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No. NA-68-10
(RD-68-27)

INTERIM REPORT

Project No. 232-002-02X

AN EXPLORATORY TEST OF DATA TRANSFER BY VHF TO AIRCRAFT OVER THE OCEAN IN A TROPOSPHERIC PROPAGATION ENVIRONMENT

FEDERAL AVIATION AGENCY
INFORMATION RETRIEVAL BR. HQ-630

JUNE 1968

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

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Prepared by:
JOSEPH J. SCAVULLO

for

SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

June 1968

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DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
National Aviation Facilities Experimental Center
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ABSTRACT

Two very high frequency (VHF) troposcatter antennas, each with 16 colinear dipoles in a vertical array, were installed about 80 wavelengths apart at a site near the coast at Avalon, New Jersey. These antennas had flat, broad, high-gain radiation patterns directed in parallel toward the horizon. Exploratory tests were conducted while transmitting test signals, in a controlled sequence, between the site and a project aircraft operating over the ocean. In the sequence of test signals, a period of no modulation was followed by a calibrated audio tone, teletype messages and voice messages. Each sequence was repeated so that performance during phase modulation of the VHF transmitter could be compared with performance during amplitude modulation. The test site, test experience, and data are described as guidance for further experimentation in the same environment.

The majority of the comparative data was collected during shuttle maneuvers by the aircraft across the down-range threshold of reception. Communication distances, often two- to three-hundred miles beyond the radio horizon, were about the same regardless of modulation mode. The test indicated that simple substitution of low-speed data modulation for voice modulation, or of phase modulation for amplitude modulation, would not produce a substantial change of performance in a system designed for voice communications. The report recommends a test to determine probable operational coverage of these troposcatter antennas.

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INTRODUCTION

Purpose

The purpose of this phase of the project was to perform exploratory tests with an experimental coastal site established in order to prepare for an investigation of automatic communications by tropospheric propagation at very high frequency (VHF) with aircraft operating in an over-ocean environment.

Background

The Federal Aviation Administration (FAA) is attempting to extend the coverage of operational radio for ground-air-ground communications at frequencies employed for air traffic control. During an early phase of experimentation with tropospheric scatter in 1964, the strength of received signals and the ratio of signal-plus-noise to noise had been measured in an aircraft over the Atlantic Ocean. Two reports described the exchange of test signals between the aircraft and either of two high performance terminals on the ground, one at Barnstable, Massachusetts,[1] the other at Palmer, Puerto Rico.[2] Altitude, distance, and bearing of the aircraft from each of these two ground stations had been varied during a 2-month survey of radio frequency propagation beyond the radio horizon. The 1964 experiment revealed that system performance could probably be improved more by introducing better airborne antennas than through changes to any other single element of the available system. The results generally confirmed published theory of troposcatter propagation and demonstrated that high-gain antennas could support reliable communications well beyond the radio-line-of-sight from coastal ground facilities.

Meanwhile, over-ocean observations and experiments with VHF tropospheric propagation also had been performed by members of the aerospace and aviation industries. In 1963, along with reports of these

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[1] DeZoute, O. J., "Long Distance VHF Communications System Tests at Barnstable, Massachusetts," FAA Interim Report No. RD-64-139, NAFEC, Atlantic City, New Jersey, October 1964.

[2] DeZoute, O.J., and Pearson, L., "Long Distance VHF Communications System Tests at Palmer, Puerto Rico," FAA Interim Report No. RD-64-140, NAFEC, Atlantic City, New Jersey, October 1964.

observations, an international symposium published the operational requirement for reliable communications with aircraft approaching landfall within a radius of 500 nmi from air traffic control facilities.[3]

In response to the general trend toward automation, another phase of experimentation with troposcatter propagation was initiated. This later phase was expected to include a careful investigation of several modern techniques for the transmission of digital data. The new program would also investigate whether the tropospheric propagation medium would allow automatic systems to exchange data with aircraft out to a 500-nmi radius. For some time there has also been considerable interest in whether data transmission would compare favorably with voice transmission in radius of coverage and communication reliability.[4]

This report briefly describes the coastal test site, prepared as an experimental troposcatter terminal, at Avalon, New Jersey. It also describes a short series of exploratory tests which revealed the orientation and coverage of the fixed antennas erected at the site, identifies several other planning factors, and illustrates the kind of experimental information obtainable through over-ocean test operations.

Description of Exploratory Test System: The system assembled for exploratory test flights included a ground terminal and an airborne terminal (Figure 1). The basic ground terminal consisted of a directional high-gain VHF antenna and a trailer van equipped with a message-generating facility, sequencer, modulators, and a linear VHF amplifier operated as a transmitter. The trailer van was parked at the base of one of the directional antennas to which the 2-kilowatt linear amplifier was connected. Another identical high-gain antenna, erected near the same site, was equipped with a receiver and amplifier to monitor incidental voice communications from the project aircraft. The airborne terminal consisted of the airborne antenna, special receivers, demodulators, and recorders.

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[3] See also Gentle, J.R., and Smith, J.G., Ed., "Proceedings Symposium on Extended Range VHF Air/Ground Communications." International Aeradio Limited, Hayes Road, Southall, Middlesex, May 1963. The symposium held at the Royal Geographical Society, London, on May 7 and May 8, 1963, covered requirements, experience, and expectations for the ground station, airborne terminals, propagation, and international standardization.

[4] The FAA project to extend both voice and data communications via the VHF troposcatter medium has been pursued in parallel with its effort to cover the air space over the open ocean by means of a satellite relay. The question remains whether line-of-sight troposcatter and satellite facilities can be kept technically compatible despite overlapping of VHF propagation in a practical system.

