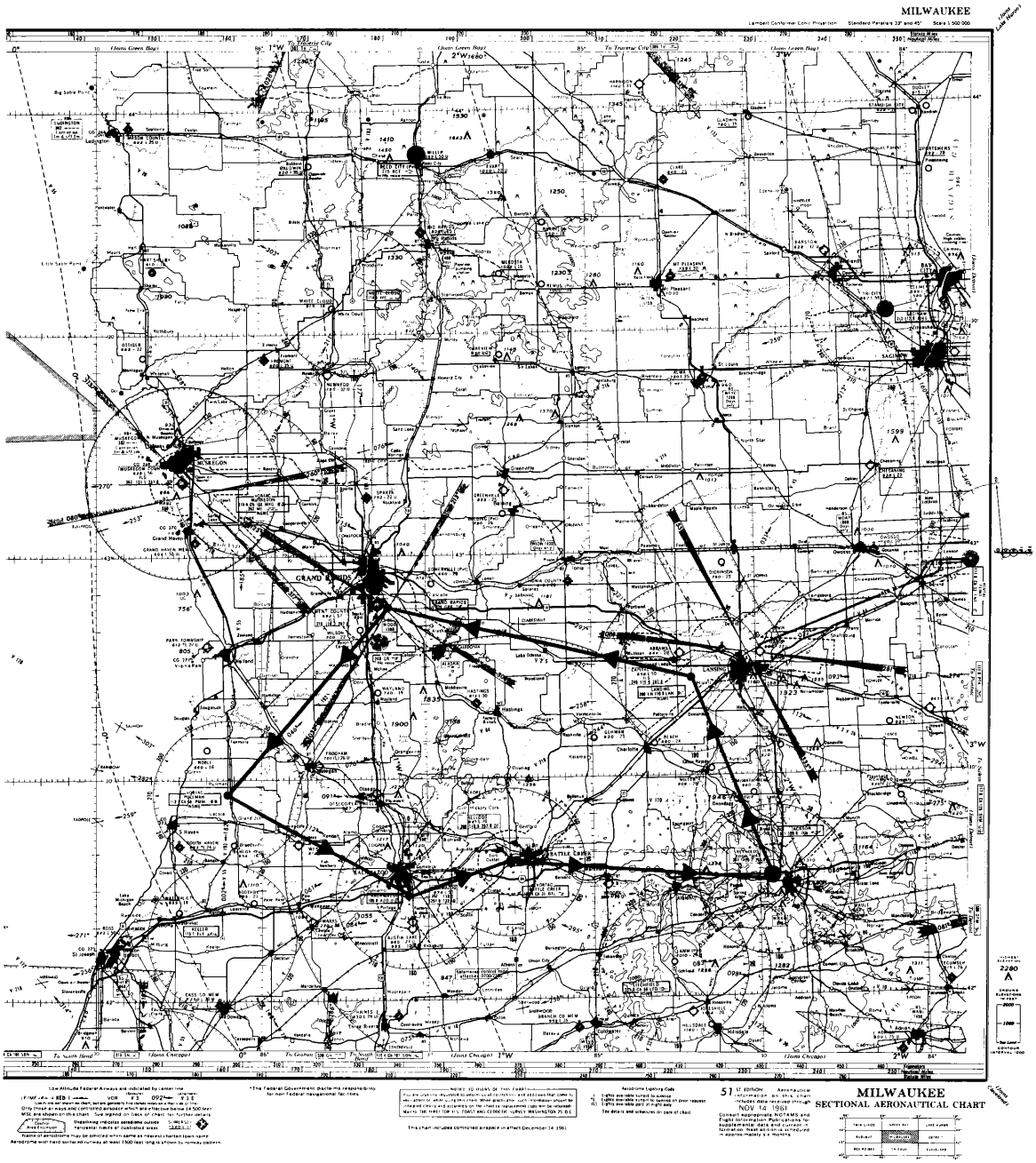

Fig. A1 - Shakedown Flight Test Route

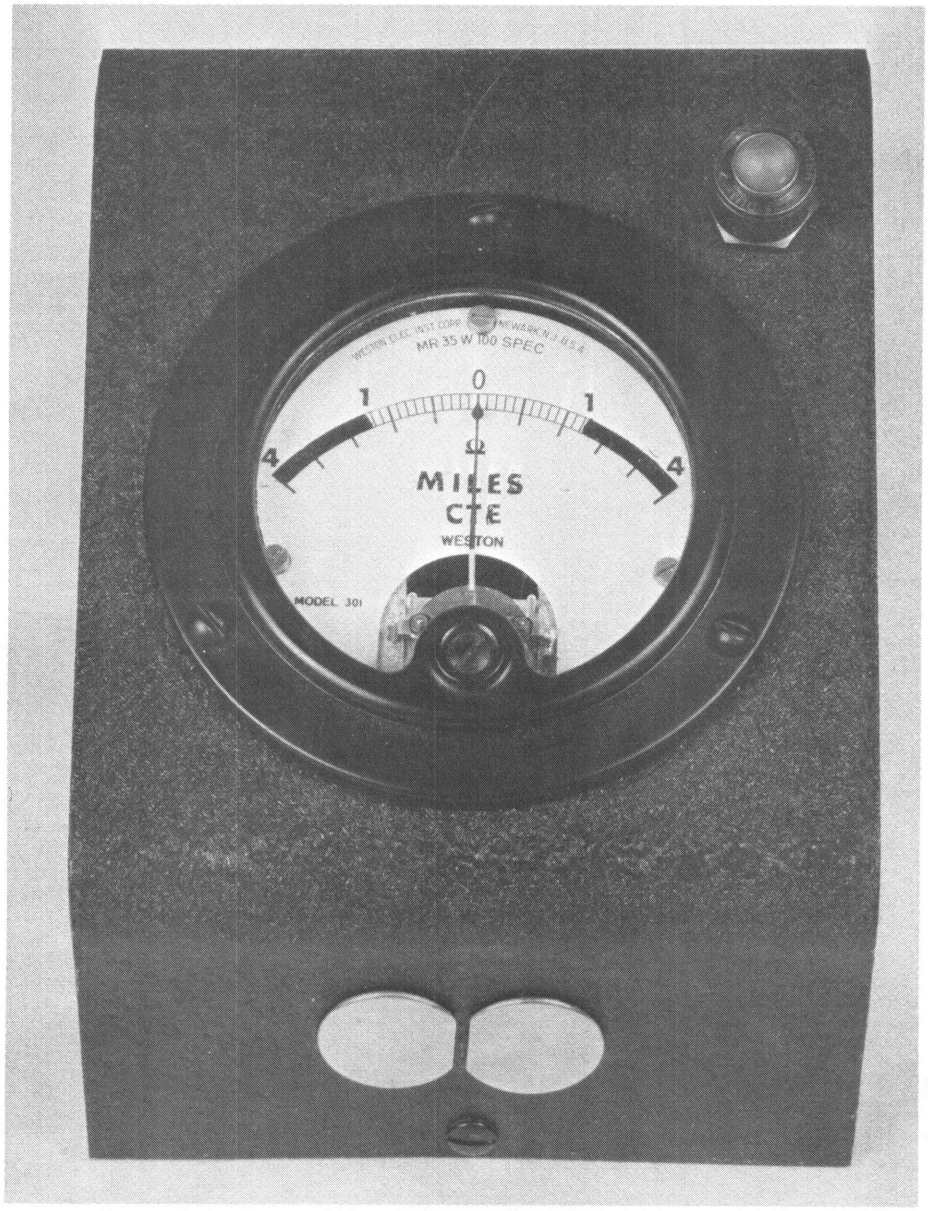

Fig. A2 - Mark III Course Deviation Indicator

