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# OPERATIONAL EVALUATION of an AIRBORNE OMEGA NAVIGATION SYSTEM

## VOLUME I
## BACKGROUND AND RESULTS

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**October 1973**

**Final Report**

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16. Abstract

This report covers the evaluation of the Omega Navigation System for aircraft utilization on routes traversing the North Atlantic from the East coast of the United States to Europe. The user equipment was a commercial version of the AN/ARN-99 which is an automatic computerized Omega receiver designed for airborne use and was installed on a DC-8 type aircraft. The principal areas of interest in this evaluation were operational utility, signal reliability and track comparison with other aids available. The Omega system demonstrated its ability to provide smooth bounded position information in a varying and somewhat limited signal environment due to a transitional transmitter configuration.

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## PREFACE

The Systems Research and Development Service section of the Federal Aviation Administration has been actively sponsoring projects using Omega to determine its potential as a reliable error-bounding system for oceanic areas.

This report presents the results of an operational evaluation of Omega as it would be used in its basic form. With the transmitters still being in a development status during the period of this evaluation, the purpose was not to determine accuracy but to explore the areas of operational suitability, signal coverage, signal reliability, equipment installation considerations, as well as position comparison with other available navigation references.

The equipment utilized on this project was an AN/ARN-99 Airborne Omega Navigation Set provided by the Northrop Corporation, which was installed on a charter aircraft provided by World Airways, Inc., which made regular crossings of the North Atlantic ocean.

The technical monitor for this project was George Quinn of FAA, Washington. Technical support was provided by W. Molesworth and F. A. Eide also of FAA, at San Francisco International field office. The project engineer at Northrop was R. C. Sanders. The principal technical contributor was R. Latchford. Other technical contributors were A. Eldridge, E. Smith, P. Prelitz, and R. Ohnersorgen. Special thanks are accorded to D. Larson, K. Healy and L. Wuth, and all participating flight personnel of World Airways, Inc. for their help and understanding during this endeavor. Also, appreciation is expressed to the station agents at the many WOA ground operations who were so considerate.

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# I. INTRODUCTION

The FAA and Northrop entered into a contract in June 1971 for an operational flight evaluation of Omega signal coverage, and its effect on navigational accuracy, in the North Atlantic area. The test aircraft was a World Airways DC-8-63F (WA#802). The aircraft is one which operates a great deal of the time over the desired test routes between eastern North America and western Europe. The navigation system used in the test program was a Northrop provided AN/ARN-99 Omega Navigation Set. The flights were conducted over a period from Jan. 1972 to July 1973. During this time various Omega station configurations were operational. Omega signal and navigational data were acquired on a total of 35 flights over the North Atlantic routes.

The organization of this report is as follows:

Section 2 is a brief summary of the navigational results during the test program.

Section 3 presents a description of the Omega System in general and a description of the AN/ARN-99 Omega Navigation Set.

Section 4 describes the installation of the equipment in the aircraft.

Section 5 discusses the type of data acquired and method of error measurement.

Section 6 describes the performance experienced under different Omega station configurations.

Section 7 presents the navigational results of the flights in table and chart form, and also discusses fix update capability and Greenland overflights.

Section 8 presents conclusions.

Section 9 presents recommendations.

## II. SUMMARY

Signal coverage from the existing Omega stations varied during the period of the test program. These variations were caused by changes in the number of stations transmitting, geographic location, and power output. The coverage from 3 stations, necessary to ensure accurate navigation, ranged from inadequate to marginal to adequate. On 26 of the 35 flights coverage from 3 stations was considered adequate for acceptable navigational performance. The mean error at landfall or gateway points was 2.3 miles on these 26 flights, and the standard deviation was 1.6 miles. The last 19 of these 26 flights were made after replacement of an antenna which had developed an intermittent problem. The mean landfall error on the latter 19 flights was 1.8 miles, and the standard deviation was 1.3 miles.

# III. SYSTEM DESCRIPTION

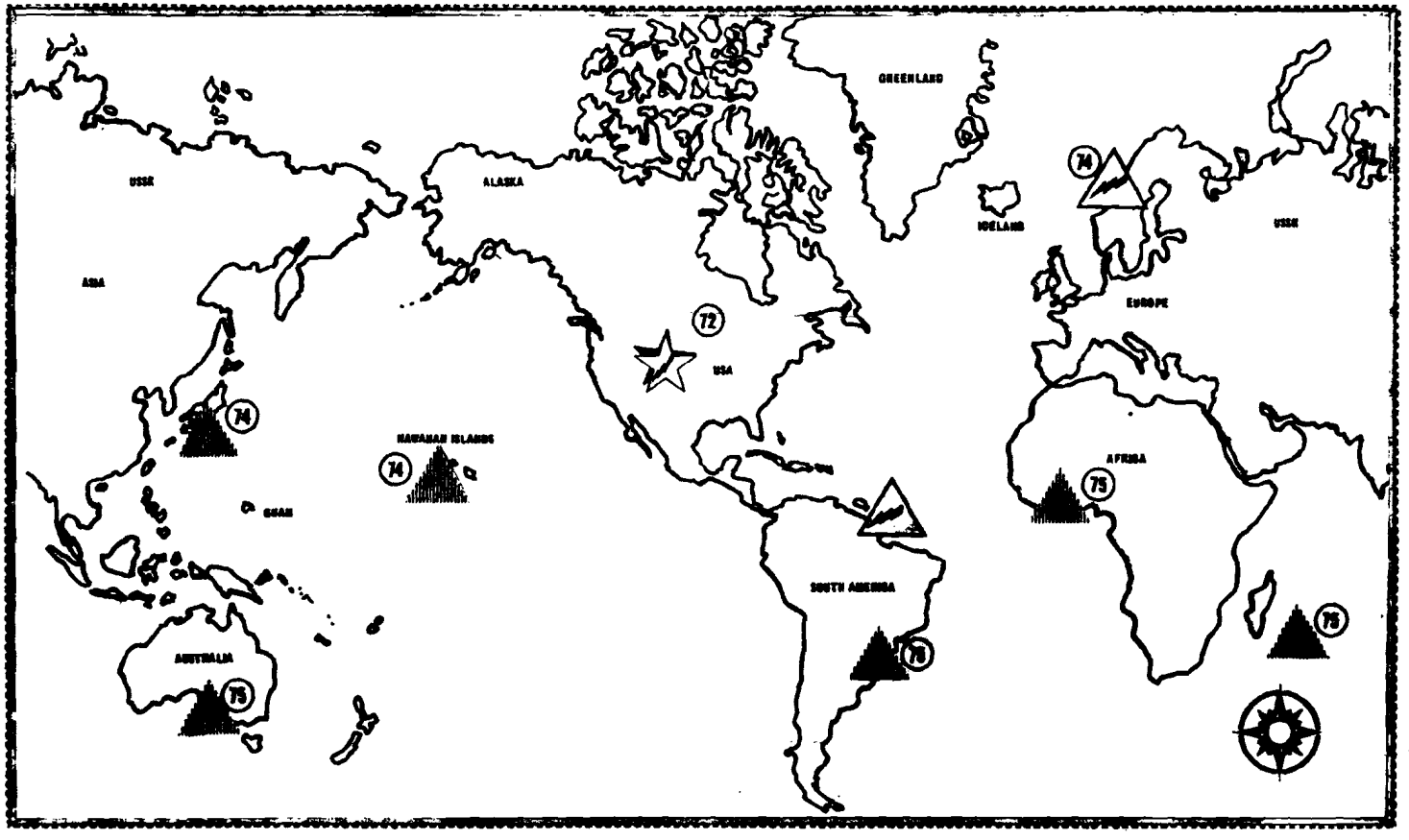
## 3.1 OMEGA System

OMEGA is a radio navigation system which uses 8 broadcasting transmitters located around the world. Figure 3.1 shows the location of these 8 stations. This description assumes a full OMEGA net although all stations are not yet operational. Figure 3.2 shows the current status of the 8 stations.

Each of the eight stations transmits a sequence of three continuous wave (cw) pulses, hereafter referred to as "bursts". The first burst is transmitted at 10.2 kHz, the second at 13.6 kHz and the third at 11-1/3 kHz. The duration of each burst is about one second; specifically the total span of a burst varies between 0.9 and 1.2 seconds with a non-transmission time between bursts of 0.2 second. After the third burst the station will not transmit navigation signals for about 6 1/2 seconds. This Omega transmission pattern repeats every 10 seconds.