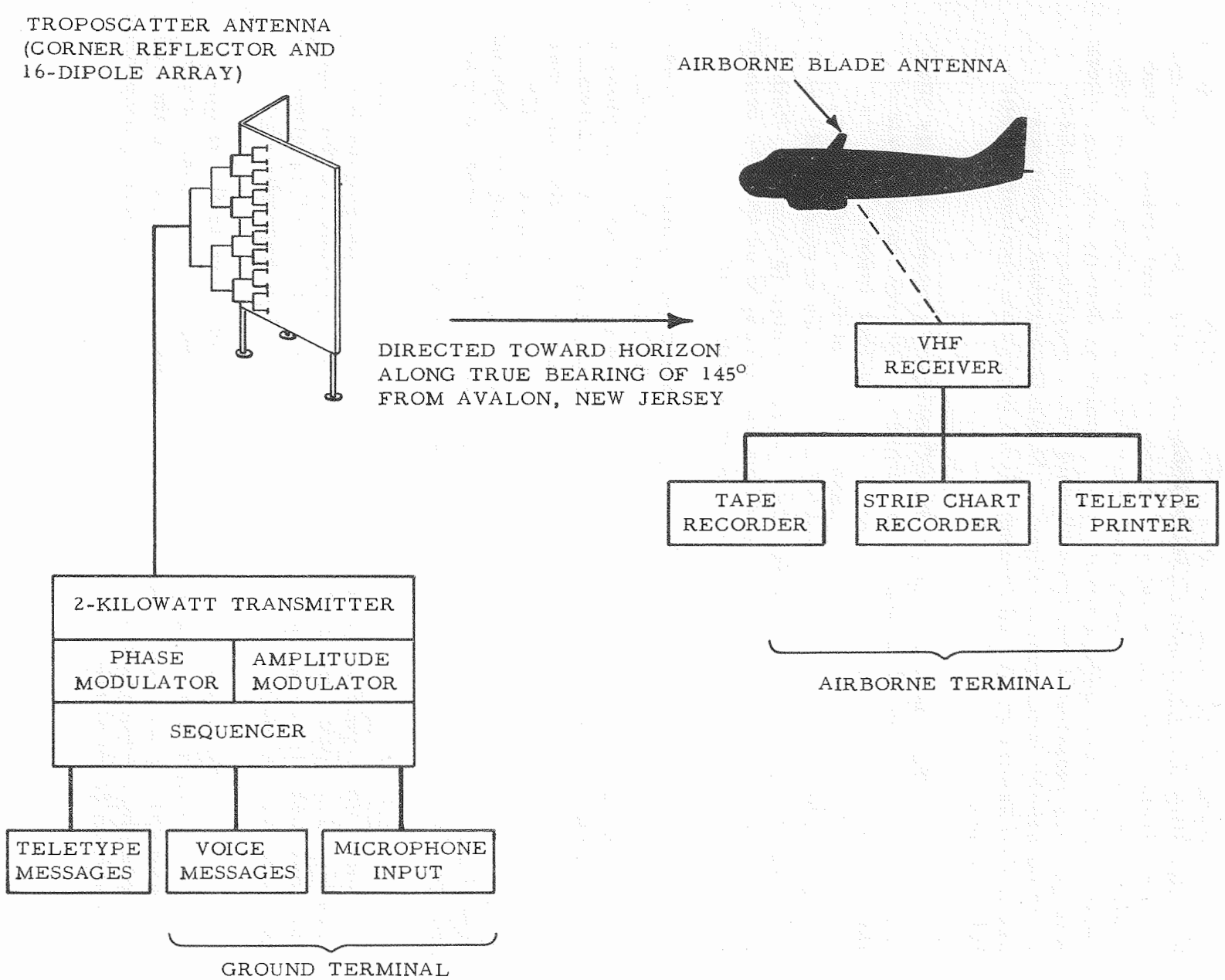

FIG. 1 SIMPLIFIED DIAGRAM OF EXPLORATORY TEST SYSTEM

Troposcatter Antennas at Ground Terminal - A survey of sites in the vicinity of the National Aviation Facilities Experimental Center (NAFEC) had identified an abandoned CONSOLAN station at Avalon, N. J., as the most desirable place to establish a troposcatter ground station. It was readily available, accessible, and relatively free of electrical or radio noise. In the surrounding rural area, population density was low, there was general isolation from trucking and heavy machinery, and there were no nearby industrial facilities. These background conditions seemed to assure continued freedom from excessive electromagnetic interference.

The slave station of the CONSOLAN system, with its 300-foot antenna, had been located approximately 5700 feet to the north of the CONSOLAN master station. After the 300-foot antenna was dismantled, the 15- by 20-foot equipment building of the slave station, latitude 39°08'20" N., longitude 74°45'25" W., was restored and two new VHF antenna towers, 110 feet tall, were erected (Figure 2). Both antennas were located near this building and arranged so that the benefits of space diversity reception could be studied with them.

Separation of the two Avalon troposcatter antennas corresponded to some 80 wavelengths in the band from 118 MHz to 136 MHz. The northeast tower was 600 feet away from the southwest tower along a true azimuth of 55°. This pair of antennas was situated in the saltwater meadows a few miles to the northwest of the beach front. Both antennas were aligned so as to radiate in parallel along a true azimuth of 145°. Each antenna had two vertical screens forming a corner reflector behind a vertical array of 16 colinear dipoles (Figure 3). Gain compared to an isotropic source was about 24 dB. See also Appendix I.

Ground Terminal Equipment - In addition to the troposcatter antennas, the experimental ground terminal included subsystems for message generation and control, for modulation and transmission, and for reception of messages from the test aircraft. The configuration operated during the exploratory tests is described in Appendix II.

The message-generating facility delivered to the radio-frequency modulators samples of a constant-frequency test tone, standard teletype signals, and voice messages. The facility repeated the cycle of tones and messages during phase modulation (PM) and during amplitude modulation (AM) of the radio-frequency carrier.