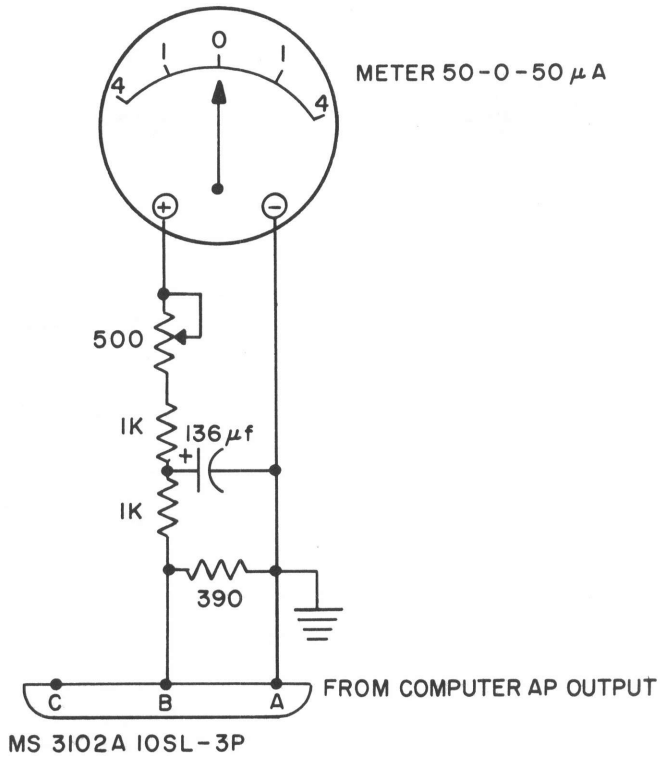

Fig. A3 - Mark III Course Deviation Indicator Schematic Diagram

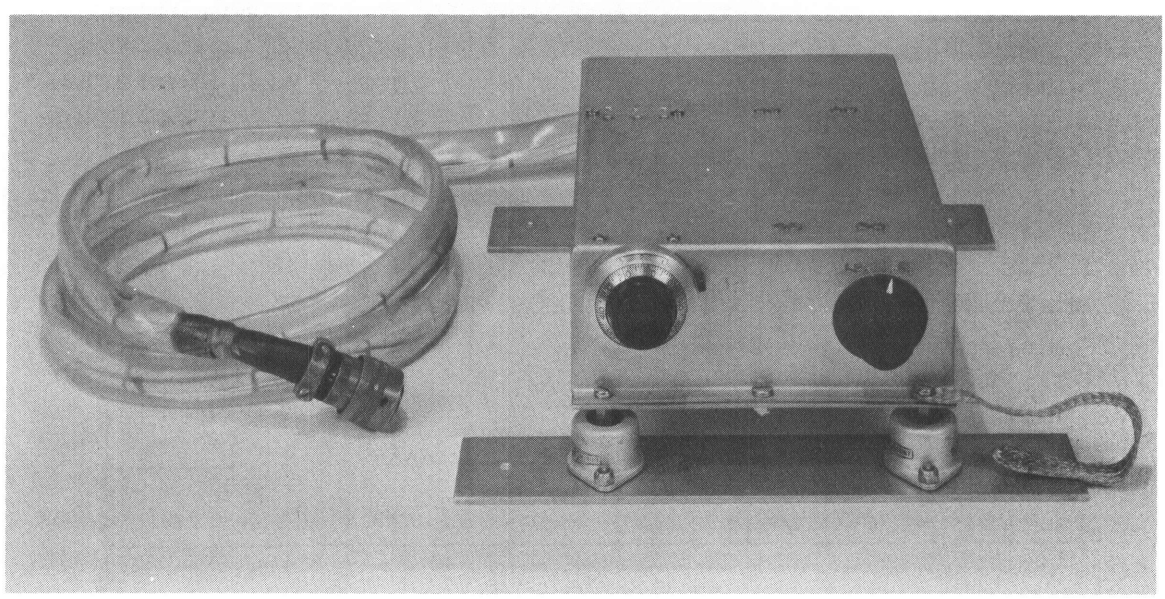