Figure 3.3 shows the specific relationships between stations. The eight stations are represented as letters A through H on the left of the transmission pattern and pulse length is represented in seconds across the top. The separation line between bursts represents the 0.2 second period of non-transmission. Notice that at any point in time (except during the 0.2 second off-time) there are three bursts being transmitted, one from each of three stations, one on each of the three frequencies. To receive the simultaneous bursts on each of the three frequencies, the Airborne OMEGA system uses not one, but three receivers, each tuned to one of the OMEGA frequencies.

## OMEGA TRANSMITTER LOCATIONS




**CURRENTLY TRANSMITTING**

- ★ FULL POWER
- ○ FULL POWER DATE
- △ PARTIAL POWER
- ▲ FUTURE/UPGRADED TRANSMITTER LOCATIONS

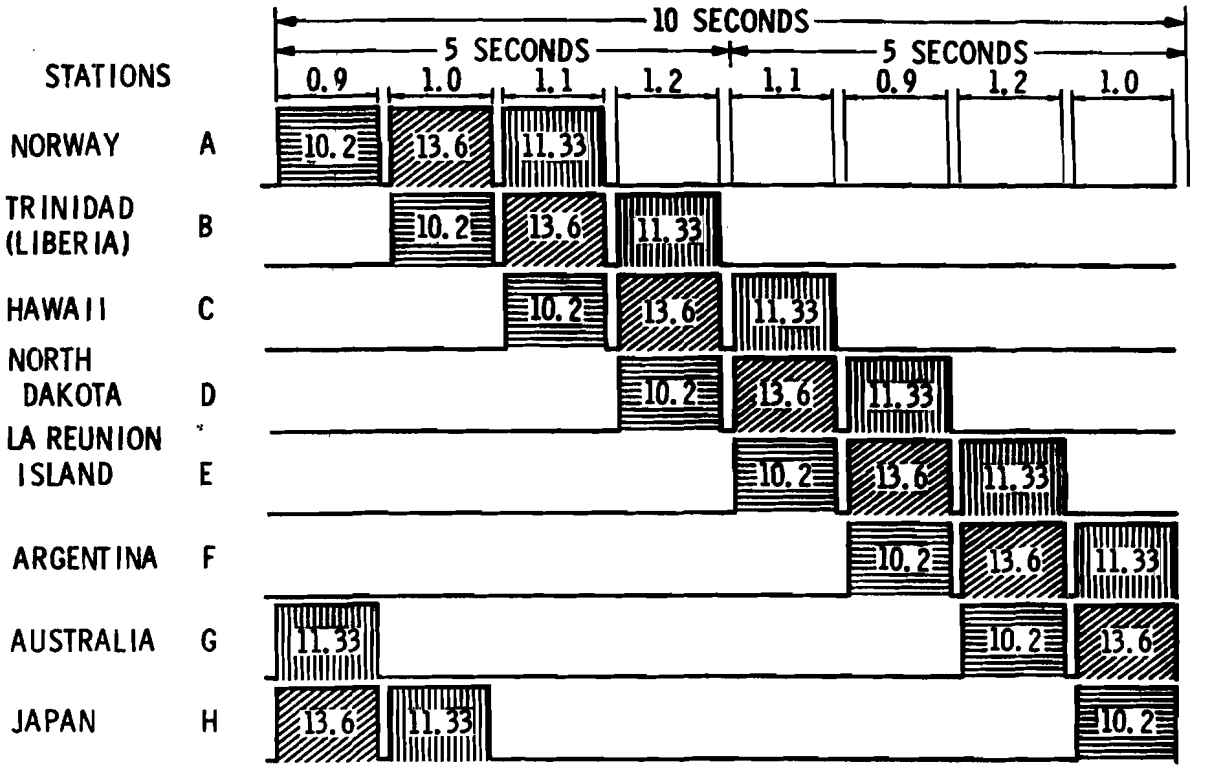
73-649B

FIGURE 3.1

| STATION | STATUS | FULL POWER DATE | COMMENTS |
|---|---|---|---|
| A - NORWAY<br>66°25.3' N<br>13°09.2' E | OFF FOR UPGRADING | 12-73 | |
| B - TRINIDAD<br>10°42.1' N<br>61°38.3' W | SEMI-OPERATIONAL<br>1 KW OUTPUT POWER | | MOVES TO LIBERIA 3-75<br>06°18.2' N<br>10°39.7' W |
| C - HAWAII<br>21°24.3' N<br>157°49.8' W | OFF FOR UPGRADING | 6-74 | |
| D - NO. DAKOTA<br>46°21.9' N<br>98°20.1' W | OPERATIONAL | 10-72 | |
| E - LA REUNION<br>TBD | ENGINEERING STARTED | 1-75 | |
| F - ARGENTINA<br>43°03.2' S<br>65°11.5' W | AGREEMENT NEGOTIATED | 3-75 | |
| G - AUSTRALIA<br>TBD | PLANNED | 12-75 | |
| H - JAPAN<br>34°36.9' N<br>129°27.2' E | UNDER CONSTRUCTION | 4-74 | |

73-647A

FIGURE 3.2 OMEGA TRANSMITTER STATUS




73-781

FIGURE 3.3 OMEGA TRANSMISSION FORMAT

There are eight stations and three frequencies; 24 bursts in each 10-second period. Each OMEGA transmitting station uses an atomic clock to generate all three frequencies. Each frequency is time-synchronized, which here means that for each station and each frequency the representative sinusoid will rise from zero at universal time-zero. This not only synchronizes the eight transmitters to universal time but to each other as well.

The CW burst pattern must be fixed in time. This is accomplished by logic gates that permit a frequency to reach the antenna and become a transmitter burst. Once the opening gate for any burst from any station is fixed in time then the entire pattern is fixed and predictable at every moment. The gate from Station A, Norway, on 10.2 kHz begins at universal time-zero.

Each receiver uses a reference oscillator to measure the difference in phase between itself and the incoming CW bursts. This oscillator is not as precise as the atomic clock of the transmitting stations, and thus may drift a bit. Also, when the OMEGA receiver is turned on the oscillator zero time is unknown. However, the fact that the receiver oscillator is not time-synchronized to universal time zero is unimportant, for either the measurements from two stations can be differenced, thus subtracting out the arbitrary oscillator zero time, or the error in receiver oscillator zero time can be calculated, its drift measured and tracked, thereby permitting single station phase measurements.

Position fixing by the first method, using two-station, difference measurements, is referred to as hyperbolic navigation; position fixing by the second, which uses the phase measurements from each station, is called circular or rho-rho navigation. The Northrop Airborne OMEGA system uses rho-rho navigation once the error in oscillator start time has been determined.

## 3.2 AN/ARN-99 OMEGA Navigation Equipment

The OMEGA equipment utilized for this test is shown in Figure 3.4. It consists of a Receiver-Computer, a Control Display Unit, and an Orthogonal Loop Antenna. This equipment was manufactured by the Northrop Corporation and is essentially equivalent to the military version of the AN/ARN-99 (XN-1) developmental OMEGA Navigation Set. This equipment is a completely automatic computerized OMEGA navigator designed for use in aircraft applications.

The primary element of the OMEGA Navigation Set is the Receiver-Computer which provides a means of processing transmitted OMEGA signals and computing navigation data. The Receiver-Computer is comprised of receiver section, computer section, power supply section, and an input-output section all housed in a single chassis which contains the interconnecting wire harness. The receiver section consists of four replaceable plug-ins which converts the transmitted three frequency OMEGA signals to the sines and cosines of phase data to digital form for processing in the computer.