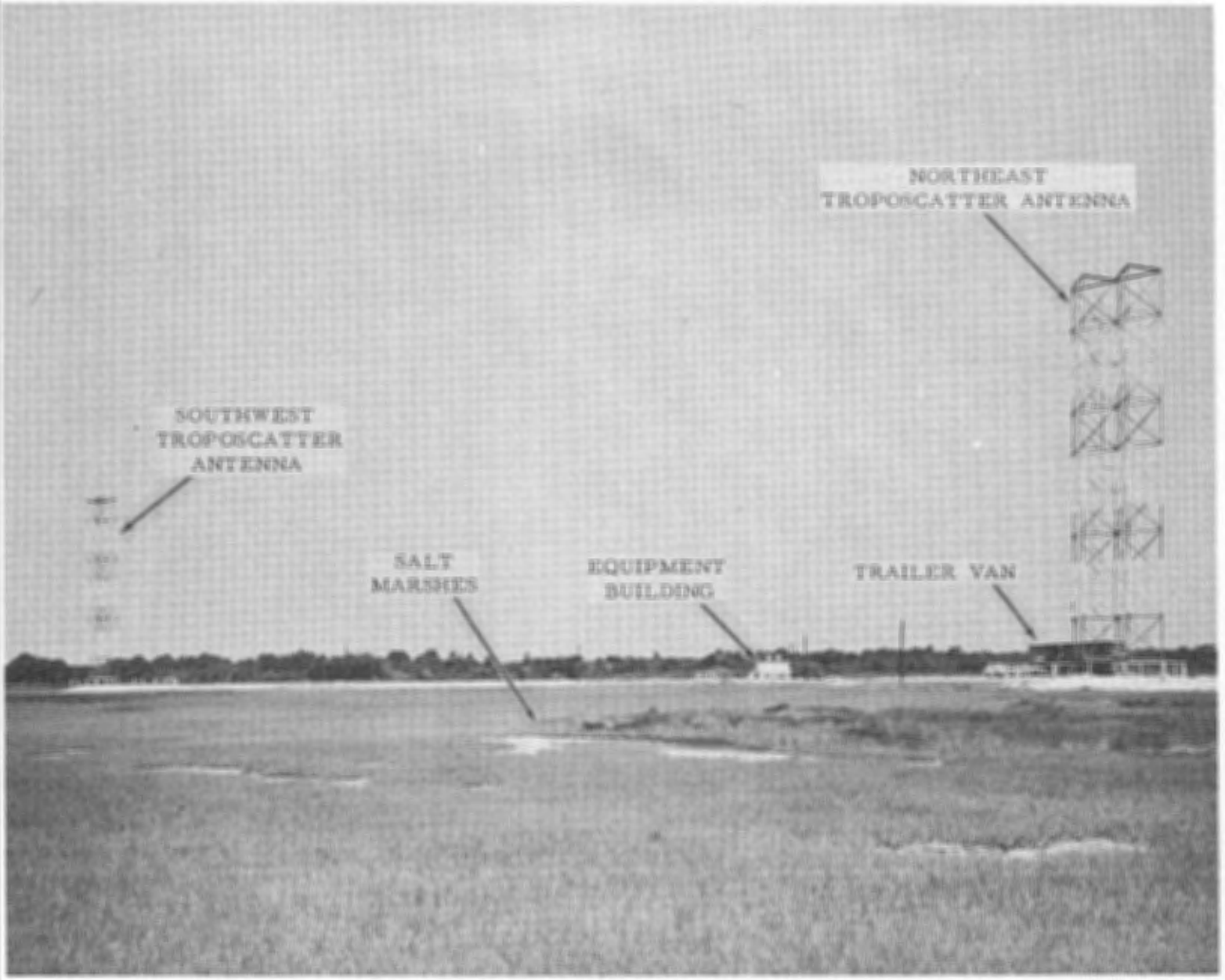

FIG. 2 VIEW OF TWO VHF TROPOSCATTER ANTENNAS AT AVALON, NEW JERSEY

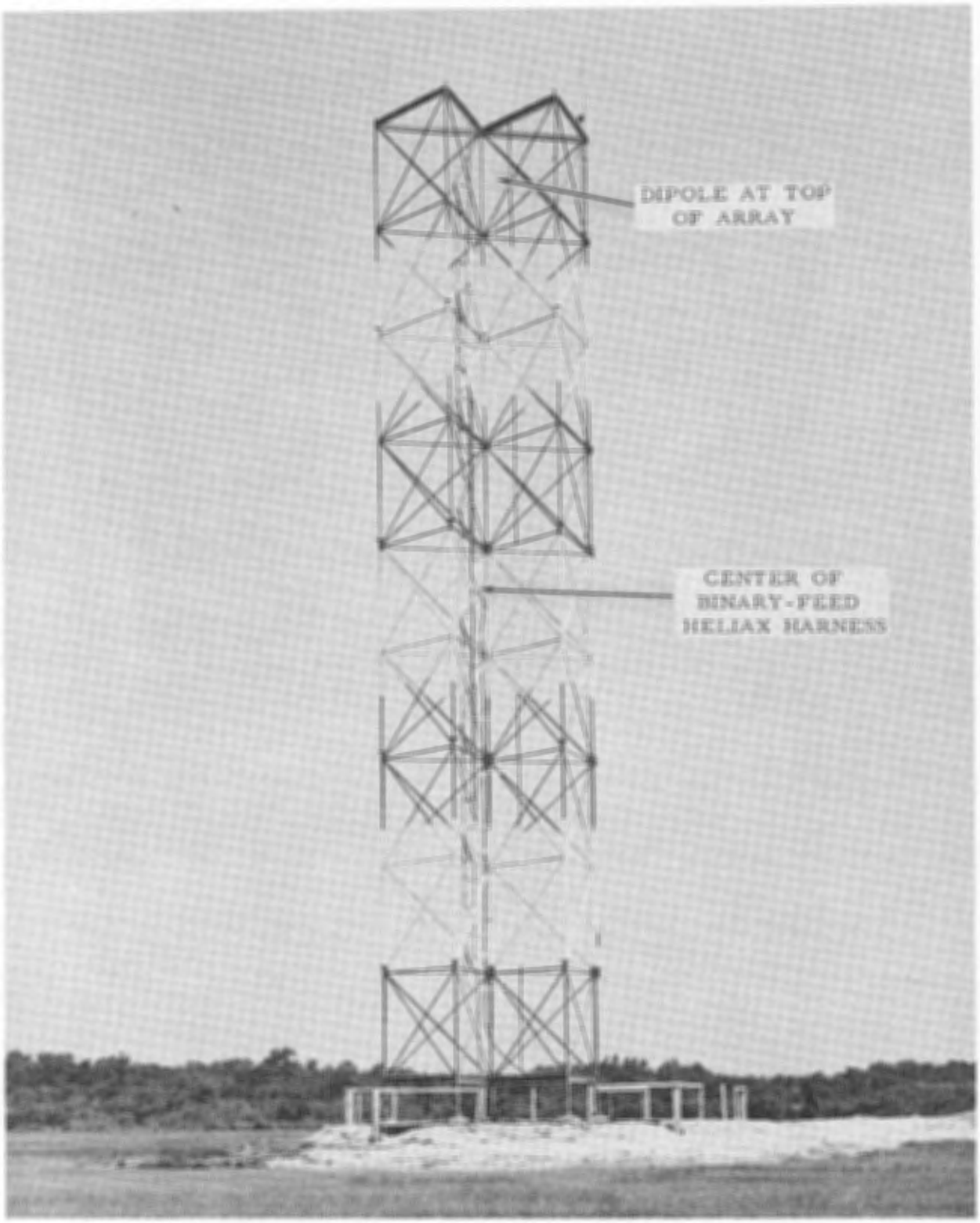

FIG. 3 CLOSE-UP VIEW OF TROPOSCATTER ANTENNA WITH 16 DIPOLES IN A VERTICAL ARRAY

Output power at VHF frequencies was derived from a 2-kW linear amplifier driven by a 50-W exciter.

A Collins Type TE-204 A-4 Data Modem, using frequency-shift keying to convert binary data into four audio tones, modulated the exciter. Although capable of detecting as well as producing Audio-Frequency Shift Keying signals, the data modem functioned only as an AFSK modulator in the ground terminal.

Airborne Antennas - The airborne antenna, Bendix Radio Type ANA-22A, was mounted at an opening provided for project antennas about 5 inches to the port side of the top centerline at Station 265 of a Grumman G-159 "Gulfstream" aircraft, (Figure 4). This location was aft of the propellers and nearly in line with the leading edge of the wing at its root. The special antenna was offset from the top centerline to avoid cutting structural members; it was tilted from the vertical approximately 5° to the port side. The ANA-22A antenna had been designed to handle as much as 250 watts of transmitter power from 118 to 150 MHz.

The smaller operational VHF antenna, not shown in Figure 4, was located on top of the aircraft, forward of the project antenna, at Station 237; it was aligned vertically at the centerline. One end of a high frequency (HF) communications antenna wire was secured to the top of the aircraft structure at Station 151 near the cockpit and the other end was secured near the top of the vertical tail surface at Station 637.

Airborne Terminal Equipment - Compatible with the airborne antenna, the airborne terminal included subsystems for reception, processing and recording both the test messages and certain performance data. The airborne equipment and test instrumentation for the exploratory tests are described in Appendix III. In addition, there were airborne transmitters which delivered test signals to the airborne antennas during preliminary tests and furnished incidental air-to-ground communications signals during the exploratory testing program.

The airborne receiver for the test messages was especially chosen for its performance and versatility. In the laboratory, the sensitivity of this receiver was measured at -127 dBm. However, as installed the effective sensitivity was in the order of -124 dBm.

Audio output of the receiver was monitored, recorded, and processed. A data modem, identical to the Type TE-204 A-4 utilized at the ground, recovered binary data from the received four-tone modulation.

FIG. 4 VIEW OF "GULFSTREAM" G-159 AIRCRAFT CONTAINING AIRBORNE TERMINAL

Theoretical Notes: In Appendix IV consideration is given to several aspects of propagation theory which were part of the background behind the planning of tests and interpretation of results.

Unknown at the beginning were the most efficient type of flight plan, the problems of data processing that would arise, the system behavior when carrier-signal level was just above the threshold of receiver sensitivity, the shape of the antenna radiation patterns, and whether the environment might actually confound the results of tests.

One of the assumptions underlying the experiment, therefore, was that absolute control of all the test conditions was not needed for a comparative evaluation.

It was expected that the aircraft would reach a distance beyond the horizon before the level of carrier-signal power would approach the limit of receiver sensitivity and the airborne radio receiver would no longer be able to sense the intelligence in a message. Before signals were lost, errors were to be counted during teletype transmissions as the basis for comparing modulation techniques.

All of the observations reported herein were concentrated during the summer months when meteorological conditions have been known to favor over-ocean propagation of radio signals. Earlier experiments had suggested that during winter, communication distances would be less than during the summer. Nevertheless, summertime conditions were accepted as a useful sample of tropospheric propagation conditions for a test to compare one form of modulation with another.