Fig. A4 - Mark III Antenna Switching and Phasing Unit

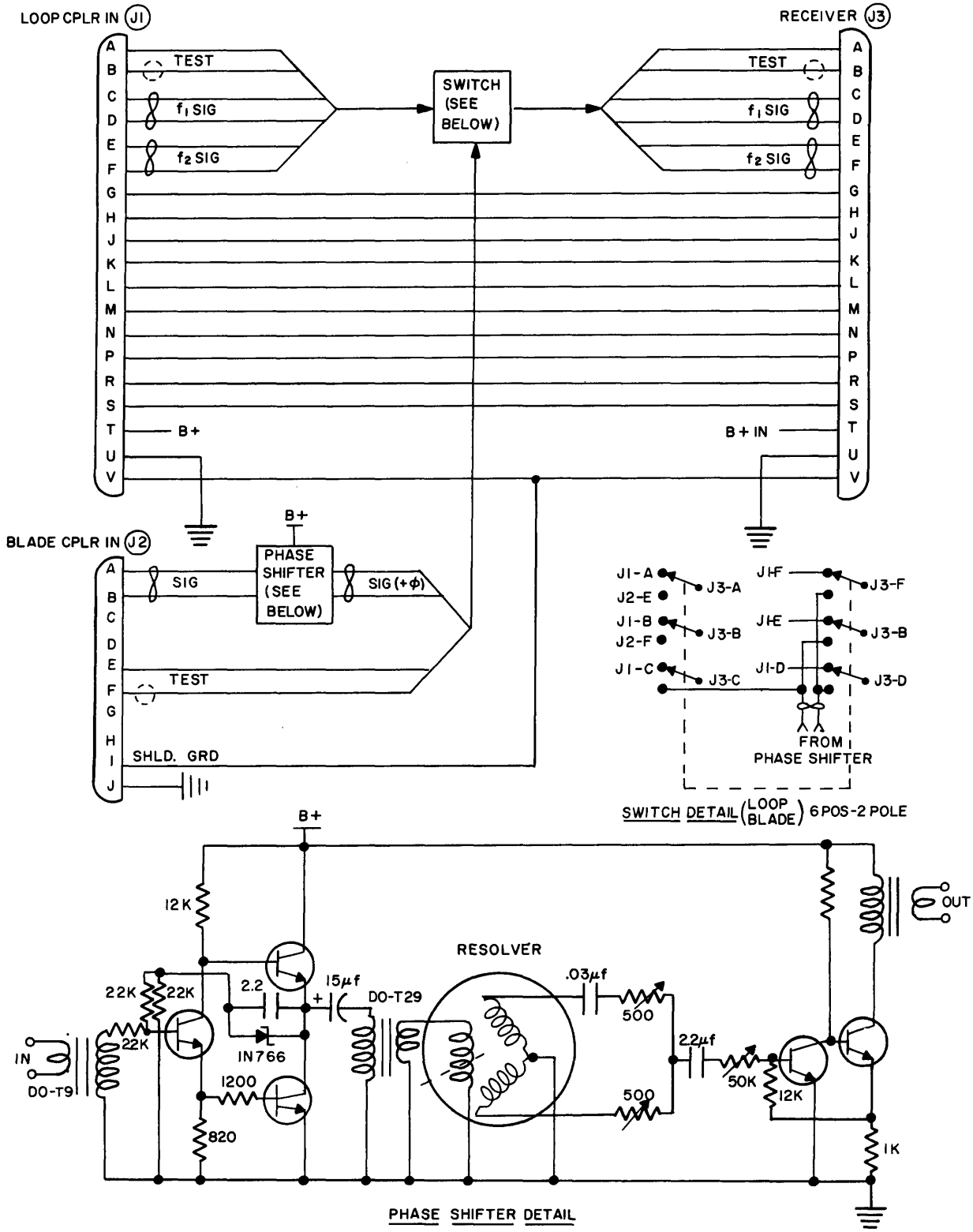

Fig. A5 - Antenna Switching and Phasing Unit Schematic Diagram

APPENDIX B

METHODS OF COMPUTING STATISTICAL ACCURACY

1. Mathematical Conversions

a. Method of converting Latitude-Longitude differences to Range and Bearing:

$\overline{LAT}$ = LATITUDE (Degrees)

$\overline{LONG}$ = LONGITUDE (Degrees)

$\overline{\Delta LAT}$ = LATITUDE DIFFERENCE (Minutes)

$\overline{\Delta LONG}$ = LONGITUDE DIFFERENCE (Minutes)

$$\Delta x = \overline{\Delta LONG} \cdot \overline{COS\ (LAT)} \text{ (NMI)}$$

$$\Delta y = \overline{\Delta LAT} \text{ (NMI)}$$

$$\underline{RANGE} = \sqrt{\Delta \bar{x}^2 + \Delta \bar{y}^2} \qquad \text{(See Figure B1)}$$

$$\underline{BEARING} = \theta = -TAN^{-1}\left(\frac{\Delta x}{\Delta y}\right) + 360n$$

where n = 0 or 1 and

$$-180° \leq TAN^{-1}\left(\frac{\Delta x}{\Delta y}\right) \leq +180°$$

b. Method of computing RMS errors from Latitude-Longitude Differences:

$$\text{RMS ERROR (NMI)} = \sqrt{\frac{\sum_{i=1}^{N} (\Delta x_i)^2 + \sum_{i=1}^{N} (\Delta y_i)^2}{N}}$$

Where N = the number of data points and Δx_i and Δy_i are computed as in (a) above.

c. Method of computing σ distribution (RMS error about mean offset) from Latitude-Longitude Differences:

$$\bar{x} = \frac{\sum_{i=1}^{N} \Delta x_i}{N}$$

$$\bar{y} = \frac{\sum_{i=1}^{N} \Delta y_i}{N}$$

as in (a,b) above

$$\text{MEAN OFFSET RANGE} = \sqrt{\bar{x}^2 + \bar{y}^2}$$

$$\text{MEAN OFFSET BEARING} = \text{TAN}^{-1}\left(\frac{\bar{x}}{\bar{y}}\right) + 360n$$

where n = 0 or 1 and $-180° \leq \text{TAN}^{-1}\left(\frac{\bar{x}}{\bar{y}}\right) \leq 180°$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (\Delta x_i)^2 + \sum_{i=1}^{N} (\Delta y_i)^2}{N} - \left(\bar{x}^2 + \bar{y}^2\right)}$$

d. Method of computing RMS errors from MARK III <u>RANGE</u> and <u>BEARING</u> ERROR READOUT:

$$\begin{aligned} \text{RANGE} &= R \text{ (NMI)} \\ \text{BEARING} &= \theta \text{ (degrees)} \\ \Delta x &= R \sin\theta \\ \Delta y &= R \cos\theta \end{aligned}$$

$$\underline{\text{RMS RANGE ERROR (NMI)}} = \sqrt{\frac{\sum_{i=1}^{N} (\Delta x_i)^2 + \sum_{i=1}^{N} (\Delta y_i)^2}{N}}$$

where N is as in (b) above.

e. Method of computing σ distribution (RMS error about mean offset) from MARK III RANGE and BEARING ERROR READOUT:

same as in (c) above with Δx_i and Δy_i computed as in (d) above.

2. Special Computations for Circular Coordinate Difference Frequency Monitor Data

Apparently due to the effects of long term master oscillator drift (Rubidium Frequency Standard), the circular coordinate monitoring data of 9, 10, 11 and 12 November 1968 appeared to drift in position over the 4-day period. In actual flight operations this offset is removed by the oscillator correction on the Mark III navigation computer.

In order to remove the effects of long term oscillator drift during this test the σ error was calculated 3 times during each 24-hour period and the offset removed from each calculation. For daytime accuracies (1600-2130 GMT) the offset was removed and the RMS error for each day was calculated as in Appendix 1. σ for daytime data was then calculated as:

$$\sqrt{\frac{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \sigma_4^2}{4}} = \underline{4.43 \text{ miles}}$$

where $\sigma_1 \ldots \sigma_4$ were the RMS accuracies for each day.