The OMEGA receiver is a single conversion heterodyne, hard limiting type which allows signal compression over the entire range. The computer section consists of seven replaceable plug-ins which takes the sine and cosine phase data and further processes this information along with the current aircraft speed and heading and navigational data to derive accurate position data. Four of the seven computer section plug-ins comprise the arithmetic and control functions for a 16-bit word general purpose digital processor with a clock frequency of 4.5 MHz. The other three computer plug-ins make up an 8,192 word, 16 bit, core memory. The power supply section is a single plug-in which converts the incoming 400 hz line power to the DC voltages necessary to operate the OMEGA Navigation Set. The input-output section consists of one plug-in and provides the

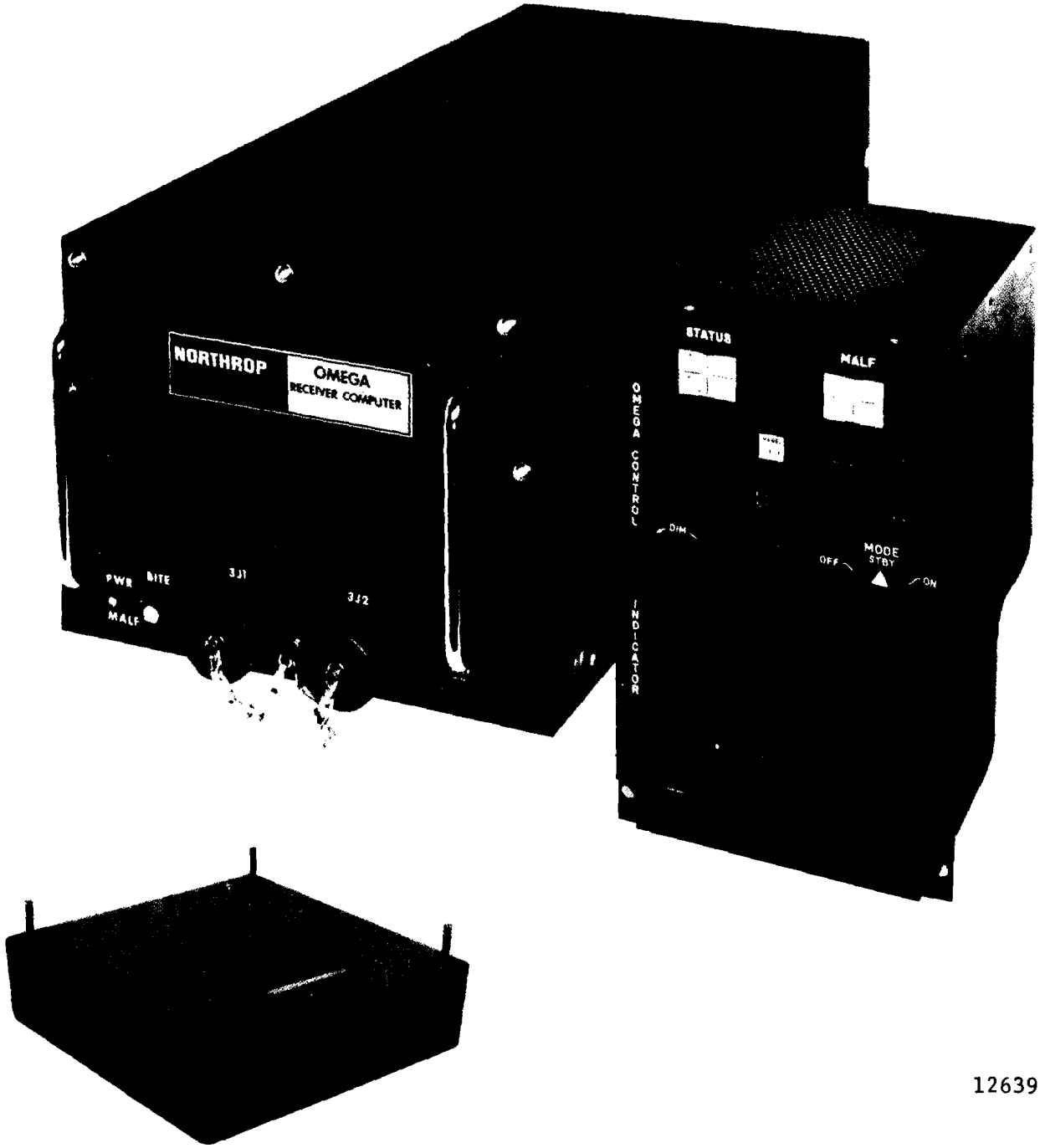



FIGURE 3.4 OMEGA NAVIGATION SET AN/ARN-99

necessary interface between the computer section, the receiver section, the Control Display Unit and the analog speed and heading information obtained from other sensors onboard the aircraft.

The second hardware element is the Control-Display Unit which provides the man-machine interface between the operator and the Omega Navigation Set. The controls allow the operator to manually energize and de-energize the system, insert data, select operating modes, and select specific data for display. The front panel displays provide the operator with visual navigation information.

The third and last OMEGA hardware element used for these tests is the antenna. To take advantage of the inherent immunity to "P-Static" type noise, a loop (H-field) antenna was used. "P"-Static or Precipitation Static is electrostatic noise produced by corona discharge and caused by the movement of the aircraft through the air. The intensity is greatest when the aircraft is moving through clouds. This single unit consists of two pairs of ferrite rods forming loops in orthogonal relationship to each other. Each loop has an associated amplifier and the entire unit is enclosed within an electro-static shield. The antenna operates over a range from 10 KHz to 14 KHz with outputs provided to the receiver over two pairs of balanced lines.

## IV. AIRCRAFT INSTALLATION

The OMEGA Navigation Set equipment and cabling were installed on WA#802, a World Airways DC8-63F, at World Air Center, Oakland.

### 4.1 Receiver/Computer and Control/Indicator Installation

All equipment, except the antenna, was installed in the cockpit at the Navigator's station (portside aft). The Control/Indicator Panel was secured to a bracket mounted on top of the Navigator's table. The Receiver/Computer was mounted to brackets on the cockpit deck below the same table. The interconnecting cabling was secured to the deck and port bulkhead below the table. Aircraft power to the system was 115 volt 400 Hz and 28 volt D.C. Rate Aid inputs from the aircraft were True Air Speed and the Magnetic Compass synchros. The aircraft inputs were picked up from a terminal board in the Navigator's console. Doppler Ground Speed and Drift Angle synchros were also brought to the terminal board for possible future application but these inputs were never used as rate aids by the system. Although the Doppler supplies a much more accurate velocity source for rate-aid purposes than does the True Air Speed, it was decided that, at least initially, the navigation set should have a minimum of "help". This would ensure that the set would rely on OMEGA signals for performance and not become, in essence, a Doppler DR system.

### 4.2 Antenna Installation

The NOLA loop antenna was originally mounted in the nose radome. However, this location proved unsatisfactory due to excessive 400 Hz noise generated by the drive motor of the weather radar. The antenna which was mounted on a bracket on the aft bulkhead of the radome below the Radar dish was saturated by the 400 Hz. Moving the antenna only a few feet away from its initial location improved reception to the extent

that interference from the drive motor was not noticeable. However, the needed few feet was external to the radome.

A cursory noise environment investigation was made to identify an alternate antenna location. An acceptable location was found at Station 710 on the bottom of the fuselage left of the centerline. Station 710 is 11 feet forward of the main landing gear. This location was not the best from an electrical noise standpoint but was the most accessible mechanically. A removable access plate existed at this location. A duplicate plate with a fiberglass cutout was fabricated and installed in place of the original plate. The antenna was mounted on top of the fiberglass cutout inside the skinline.

Station 540, among others, was electrically quieter than Station 710, however, an antenna installation at this location would have necessitated cutting into the skin. The installation at Station 710 required a cable run of about 100 feet. Experience later in the program showed that signal reception with this aircraft was not as good as reception in other aircraft that had the antenna located in a less noisy area and external to the skin. However, it was felt that signal reception was adequate to permit navigation over the flight route profiles. The installation was approved on a check flight from Oakland to New York on October 6, 1971 and a Supplemental Type Certificate (STC) was granted. The STC was approved for evaluation of the Omega Navigation System based on non-interference with other aircraft systems. Aircraft navigation was not to be predicated on Omega information.

## V. DATA ACQUISITION

All data were recorded manually from the output displays of the Control/Indicator Panel. Flight Data Sheets were used to record both OMEGA signal data and navigational data. Appendix B gives an example of a data sheet.

### 5.1 OMEGA Signal Data

The OMEGA signal data consisted of mainly 2 displays. The first is the "Burst" display which is an indication of signal-to-noise measurement of each OMEGA station's reception at the geographic location of the receiver. This display is useful by indicating the relative strength or weakness of OMEGA signals in a given area. It also indicates when an unscheduled outage of a particular station has occurred. The second OMEGA signal data display is the "Signal Acquisition" display. This output is a cumulative count of the number of times each frequency from each OMEGA station has been acquired by the system for use as a navigational update. In addition to these numerical displays there were 2 warning indicators on the Control/Indicator Panel that are a function of OMEGA signal reception. These are the Position Uncertainty (POS UNC) and the OMEGA Ambiguity (Ω AMB) indicators. The Position Uncertainty indicates that the estimated variance on system position is greater than 4 miles.

The Omega Ambiguity indicates that the system has more than one estimate of position. Both of these indications are caused by inadequate three-station reception.

### 5.2 Navigational Data

Normal navigation data was also available as outputs from the Control/Indicator Panel. These data included latitude/longitude, bearing/range to waypoints, track/groundspeed, wind, estimated time enroute/arrival, and crosstrack error.