DISCUSSION

Test Program

The test program consisted of three parts: several static tests during preparation of the exploratory test system; a few preliminary flight tests; and the formal exploratory flight tests.

Preparation of the Exploratory Test System: Incidental to the inspection of contractors' work at the site of the ground terminal, measurements were made of antenna noise temperature and voltage standing wave ratio (VSWR). Tests of other parts of the system were performed in the laboratory at NAFEC.

Antenna Noise Temperature - During the initial preparation of the site, the level of background electrical noise in the vicinity of the antennas had been surveyed. No evidence of appreciable man-made or industrial noise had been detected. Noise actually entering the troposcatter antennas was sampled. A VHF receiver, DEI Type TMR-6, a Brush strip-chart pen recorder, and a calibrated noise generator, manufactured by Airborne Instruments Laboratory, were arranged so measured amounts of artificial noise could be compared with natural noise picked up by way of the SW antenna. Antenna noise temperature in degrees Kelvin (^{o}K) was measured 48 times at 1-minute intervals by substituting a calibrated noise source for the antenna to get equivalent noise; average value was 398° K.

Voltage Standing Wave Ratio (VSWR) - A survey of VSWR over the frequency range from 118 MHz to 136 MHz was carried out by the method of comparing incident and reflected power at a Thruline wattmeter. Bendix Model RA-41A VHF transmitter was tuned across the band at 1-MHz intervals. Table I contains the results of this measurement for both antennas at the ground station. At no frequency did VSWR exceed 1.6 for either antenna. At the frequencies assigned to the project for the test program (129.25, 133.2, and 133.4 MHz) VSWR was less than 1.2 at both antennas. At the operational frequency of 123.4 MHz, the VSWR at the SW antenna was about 1.2. VSWR was also measured in the project aircraft while the airborne antenna ANA-22A was connected to the receiving terminal; the ratio did not exceed 2.0 at any frequency from 116 MHz to 152 MHz.

TABLE I

VOLTAGE STANDING WAVE RATIO MEASURED AT TWO VHF TROPOSCATTER ANTENNAS

Frequency MHz	Northeast Antenna VSWR	Southwest Antenna VSWR
118	1.33	1.33
119	1.42	1.12
120	1.24	1.55
121	1.17	1.47
122	1.27	1.37
123	1.35	1.12
124	1.22	1.20
125	1.08	1.24
126	1.16	1.07
127	1.17	1.23
128	1.09	1.26
129	1.16	1.14
130	1.22	1.26
131	1.14	1.22
132	1.12	1.04
133	1.17	1.09
133.2	1.18	1.10
134	1.12	1.04
135	1.04	1.25
136	1.11	1.58

System Test and Adjustment - Gain noted in some of the back lobes of the fixed-antenna pattern was sufficient to support static laboratory tests of the exploratory system. Before installation of the airborne equipment, it was placed in operation at the NAFEC laboratory, about 25 statute miles from the Avalon site. A yagi antenna with a forward gain of 10 dB was roughly pointed into these back lobes for a ground-to-ground check of system operation. Later, the airborne terminal was also able to receive signals at NAFEC directly from the Avalon site while undergoing pre-flight exercises in the parked aircraft. All elements were found to operate satisfactorily.

During pre-flight exercises, optimum modulation index was selected for PM and AM modes of carrier modulation. The frequency deviation in the PM module was first adjusted manually until distortion of the audio test tone was noted at the receiver. Then, the frequency-deviation control was returned to a setting at which the tone was once again free of distortion.[5]

The AM exciter was adjusted to produce 95 percent modulation as indicated on a standard oscilloscope where a sample from the resonant cavity of the linear amplifier was displayed. This method of adjusting modulation of the carrier in AM and PM modes was followed also in preparing for the exploratory tests.

After adjustment for normal operation, variations in power-output were observed. Power delivered by the 2000 watt transmitter appeared very stable. It varied throughout the ensuing flight tests not more than 50 watts, a fraction of 1 dB.

Components of the system were calibrated according to the manufacturers' instructions. Since the test was primarily a comparison between two modes of modulation, special care was taken to make their treatments and the measurements comparable. The test concept did not require exact objective determination of absolute performance, principally because there were so many uncontrolled factors, such as meteorology, but also because a short daytime sample, taken in one season only, could not be counted as representative of performance throughout the year.

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[5] No deviation meter was available; although through this cumbersome procedure the exact deviation was not determined, the adjustment was considered reasonably close to maximum allowable, and sufficiently repeatable for purposes of exploratory testing.

Preliminary Flight Tests: The flight test program started with investigation of the nominally-horizontal radiation patterns for the ground and airborne antennas followed by a series of preliminary survey flights, an air-to-ground test of diversity-reception, a long-distance flight to check operation of the complete exploratory test system, and a series of four exploratory flights, in a 3-day period, to collect the quantitative exploratory data. During the preliminary survey flights, transmission was from air-to-ground only. The later long-distance maneuvers involved transmission from ground-to-air only.

Appendix V is a copy of the Tropo Test Flight Operations Plan which governed the ground-to-air test operations. Preliminary flights had been governed by similar plans, each showing the prescribed operational routes, check points, and maneuvers.

One brief flight was conducted mainly to investigate whether there were troublesome sources of daytime electromagnetic interference within the back radiation lobes of the troposcatter antennas. There was no appreciable interference during the flight.

Test Operations Planning - Coverage attainable with the high-gain troposcatter antennas was estimated from earlier tests and examination of the antenna patterns. The weak-signal limits of the radiation from the main lobe were calculated between 500 and 600 nmi.[6] Estimates were based on the ground-antenna gain of 24 dB, transmitter power of 2 kW, minimum detectable signal level of -124 dBm, and flight altitude of 19,000 to 20,000 feet. Test operations, therefore, were expected to be concentrated within 200 nmi of Bermuda in an area bounded by longitudes from 66°W to 74°W and latitudes from 31°N to 35°N. Operations as far down range as 500 nmi from Avalon, N. J., were possible in a Gulfstream G-159 aircraft because it could operate out of Kindley Air Force Base, Bermuda.

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[6] Prior experimentation with the Barnstable system propagating over the Atlantic Ocean had indicated that ground-to-air communications could be sustained with 95% probability to a minimum all-year-round distance of 360 nmi. To achieve that performance, the airborne terminal would operate at about 20,000 feet with a receiver sensitivity of -124 dBm and the ground transmitter would deliver 4 kW to the 24 dB antenna.

General Shape of Troposcatter Antenna Patterns - To obtain data for the antenna pattern of the ground antenna, the aircraft was operated in an orbital flight about the Sea Isle VORTAC Station. With the Sea Isle VORTAC at the center of the maneuver, the aircraft flew a constant 20-mile radius at reduced speed holding an altitude of 3700 feet. During two such orbital runs, winds of about 18 knots came from a true bearing of about 210°. From the aircraft, 1 watt of continuous carrier power was broadcast at 133.2 MHz. Since the Sea Isle VORTAC is approximately 4 miles to the southwest of the Avalon antenna, the data had to be corrected for differences in the propagation path due to parallax. Furthermore, elevation angle had to be corrected, in some sectors, for parallax differences and for earth's curvature. Data taken to determine the general horizontal shape of the troposcatter antenna patterns, and corrected for parallax effects, are plotted in Figure 5.