The nighttime and transition data was divided into two periods (2200-0630 GMT and 0700-1530 GMT) and the overall nighttime and transition period σ was calculated as:

$$\sqrt{\frac{\sum_{i=1}^{8} \sigma_i^2}{8}} = \underline{4.43 \text{ miles}}$$

where σ_i = the RMS error as in (1e) above for each period.

Graphs of the raw data are shown in Figure 10. Of additional importance is the sigma distribution of the night-day and day-night transition offsets. These were computed by taking $\Delta\bar{x}$ and $\Delta\bar{y}$ for the offsets computed for each day-to-night and night-to-day period, taking the mean of the offsets and computing the RMS deviation about the mean. The mean night-to-day transition offset was 6.00 miles at 42 degrees with an RMS variation of 1.94 miles. The average day-to-night transition

offset was 8.35 miles at 217° with an RMS variation of 1.53 miles. Thus position accuracy in the circular coordinate, difference frequency mode without diurnal corrections is strongly dependent on when the position update is performed. It may be noted that use of diurnal corrections would reduce these offsets considerably. The effect of diurnal variation on circular coordinate mode of operation is much greater than on hyperbolic (in the difference frequency mode).

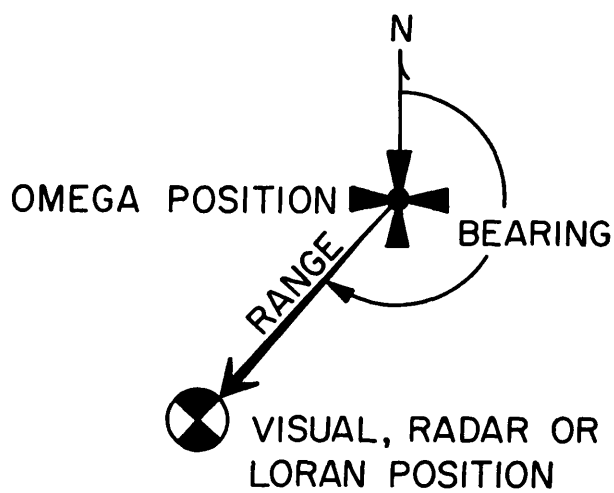

Fig. B1 - Error of Omega Position in Range and Bearing

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13. ABSTRACT

The Naval Research Laboratory has developed the Mark III aircraft receiver for use with Omega, a very low frequency radio navigation system characterized by a worldwide capability and an accuracy with respect to earth coordinates of one to two miles.

The Mark III equipment, which is the third Omega aircraft system designed and developed by NRL, consists of a crossed-loop antenna system, a receiver, a timing system and a navigation computer which generates continuous outputs including latitude-longitude, bearing and distance to a destination, and cross track error.

Evaluation flights of the Mark III were made in an NRL EC121K aircraft over the continental United States, the North Atlantic, the Pacific and the Caribbean. Omega was used as the primary navigation mode on overwater portions of the flights with a Course Deviation Indicator providing continuous steering information to the pilots. In the 10.2 kHz carrier mode, the system provided RMS in-flight accuracies of approximately one mile during daylight and better than two miles during night and transition periods. In the 1133-1/3 Hz, wide lane, carrier difference mode the system provided RMS in-flight accuracies of better than 10 miles without utilizing corrections for shift in propagation.

Abstract (Continued)

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Omega Navigation System						
Aircraft Navigation Receiver						
Omega Aircraft Navigation Receiver						
Long Range VLF Aircraft Navigation						
Loop Antenna System for Aircraft						
Precipitation Static in Aircraft (VLF)						

At landfall after six long overwater flights the average deviation of the Omega fixes from short range, shore based navigation system fixes was 1.4 miles in range and one degree in bearing.

The ability of the system to provide continuous navigation under heavy precipitation static conditions by utilizing a crossed-loop antenna was confirmed by the uninterrupted Omega tracking during a three-hour flight through a North Atlantic storm when other radio navigation and communications systems failed.

At the termination of the NRL evaluation flights the Mark III had operated over 1700 hours with only one disabling component failure.