The OMEGA System position error was determined by the range display as the aircraft passed over a radio checkpoint. The readout is in miles and tenths of miles. Obviously, an on-top mark at 30,000 feet made on a needle swing from the VOR system does not have the accuracy of the readout resolution. The estimated accuracy of the on-top type position error is 2 to 3 miles. This type of measurement was used for Landfall error and overland enroute errors. Terminal errors were based on the location of the landing airfield. The accuracy of this type of measurement is approximately 0.5 miles. Enroute overwater across the Atlantic, the only sources available to measure OMEGA position error were Doppler and LORAN "A". These sources proved to be too imprecise to define OMEGA position error to an acceptable accuracy. LORAN "A" information was sometimes spotty and it was difficult to correlate the time of the LORAN "A" fix to the time of the OMEGA position. On the initial flights, attempts were made to measure the OMEGA position to LORAN "A" chart position, but the results were inconsistent with landfall errors. On the later flights, only rough comparisons were made to indicated Doppler and LORAN "A" positions. Enroute performance across the Atlantic was therefore defined by the Landfall error at the on-top position fix.

## VI. GENERAL PERFORMANCE WITH VARIOUS STATION CONFIGURATIONS

### 6.1 Required Signal Reception

The OMEGA navigation system requires reception of a minimum of 3 stations to accurately resolve and maintain its position. Reception of less than 3 stations usually results in degraded performance which is indicated by the presence of either or both warning lights on the C/I Panel. These are the previously described Position Uncertainty (POS UNC) and OMEGA Ambiguity (Ω AMB) indicators. On infrequent occasions these lights can be on when 3 stations are being received. This situation occurs when the system detects a real or apparent signal anomaly which does not correlate with the previous history of that signal; that is, the expected phase measurement does not agree with prior phase measurements of that signal, thereby disagreeing with the geographic position of the system. This condition is usually corrected in a short time as the system resolves the problem with continued acceptable 3-station reception. Whatever the reason for the presence of these warning lights, the system continues to navigate utilizing all remaining input information available. The purpose of these indicators is to warn the operator that OMEGA signal reception is inadequate and to expect degraded performance.

Non-reception of suitable signal from a given station in a given area can be caused by many conditions. The more common reasons are as follows:

1. A combination of distance and low power output from a station results in the signal being too weak to be received.
2. Signals passing across the Greenland Icecap are attenuated.
3. A station normally received is not transmitting at a given time because of either a scheduled or unscheduled off time.
4. The receiver is within 360 miles of a station. The software in the system automatically rejects a station's signal within this radius to prevent intermodal effects which can lead to

4. (cont'd.)

erroneous position determination due to the interference between ground and sky waves. This effect is a function of transmission wave geometry and not power output. This automatic station block is called the "Proximity Limit".

The ultimate full OMEGA net will comprise 8 stations, each transmitting 3 frequencies at 10kw power output. During the period of the test program the OMEGA net consisted of a low-powered, permanent site station; a low-powered, 2-frequency, permanent site station; 2 low-powered, temporary site stations; and, eventually, a full-powered permanent site station. The configuration varied both in power output and number of stations transmitting. Only 2 stations, Norway (A) and Trinidad (B), were consistent throughout the entire period. Both stations transmitted at 1 kw power, but Norway transmitted on only 2 frequencies, 10.2 khz and 13.6 khz, rather than the normal 3. The test flights have been categorized by station configuration.

## 6.2 Period of January 1972

The first series of flights, a total of 8, were made in January 1972 with the following station configuration.

A - Norway - 1 kw (2 frequencies only)
B - Trinidad - 1 kw
C - Hawaii - 2 kw
D - New York - .125 kw (max.)

Problems with attaining consistent 3-station coverage over the flight routes between eastern North America and western Europe existed with this station configuration. Typical coverage by station was as follows:

1) Station A

The Norway signal was rarely received in the East Coast departure or terminal areas due to the signal being attenuated by the Greenland icecap. On east bound flights Norway signal would first be received in the Nova Scotia/Newfoundland area and would continue to be received across the Atlantic and in Europe. On westbound flights Norway signal was received from departure until reaching the Newfoundland area where again the signal would weaken due to Greenland. This coverage was consistent throughout the entire flight test period.

2) Station B

The signal from Trinidad was received over the entire flight route but was usually weak in western Europe. Like Norway, the Trinidad coverage was consistent throughout the flight tests.

3) Station C

The signal from Hawaii was usually received in eastern U.S. departure areas. However, the signal weakened rapidly in the Nova Scotia/Newfoundland area and was rarely received over the Atlantic. The only contribution from Hawaii was as an additional station for east coast departures and it was not a factor in coverage over the Atlantic or in Europe. Although this was the strongest transmitting station at the time the low power of 2 kw and the long distance precluded its use in the critical area of the flight routes, namely in the North Atlantic.

4) Station D

Reception from New York was the critical element for performance over the Atlantic. This station had 2 factors affecting its coverage over the flight routes. The first and more important factor was its extremely low power output of 125 watts maximum. In addition, its power output was reduced to about 60 watts when rain or snow conditions existed in the area. The second factor affecting reception from the New York station was its geographic location. Due to the 360 mile proximity limit imposed by the computer, that stations's signal was unusable throughout most of the east coast departure and arrival areas. This area included all east coast points north of Norfolk. On eastbound flights New York signal was not usable until the Nova Scotia/Newfoundland area was reached. The signal was received from that point to the eastern Atlantic. In that area the signal weakened depending on the power output at the time. Signals were rarely received in western Europe. On westbound flights New York signal would not usually be received until well out in the Atlantic. With power at 125 watts New York reception first occurred at about 40° West. With power at 60 watts it would not be received until almost 60° West. The 360 mile proximity limit would be entered over the Nova Scotia/Newfoundland area and the signal would be unused the remainder of the flight.

Of the 8 flights during this first series in January 1972 only 3 reached landfall with the warning indicators (POS UNC and Ω AMB) off indicating adequate 3-station coverage enroute. All 3 of these flights were eastbound and were made when New York power was 125 watts. Navigational accuracy as determined by landfall error was very good. On the other eastbound flight New York power was approximately 85 watts and that station's signal was lost at 40°West. Warning lights were on at landfall. All 4

of the westbound flights arrived at landfall with warning lights on. Norway and Trinidad signals were received departing Europe and enroute, however New York signal reception was insufficient for the system to resolve itself. On all of the flights 3-station coverage was not available in terminal areas. Eastbound, from landfall to the terminal airfield, only the 2-frequency Norway station and a weak Trinidad station were received. New York had usually faded out by landfall. Westbound, only Trinidad and weak Hawaii signals were received from landfall to the terminal airfield. Norway was blocked by Greenland and New York was blocked by the proximity limit. Although on the last 2 eastbound flights the warning lights were still off at landing and position errors were small, in general, navigational accuracy deteriorated between landfall and terminal airfields due to lack of 3-station coverage.

Since the New York station was critical to the performance across the Atlantic further test flights were postponed until the new, permanent, full-powered North Dakota station came on the air in the 'D' slot of the Omega signal format. See Figure 3-3. The schedule called for the start of North Dakota transmissions in late February 1972. Due to construction delays, however, this station did not begin full operation until October 1972.

### 6.3 Period of October 1972

The second series of flights, a total of 6, were made in October 1972 with the following station configuration:

A - Norway - 1 kw (2 frequencies only)
B - Trinidad - 1 kw
C - Hawaii - 1 kw
D - North Dakota - 10 kw
G - New York - .125 kw (max.)

The North Dakota station now transmitting in the 'D' slot at full 10 kw power improved performance noticeably, especially in the westbound direction. Typical coverage by station is as follows:

1) Station A/Station B

   There were no changes to the Norway or Trinidad stations. The comments in Section 6.2 apply.

2) Station C

   The Hawaii station reduced to 1 kw power since the first series of flights and had almost no effect on coverage over the flight routes.

3) Station D

   North Dakota was the first of the permanent, full-powered OMEGA stations to transmit. After transmitting at reduced power temporarily in the 'F' slot, North Dakota came on the air on Oct. 1 at 8 kw in its permanent 'D' slot. On Oct. 10 it came up to full 10 kw power. On eastbound flights North Dakota signal was strong in departure areas and across the Atlantic. Signal weakened in the eastern Atlantic and over Europe. On westbound flights very little signal was received in departure areas. North Dakota would normally be received departing the European mainland and strengthen across the Atlantic. It was also strong in arrival areas on the East Coast.

4) Station G

   The temporary New York station was removed to the 'G' slot when North Dakota became operational. The coverage was the same as on the first series of flights.