At a true bearing of 40° and a distance of 16 nmi from Avalon, the elevation angle to the aircraft, corrected for effects of earth's curvature, was 2.1° above the horizontal. At a true bearing of 220° and a distance of 24 nmi from Avalon, the corrected elevation angle to the aircraft was 1.3°. In the direction of the principal axis, that is, along a true bearing of 145°, while the radial distance was 20 nmi, the corrected elevation angle was 1.6°.

For purposes of test planning, the horizontal pattern was assumed to be symmetrical about its axis along 145°T, both halves resembling very closely the shape of the sector plotted in Figure 5 between azimuth angles from 145°T to 325°T. Effects of geometric distortion and instrumental inaccuracies probably deteriorated the data by 1 to 2 dB.

Throughout a sector from 70°T to 220°T most of the available energy was radiated. The test generally confirmed that the orientation of the principal axis was along a true bearing of 145°. Furthermore, back radiation lobes had been suppressed to levels 35 dB or more below the maximum level of the principal forward lobe. Nevertheless, the back lobes still had enough gain to permit VHF communication signals or interference to enter the antenna at detectable levels.

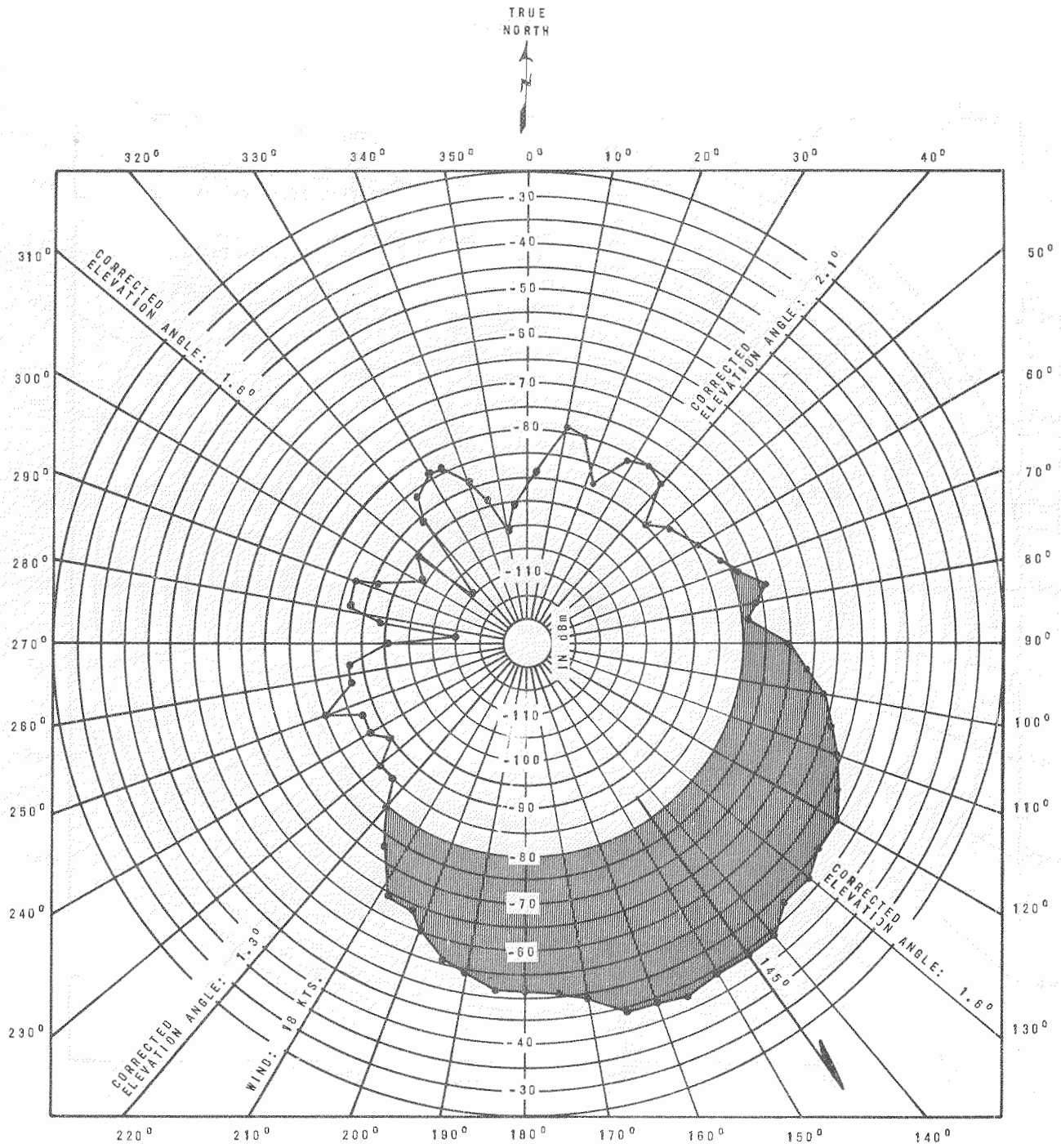

FIG. 5 NEAR-HORIZONTAL RADIATION PATTERNS OF N. E. TROPOSCATTER ANTENNA AT 133.2 MHz

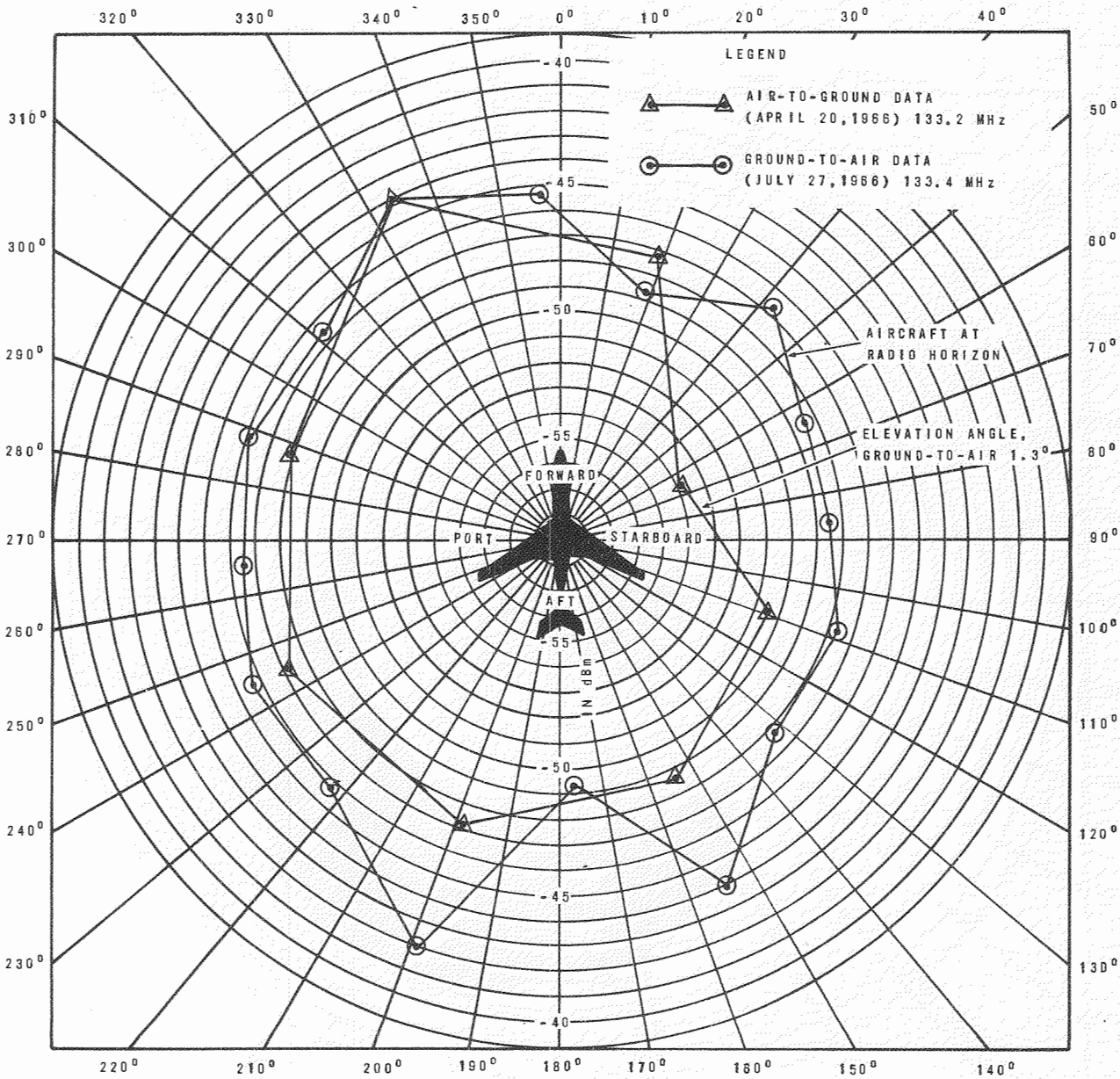

FIG. 6 HORIZONTAL AND NEAR-HORIZONTAL RADIATION PATTERNS OF AIRBORNE ANTENNA

General Shape of Airborne Antenna Patterns - The general shape of representative radiation patterns of the airborne antenna, Type ANA-22A, as mounted at Station 265, offset by 5 inches from the top centerline of the Grumman G-159 aircraft, was determined by flight testing. The first test made use of an airborne transmitter operating at a constant level of output power through the airborne antenna. Received signal levels were recorded at the troposcatter antenna as the aircraft was maneuvered through a cloverleaf pattern into eight straight-line courses. These straight runs were arranged in the pattern so that all intersected over a common point. Since the altitude of the aircraft for this test was 20,000 feet and the distance 100 nmi, effective elevation angle in the vertical pattern, taking into account the earth's curvature correction, was down 1.3°. Results are presented as an eight-point pattern in Figure 6.

Since the project antenna was offset from the centerline and tilted 5° to the port side, it was not a surprise to find the pattern asymmetrical. The pattern showed several dB greater gain to port than to starboard. The pattern also suggests that gain was slightly greater looking forward than aft.

A second test was conducted to assess qualitatively the performance of the system as a function of aircraft orientation, for relatively low signal strengths. For this test, a signal was radiated from the troposcatter antenna and received in the airplane. The airplane was maneuvered very close to the radio horizon in a cloverleaf pattern with 16 headings. Distance from ground station to aircraft was 150 nautical miles, and aircraft altitude was 15,000 feet. Results of this test are also shown in Figure 6.