Of the 6 flights made with this configuration 4 arrived at landfall with the OMEGA warning indicators off. The first flight using North Dakota was unfortunately ill-timed. An hour after takeoff, eastbound, the station went off the air for 3 hours. Warning lights were on enroute over the Atlantic. The other two eastbound flights were normal although one of them had warning lights on at landfall. All 3 westbound flights had very good performance enroute and at landfall.

A problem affecting performance existed during this 6 flight series. The onboard antenna had an intermittent malfunction that affected one of the two loops. The effect of the intermittent was most noticeable during climbout. Almost no signal from the affected loop was received from take-off to cruise altitude regardless of the strength of the signal. Once at cruise altitude the symptoms disappeared and signal reception appeared normal. The problem on climbout was most likely induced by vibration. The antenna was removed after this series of flights and lab tested. It was found that one of the ferrite rods was cracked. This defective antenna had been a pre-production prototype. A new production type antenna was then installed for the balance of the flights.

## 6.4 Period of December 1972 to July 1973

The last series of flights, a total of 21, were made in December 1972, March, April, and July 1973, with the following configuration:

A - Norway - 1 kw (2 frequencies only)
B - Trinidad - 1 kw
D - North Dakota - 10 kw

Note: The Hawaii station was still transmitting at 1 kw in the "C" slot during the 4 flights made in December 1972. As stated previously, it had little effect on coverage over the flight routes. Hawaii shut down in February 1973.

This configuration, essentially 2 2/3 station, was the minimum for the OMEGA system to resolve and maintain position. Typical coverage for Stations A and B was unchanged from the prior flights. Although Station D had the same power output as on the October flights, the signal appeared to be stronger in Western Europe. In general, the North Dakota signal was received further along on eastbound flights and picked up earlier on westbound flights than was the case during the October flights. This improved reception occurred after replacement of the antenna.

Of the 21 flights made with this configuration, 19 arrived at landfall with OMEGA warning indicators off. Navigational accuracy on all 19 flights was excellent at landfall. On eastbound flights, with the improved reception of North Dakota signal in Europe, the performance between landfall and terminal airfields was likewise improved. Although North Dakota signal weakened over mainland Europe, relative to the Atlantic, sufficient reception was acquired so that 7 of the 8 eastbound flights arrived at terminal airfields with OMEGA warning indicators still off and with good positional accuracy. All 11 westbound flights arrived at landfall with warning indicators off and small position error. A total of 5 of the 11 flights arrived at terminal airfields with the indicators off; on 2 of these, the landfall and terminal points were the same. The problem of degraded performance between landfall and terminal still existed on westbound flights because Norway signals were usually lost over the mainland, leaving only 2-station coverage.

Only 2 of the series of flights arrived at landfall with OMEGA warning indicators on. Both were eastbound flights. On one of these flights the effect was attributable to loss of North Dakota signal due to that station being blocked by Greenland. The flight was inbound to Keflavik, Iceland when the POS UNC indicator came on six minutes before landing. The flight had been normal to that point and position

was extremely accurate at 50 miles out. At that point, a DME reading indicated less than 1 mile error. North Dakota signal had deteriorated the last part of the flight most likely due to signal path crossing the southern part of Greenland. The reason on the other flight is not readily explainable. During what had been a routine flight to Europe, the POS UNC indicator came on less than an hour before landfall. The system detected an apparent incoherent condition in the North Dakota signal.

## VII. NAVIGATIONAL FLIGHT RESULTS

7.1 There were 35 accountable Data Flights made during the test period. These are listed chronologically in Table 7.1 by World Flight Number, Date, OMEGA Warning Indicator Status at Landfall, and Station Configuration.

| Sequence No. | Flight No. | Date | Landfall Omega Warning Indicator Status | | Station Configuration |
|---|---|---|---|---|---|
| | | | ON | OFF | |
| 1. | W0105 | 1/ 5/72 | X | | ABCD |
| 2. | W0106A | 1/ 6/72 | | X | D= New York |
| 3. | W0106B | 1/ 6/72 | X | | |
| 4. | W0107A | 1/ 7/72 | | X | |
| 5. | W0107C | 1/ 7/72 | X | | |
| 6. | W0109A | 1/ 9/72 | | X | |
| 7. | W0109C | 1/ 9/72 | X | | |
| 8. | W0112 | 1/12/72 | X | | |
| 9. | W1010A | 10/10/72 | X | | ABCD G |
| 10. | W1011A | 10/11/72 | | X | D= North |
| 11. | W1012B | 10/12/72 | | X | Dakota |
| 12. | W1013C | 10/13/72 | | X | |
| 13. | W1017A | 10/17/72 | X | | |
| 14. | W1017B | 10/17/72 | | X | |
| 15. | W1210A | 12/10/72 | | X | AB D |
| 16. | W1210D | 12/10/72 | | X | |
| 17. | W1228 | 12/28/72 | | X | |
| 18. | W1231B | 12/31/72 | | X | |
| 19. | W0314C | 3/14/73 | X | | |
| 20. | W0315 | 3/15/73 | | X | |
| 21. | W0325A | 3/25/73 | | X | |
| 22. | W0325C | 3/25/73 | | X | |
| 23. | W0326B | 3/26/73 | | X | |
| 24. | W0326C | 3/26/73 | | X | |
| 25. | W0327A | 3/27/73 | X | | |
| 26. | W0327B | 3/27/73 | | X | |
| 27. | W0419 | 4/19/73 | | X | |
| 28. | W0420 | 4/20/73 | | X | |
| 29. | W0712B | 7/12/73 | | X | |
| 30. | W0713C | 7/13/73 | | X | |
| 31. | W0714A | 7/14/73 | | X | |
| 32. | W0714C | 7/14/73 | | X | |
| 33. | W0725D | 7/25/73 | | X | |
| 34. | W0727A | 7/27/73 | | X | |
| 35. | W0727B | 7/27/73 | | X | |

TABLE 7.1

7.2 On the first series of flights with the New York station in the "D" slot, only 3 of 8 flights arrived at landfall without OMEGA warning indicators. The position errors are tabulated in Table 7.2 below. Mean Landfall Error was 3.1 miles.

| Sequence Number | Date | Route | Landfall Point | Landfall Error |
|---|---|---|---|---|
| 2 | 1/6/72 | McGuire Frankfurt | Cork | 4.9 |
| 4 | 1/7/72 | McGuire Zurich | Quimper | 2.0 |
| 6 | 1/9/72 | Bangor Frankfurt | Cork | 2.4 |

Table 7.2

7.3 On the second series of flights with North Dakota now in the "D" slot and New York temporarily in the "G" slot, 4 of 6 flights arrived at landfall without OMEGA warning indicators. This series of flights were made with the intermittent antenna. Position errors are tabulated in Table 7.3. Mean Landfall Error was 3.8 miles.

| Sequence Number | Date | Route | Landfall Point | Landfall Error |
|---|---|---|---|---|
| 10 | 10/11/72 | Malaga Bangor | Sable Island | 2.2 |
| 11 | 10/12/72 | McGuire Frankfurt | Belfast | 5.7 |
| 12 | 10/13/72 | Amsterdam Baltimore | Sable Island | 6.0 |
| 14 | 10/17/72 | Paris Boston | Gander | 1.4 |

Table 7.3

7.4 On the last series of flights with only the A, B, and D stations on, 19 of 21 flights arrived at landfall without OMEGA warning indicators. Position errors are tabulated in Table 7.4. Mean Landfall Error was 1.8 miles, and the standard deviation was 1.3 miles.

| Sequence Number | Date | Route | Landfall Point | Landfall Error |
|---|---|---|---|---|
| 15 | 12/10/72 | Bangor Zurich | Cork | 1.6 |
| 16 | 12/10/72 | Vienna Goose Bay | Goose Bay | 1.2 |
| 17 | 12/28/72 | Los Angeles Amsterdam | Glasgow | 0.6 |
| 18 | 12/31/72 | Amsterdam New York | Goose Bay | 1.2 |
| 20 | 3/15/73 | Keflavik Bangor | Port Menier | 1.1 |
| 21 | 3/25/73 | New York Frankfurt | Land's End | 3.7 |
| 22 | 3/25/73 | London Toronto | Springdale | 2.2 |
| 23 | 3/26/73 | McGuire Frankfurt | Land's End | 3.1 |
| 24 | 3/26/73 | Frankfurt McGuire | Heath Point | 1.1 |
| 26 | 3/27/73 | Frankfurt McGuire | Cartwright | 1.2 |
| 27 | 4/19/73 | Niagara Falls Amsterdam | Belfast | 1.7 |
| 28 | 4/20/73 | Amsterdam Dulles | St. Anthony | 0.7 |
| 29 | 7/21/73 | Bangor Rome | Cork | 2.0 |
| 30 | 7/13/73 | Prestwick New York | Cartwright | 0.9 |

Table 7.4

Table 7.4 (cont'd.)

| Sequence Number | Date | Route | Landfall Point | Landfall Error |
|---|---|---|---|---|
| 31 | 7/14/73 | New York London | Shannon | 0.8 |
| 32 | 7/14/73 | Prestwick Bangor | St. Anthony | 2.0 |
| 33 | 7/25/73 | Brussels New York | Cartwright | 5.8 |
| 34 | 7/27/73 | Bangor Rome | Shannon | 3.5 |
| 35 | 7/27/73 | Paris Gander | Gander | 0.0 |

7.5 The following are distribution charts and histograms of Landfall Error by the categories listed below.

7.5.1 All 26 flights

7.5.2 Flights after the antenna change (19)

7.5.3 Eastbound (12)/Westbound (14) flights

LANDFALL ERROR DISTRIBUTION - ALL 26 FLIGHTS

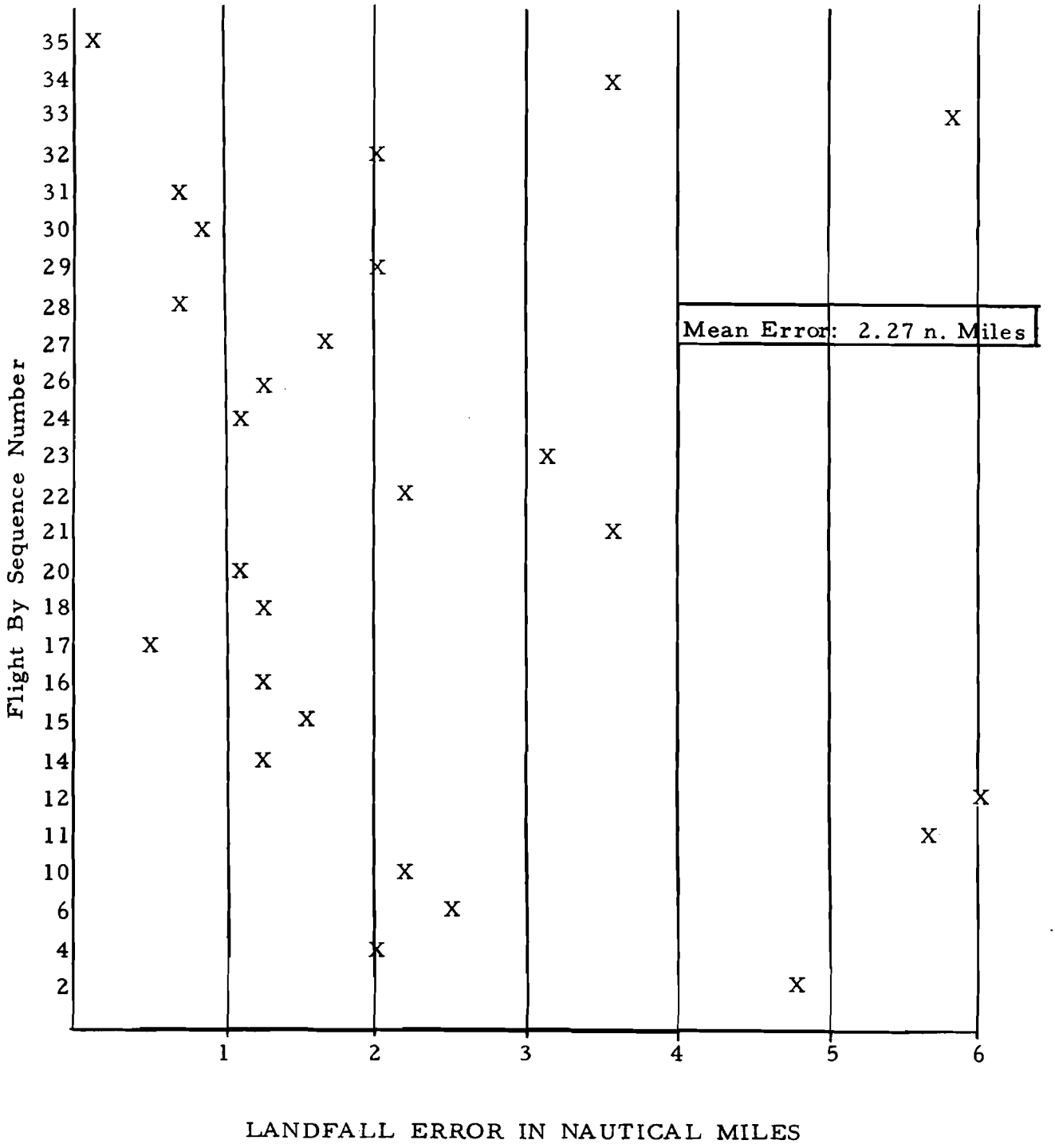



CHART 7.5.1

LANDFALL ERROR HISTOGRAM - ALL 26 FLIGHTS

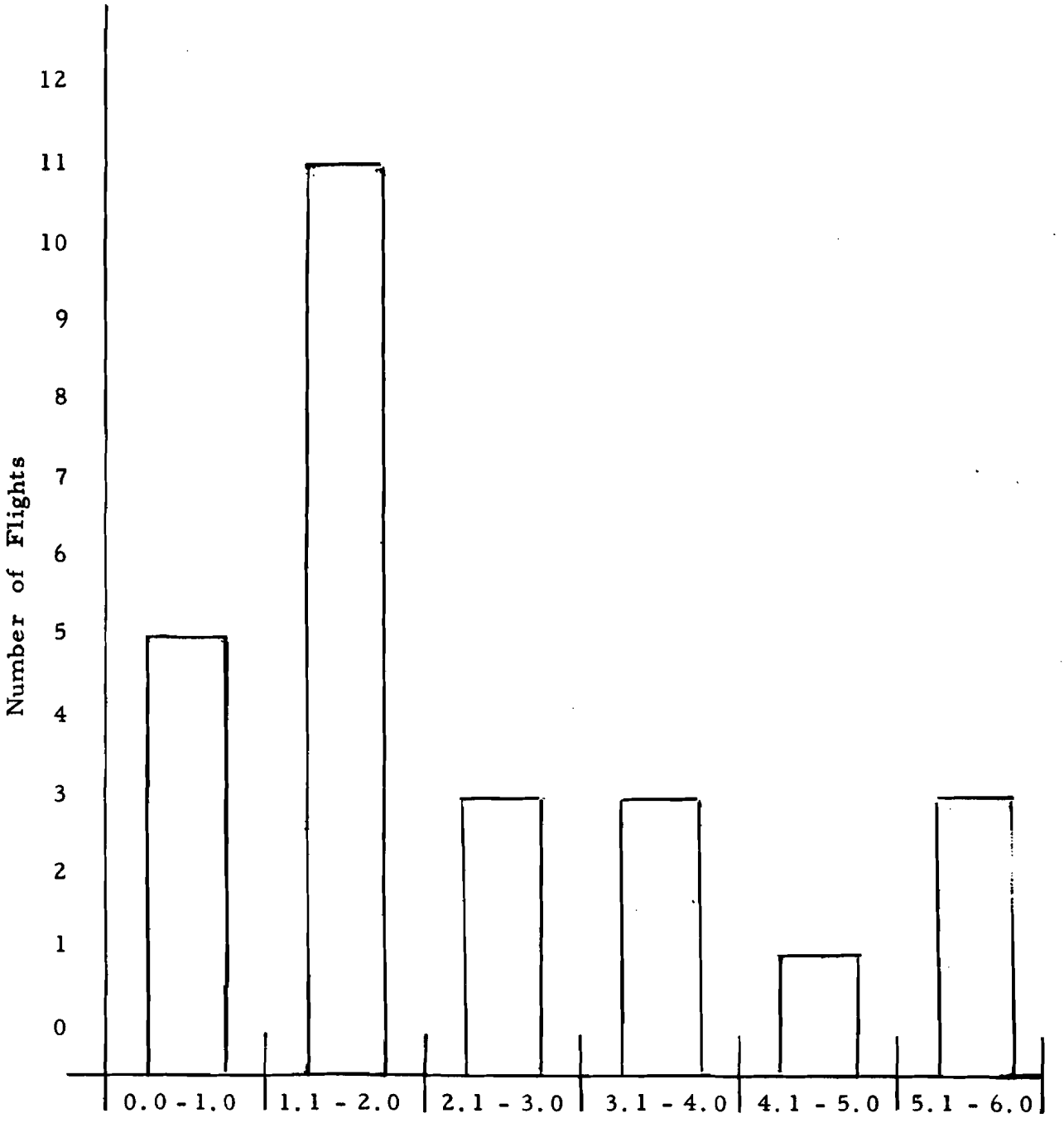
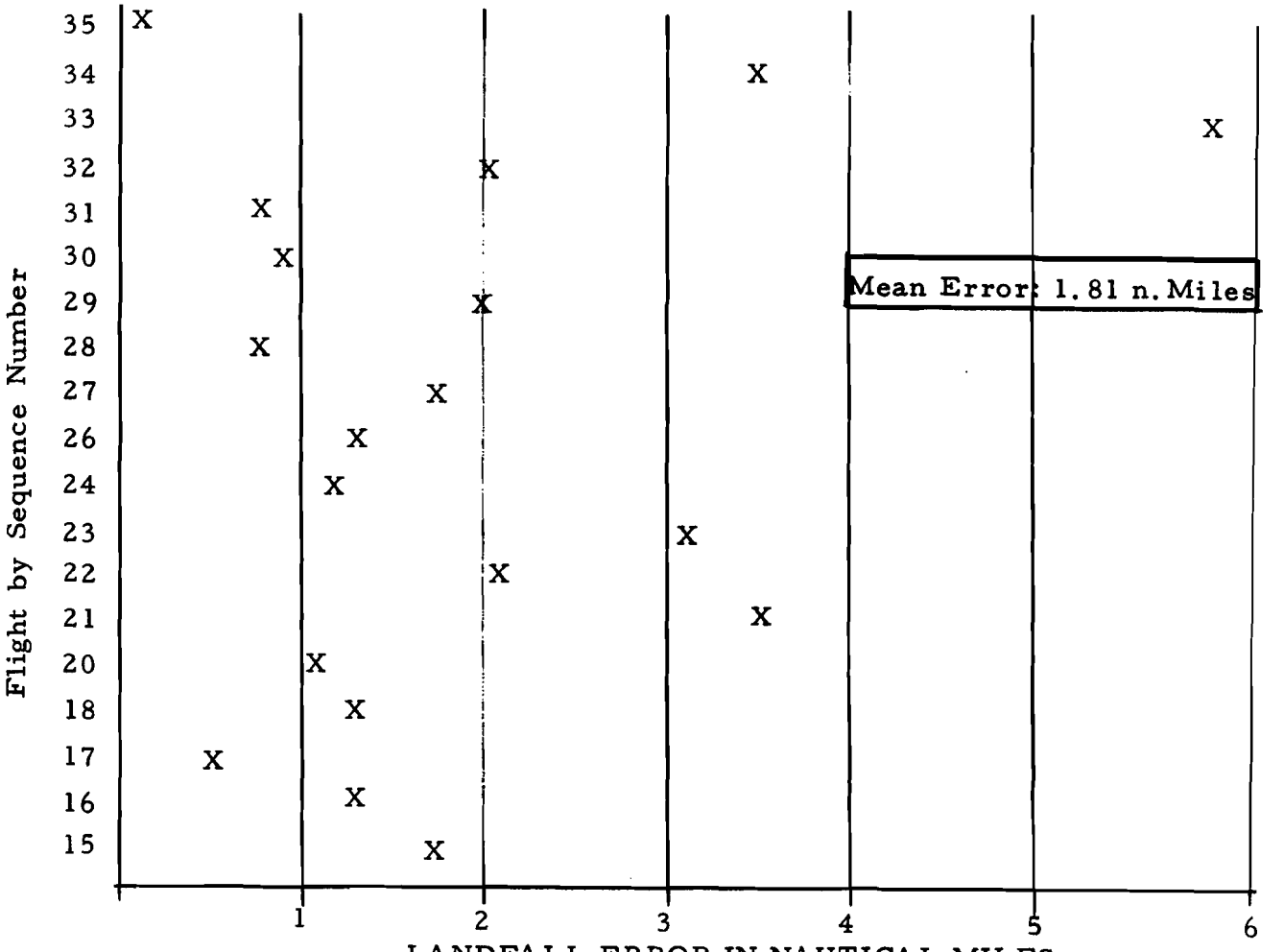



CHART 7.5.1

LANDFALL ERROR DISTRIBUTION - FLIGHTS AFTER ANTENNA CHANGE (19)