Diversity Reception - Fading has been common in VHF radio reception. Great changes of carrier-signal level have been reported, sometimes for brief moments and sometimes at length. When communication distances are extended so far that the system is operating at the limits of its performance, deep fades can hold the carrier level below receiver sensitivity for seconds; fading, therefore, can interrupt messages. Arrivals of energy at the receiving antenna via several alternate paths of slightly different length probably cause most fading. Often, the effects of short-term fading, which follows a Rayleigh distribution, can be overcome by applying diversity to the system. Long-term fading, which responds

primarily to the gradient in the refractive index of the atmosphere, is not appreciably corrected by diversity. One of the preliminary experiments was to test for protection against fading by space-diversity reception at the ground station. The test consisted of recording, at both troposcatter antennas, a continuous wave of energy broadcast from the project aircraft. The flight down range, along a true bearing of 137°, was continued to a radius of 350 nmi and then the aircraft returned along the same path holding its altitude at 20,000 feet. During this test the airborne transmitter supplied 250 watts at 133.2 MHz to the airborne antenna, Bendix Type ANA-22A.

A TMR-5A receiver was connected to the NE antenna and Type RV-8-8 receiver with Type FAA-5433/4 preamplifier to the SW antenna. AGC output from these calibrated receivers was recorded as a measure of signal strength. Levels of power received at the two antennas during outbound and inbound legs of the flight are presented in Figures 7 and 8, respectively. Deep fading to the limits of receiver sensitivity was observed at the SW antenna as the aircraft reached 220, 280, 300, 310, and 330 nmi during the outbound leg. During the return leg, deep fading of signals again was observed at the SW antenna, at distances of 305, 300, and 260 nmi. Reception via the NE antenna apparently could have compensated for most of the fading at the SW antenna, but it was not feasible to obtain quantitative proof since the receivers at the two antennas were not identical.

Air-to-ground voice communications were tried with the 250-watt airborne transmitter; strong signals were still being received at 350 nmi when the aircraft turned back. Extrapolation from the plotted data suggested that usable voice messages should have been received, by one antenna or the other, at least to 450 nmi if the flight had been continued.

Preliminary Long-distance Flight Test - A long flight was made to Checkpoint Charlie on the periphery of the Bermuda control zone. At that point, some 488 nmi from Avalon, the aircraft turned. During the 3-hour flight, transmission was from ground-to-air. During 42 of the 84 teletype messages transmitted for this test program, the carrier of the 2-kW linear amplifier was phase modulated; the other 42 were propagated as amplitude modulation. Seventy-seven of these messages were error free while seven erroneous messages occurred, three during phase modulation, and the other four during amplitude modulation. A total of eight erroneous characters was observed throughout the flight out of almost 12,000 characters transmitted.

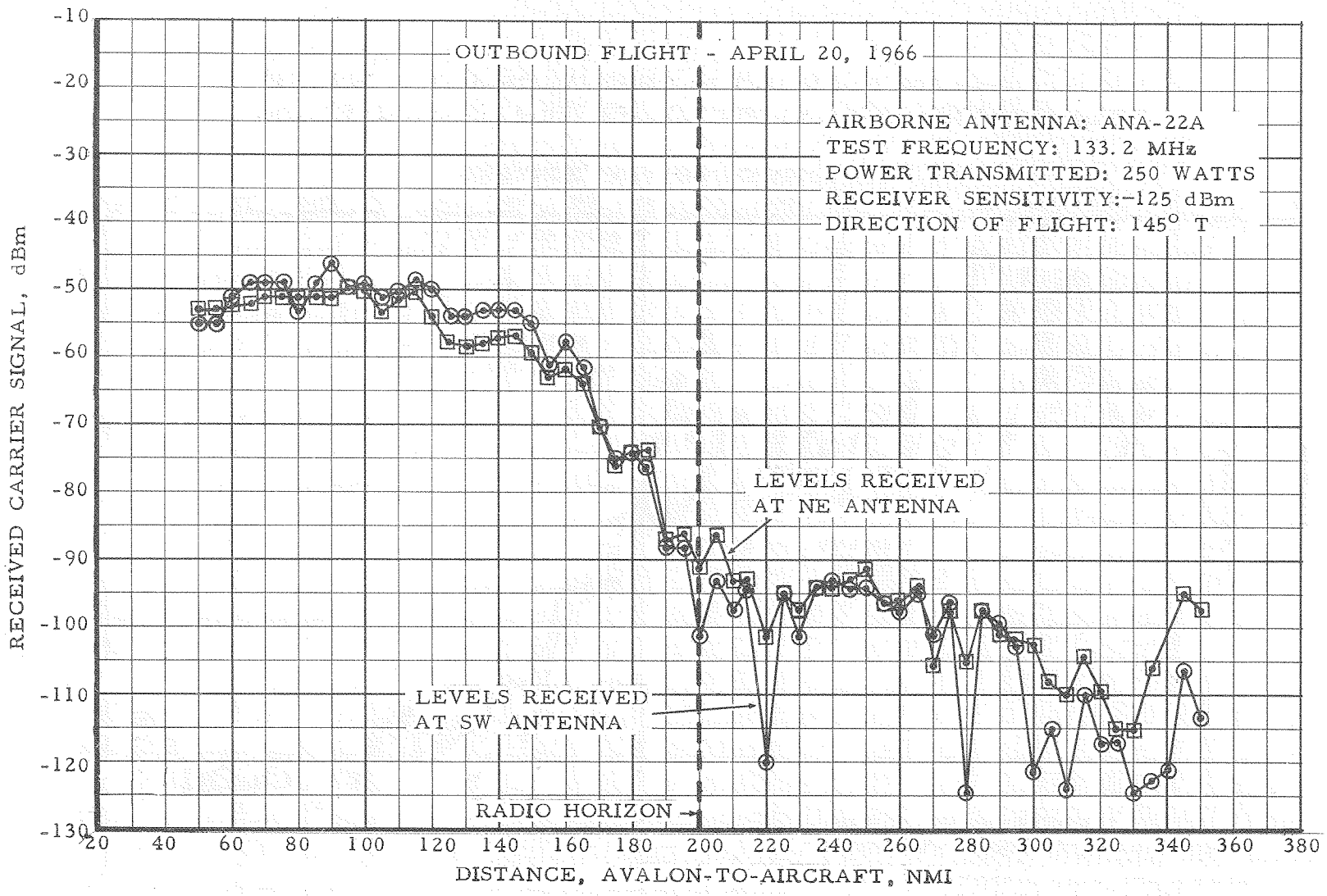

FIG. 7 SPACE-DIVERSITY RECEPTION VIA TWO VHF TROPOSCATTER ANTENNAS DURING OUTBOUND FLIGHT AT 20,000 FEET, APRIL 20, 1966

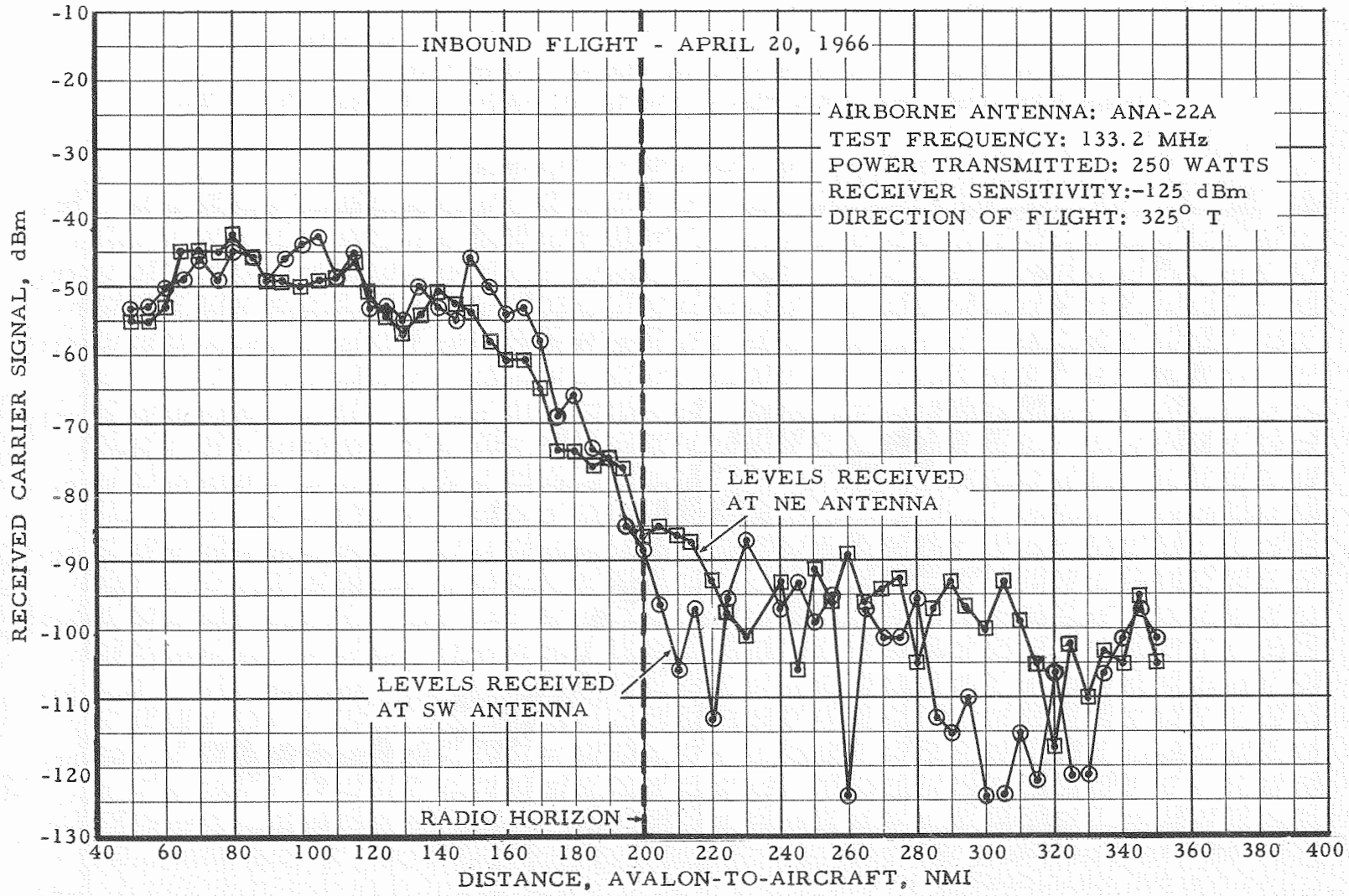

FIG. 8 SPACE-DIVERSITY RECEPTION VIA TWO VHF TROPOSCATTER ANTENNAS DURING INBOUND FLIGHT AT 20,000 FEET APRIL 20, 1966

After the end of each received message, whether the printout was correct or partially incorrect, there appeared, usually on a lower line, a number of additional characters which had not been transmitted and made no sense. The exact cause was not determined; but the extraneous characters were attributed to the interruption of synchronization of the Collins Data Modem as the sequencer at the ground station switched from one type of test signal to another. Occasionally the random characters after a message overprinted part of the last line of the message.

Three of the eight observed errors were the absence of a figure "3" after a space. These errors were attributed to the condition of the airborne printer. Thus, only five independent errors were counted.

Figure 9 shows how carrier signal level varied with time and distance during the 200-minute test. Also shown at the top of the figure is the direction of flight relative to Points SHAD and CHARLIE. At no time during this test did the level of carrier signal fall below the threshold of receiver sensitivity of -127 dBm; background noise and noise associated with the airborne installation placed the practical limit of receiver sensitivity at -124 dBm.

A weak cold front had been observed near Avalon. There was cloudiness to the north and west of the front, but clear skies to the south. Air aloft was relatively dry and a superrefractive layer existed near the surface. Flow was southwesterly near the surface and westerly at 20,000 feet.

Exploratory Flight Tests: After the main features of the radiation patterns of both the fixed and airborne antennas had been investigated, two types of carrier modulation were compared; test messages were alternated between them while measurements of the received power were being made in the project aircraft. For the formal exploratory tests, signals were propagated from ground-to-air by VHF carrier, modulated first by PM and then by AM.