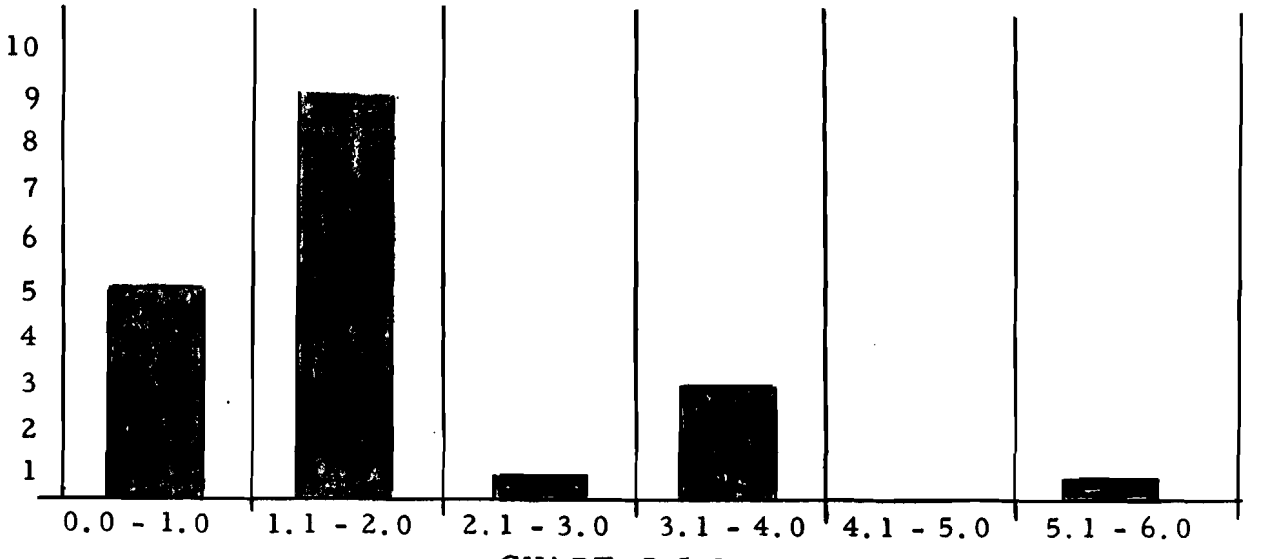




CHART 7.5.2

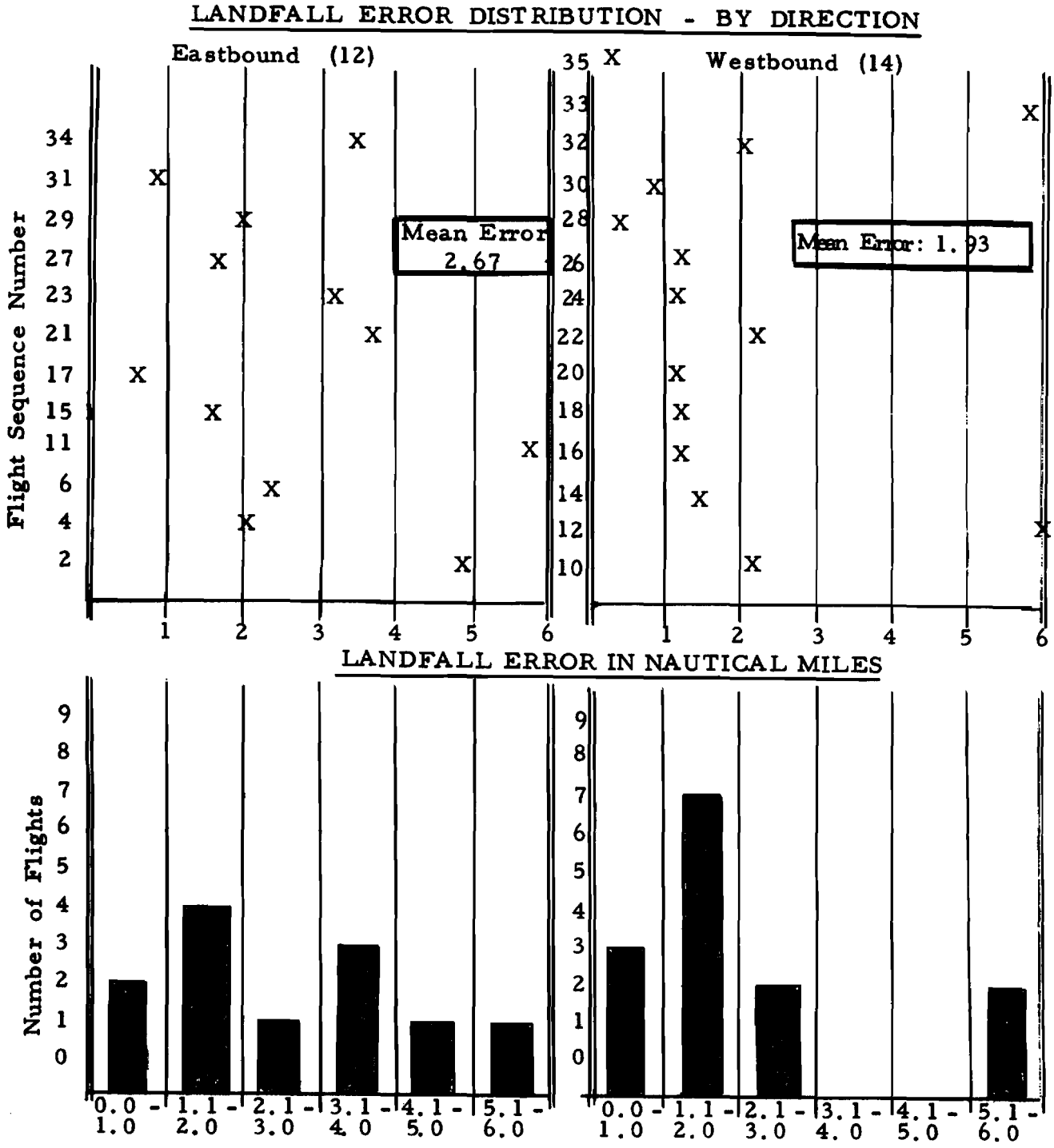

LANDFALL ERROR DISTRIBUTION - BY DIRECTION
Eastbound (12)
Westbound (14)
Mean Error 2.67
Mean Error: 1.93
Flight Sequence Number
LANDFALL ERROR IN NAUTICAL MILES
Number of Flights
0.0 - 1.0
1.1 - 2.0
2.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 6.0

CHART 7.5.3

7.6 Of the 35 Data Flights, only 9 arrived at landfall with OMEGA Warning indicators on. During the first series of flights when the low-powered New York station was in the "D" slot, 5 out of an attempted 8 flights arrived with the indicators on. During the second series, with the intermittent antenna, 2 out of 6 flights had warning indicators; and on the last series, only 2 out of 21 attempted flights arrived at landfall with these indicators on.

These 9 flights and the reason for the lack of 3-station coverage are described below.

Sequence #1

This was the first flight of the program and the only eastbound flight in the first series that OMEGA warning indicators were on at landfall. The flight departed McGuire AFB with the New York station transmitting 85 watts. Position accuracy was good over the Atlantic until 30° west. The signal from New York had faded out at this point and the Position Uncertainty indicator came on at that time. Only Norway and Trinidad signal was received the remainder of the flight. A total of 78 acquisitions of New York signal were made across the Atlantic. Landfall error at Cork was 8.9 miles.

Sequence #3

This was the first westbound flight of the series. The New York station was transmitting its maximum 125 watts but that station's signal was not received until 40° West. The system estimated position variance began to decrease at this time, but reception from New York was insufficient for the system to resolve by landfall. Only 20 signal acquisitions were made across the Atlantic. Landfall error was 9.3 miles.

Sequence #5

The New York station was transmitting about 70 watts during this westbound flight. New York signal was first received at 40° West, but only 54 acquisitions were made across the Atlantic. Landfall error was 5.3 miles.

Sequence #7

This westbound flight departed Amsterdam with the New York station transmitting 125 watts. However, that station reduced to 60 watts soon after takeoff. This was the poorest flight of the entire series. New York signal was not received until 60° West. Only 2 acquisitions were made from New York enroute across the Atlantic. System position variances were large the entire flight. Landfall error was 52.2 miles.

Sequence #8

This westbound flight departed Geneva with New York transmitting at 125 watts. New York signal was first received at 30° West, but only 33 acquisitions were made across the Atlantic. Landfall error was 7.5 miles.

Sequence #9

This was the first Data Flight with North Dakota transmitting in the "D" slot. The flight departed New York but little signal was acquired initially due to the faulty antenna. At altitude North Dakota signal was received normally but the station shut down an hour after takeoff. It remained off for 3 hours and came back on when the aircraft was at 28° West. Only 17 signal acquisitions from North Dakota were made enroute. Landfall error was 12.5 miles.

Sequence #13

This flight departed Dulles with only the problem of signal loss on climbout due to the antenna intermittent. Most of the flight across the Atlantic was normal with good reception from North Dakota. At about 20° West, Trinidad signal appeared to weaken and at 10° West the OMEGA warning indicators came on. North Dakota signal was still being received at the time. Landfall error was 9.1 miles.

Sequence #19

This flight has been briefly described previously. The route was from Bangor to Keflavik. Signal reception and position accuracy was very good enroute. North Dakota signal was very weak the last 30 minutes of the flight due to the signal path over southern Greenland. At 15 minutes before landing, a 50-mile DME reading indicated less than 1 mile error. The OMEGA warning indicators came on 6 minutes before landing. Landing error was 4.6 miles.

Sequence #25

This eastbound flight departed McGuire AFB. Signal reception and position accuracy was normal for most of the flight. At 15° West, the OMEGA warning indicators came on. All 3 stations were being received at the time. North Dakota signal appeared to be incoherent and slightly weaker than is normally seen in this area. The U.S. Naval Observatory Daily Phase Value Series 4 publication stated that Propagation Disturbances occurred on this date at 1000Z. The OMEGA warning indicators came on at 1018Z. Landfall error at Cork was 7.5 miles.

## 7.7 Fix Update Capability

The OMEGA Navigation Set has the capability to be both fix updated or airstarted inflight, if necessary. The fix update procedure is similar to initial Present Position input and is usually made on top of a radio checkpoint. An airstart involves a power cycle and a reinitialization of of the system. Fix updates were made on occasion at the discretion of the system operator prior to entering the Atlantic route.

Sequence #34 is of particular interest in that it demonstrates the capability of the system to be manually corrected after erroneous information has been inserted. The flight route was Bangor to Rome. The system operator inadvertently inserted the wrong latitude for Present Position when the system was initialized on the ground at Bangor. Latitude

was inserted as 41°48.5N rather than the actual 44°48.5N. The system was unable to resolve this 3° error as the aircraft proceeded across eastern Canada. Both OMEGA warning indicators were on during this time. Upon realization of the erroneous input, the operator made a fix update as the aircraft passed over Gander VOR. In 3 minutes the system resolved and the warning indicators went off. The rest of flight across the Atlantic and Europe was normal. Both landfall and terminal errors were very good and no warning indicators existed after the fix at Gander.

### 7.8 Greenland Overflights

There were two flights during the program that were not considered as Data Flights. The flights are of interest in that they show the effect of the Greenland ice cap on the necessary three-station coverage. Both flights were eastbound originating in western North America and crossed Greenland at 63° and 67° North. The flights were made in June and July 1973 when the station configuration consisted of Norway, Trinidad and North Dakota. On the west side of Greenland, the Norway signal was not received. On the east side of Greenland, the North Dakota signal was received but was extremely weak. Essentially, these flights had only two-station coverage throughout.

## VIII. CONCLUSIONS

Based on the flight tests conducted over the trans-Atlantic routes, it can be concluded that the Omega system when fully implemented will be a viable and effective navigation system. The system demonstrated its capability to accurately determine its position (mean error between landfalls of 1.8 miles) in a somewhat limited signal environment. Implementation of the entire Omega network with all stations at full power will substantially increase the signal coverage in the area of trans-Atlantic crossings.

In addition to demonstrating its ability to provide smooth, bounded position information, the system proved easy to use with a capability to respond to in-air position fixing, which could preclude the necessity for pre-flight system operation (i.e., warmup or alignment). The test also pointed up the necessity to carefully select the antenna location and routing of the antenna cable.

## IX. RECOMMENDATIONS

This test program was conducted on North Atlantic routes between the East coast of the United States and Europe. It is recommended that additional flight testing be conducted in the greater Atlantic area after all northern hemispheric stations are at full power. This would test the Omega system performance at high latitudes and the effect of the Greenland icecap and would also measure Omega's effectiveness beyond the landfall gateways.