The test-message sequence began with a steady tone followed by a period of no modulation during which noise could be observed. Then the sequence continued with a prepared teletype message, a short period available for a live-voice message, and finally a taped voice message. After each AM sequence, the carrier-frequency signal was interrupted to afford the transmitter a brief rest period.

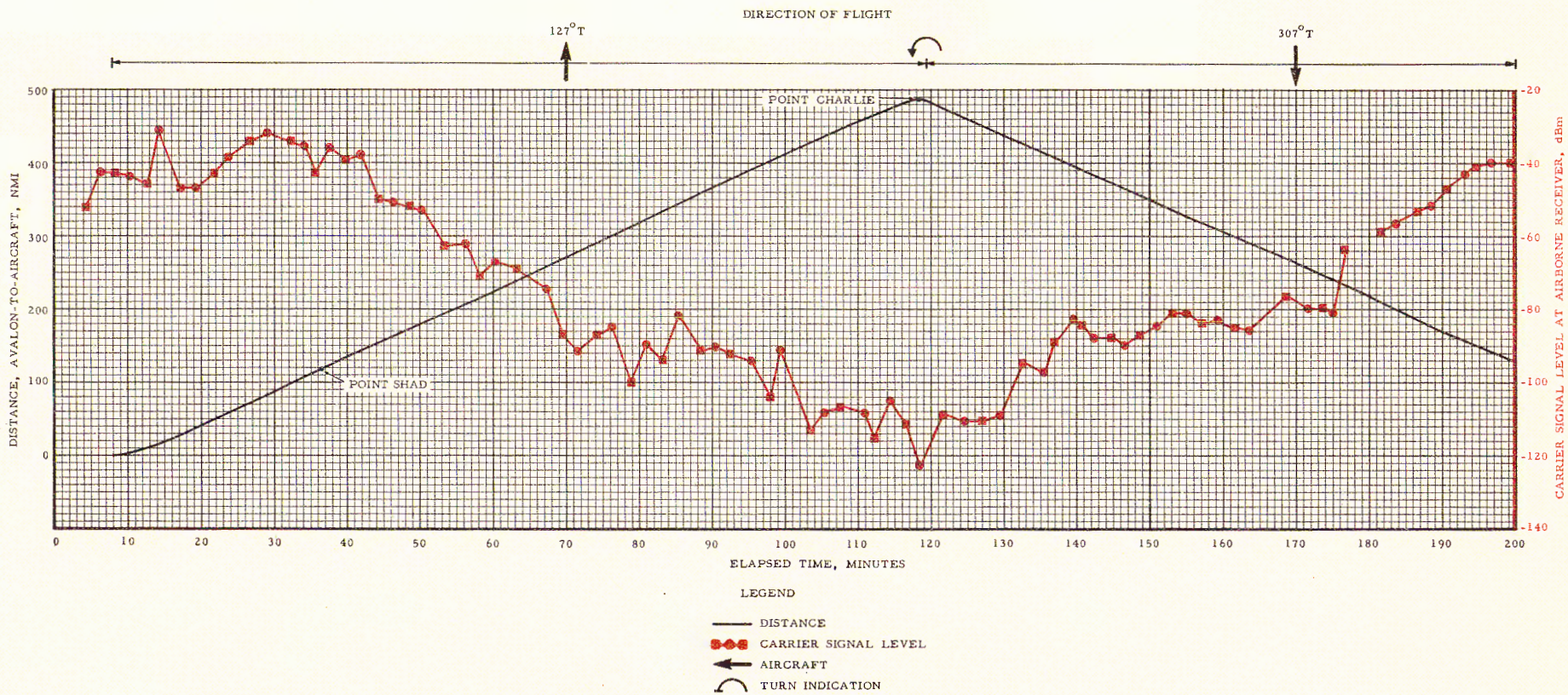

FIG. 9 DISTANCE TO AIRCRAFT AND CARRIER SIGNAL LEVEL AS FUNCTIONS OF ELAPSED TIME DURING PRELIMINARY FLIGHT JULY 27, 1966

The airborne test record on magnetic tape, on strip charts, and on the teletypewriter as appropriate, indicated how teletype message errors, VHF-carrier signal power, the ratio of signal-plus-noise to noise, and the general quality of voice messages varied as they were received in the down-range regions where the level of the carrier power was very low.

Meteorological Conditions During Exploratory Flight Test - Winds aloft were steady and light during the exploratory flights. During most of Flight #1, winds were from 220° at 15 to 20 knots producing an average crab angle of 3.5° to the right. During Flight #2, winds were from 240° at 15 knots producing 3° of crab angle to the right when heading toward Bermuda and to the left when heading away from Bermuda. Crab angle was less than 1° during the excursion from the Victor route to the axis of the Avalon pattern antenna. Similar wind conditions also existed during Flights #3 and #4. The 500 millibar charts of the Daily Weather Map, U. S. Department of Commerce, for the 3-day flight test, showed a steady southwesterly flow over the first few hundred miles off the coast of New Jersey. Throughout the 3-day period slight precipitation of a few hundredths of an inch per day was recorded by the Weather Bureau over the South Jersey area.

Surface refractivity at the transmitter site was not available. Surface refractivity at Wallops Island, Virginia, was from 370 to 380 N units.[7] Refractivity gradients determined at Wallops Island from the soundings at 1200 feet showed some indications that these could have been superrefraction at the surface and at 4000 feet on the second day. Trapping conditions were not identified. Superrefraction also was indicated at Bermuda without evidence of trapping.

General Description of Exploratory Flights - On the morning of the first day the Gulfstream passed over the Avalon site, followed the nearby air corridor to the corner of the warning zone near Checkpoint Shad and thence continued at 20,000 feet along a true bearing of 145°, parallel to the Yankee Route laid out over the principal axis of the troposcatter antenna pattern (See Appendix V, Figure V-1). When

[7] $N=(n-1)x10^{+6}$ where n is the index of refraction.

the signal received in the aircraft was no longer satisfactory, at a distance down range of about 515 nmi, the aircraft proceeded to Kindley Air Force Base in Bermuda. On the second and third days the aircraft flew back and forth along the Victor Route, course 129°T through the weak-signal regions of the troposcatter propagation (See Appendix V, Figure V-2). On the afternoon of the third day the aircraft returned to Avalon along the Charlie Route, course 307°T, for the fourth and final flight of the 3-day test. Fourteen transits of the weak-signal threshold region had been completed. During these flights, the aircraft traveled along its straight and level courses at a speed of about 5 miles per minute. Thus, the position of the aircraft changed by almost 1 mile from the start to the end of a teletype message.

A total of 8 hours of test recording was accumulated as follows: Flight #1, 112 minutes starting about 0945 EDST; Flight #2, 183 minutes starting about 0903 EDST; Flight #3, 124 minutes starting about 1000 EDST; and Flight #4, 76 minutes starting about 1530 EDST.

While the NE antenna was being used for transmission during the exploratory tests, the SW antenna was rigged for reception via the operational VHF systems of the project aircraft.

After the scheduled shuttle maneuvers had been accomplished on the second day, aircraft re-entered the radiation pattern and, upon reaching a point about 420 nmi from Avalon, turned left to make a lateral excursion from the Victor Route onto a course of 217°T. This course was followed until the aircraft came over the axis of the main lobe along the true bearing of 145° from Avalon. The aircraft turned 180°, returned to the Victor Route, where it made the only right turn of the test, and then passed over Point Charlie on its way back to the Bermuda base.

All the exploratory flight tests described above made use of the northeast antenna.

An incidental observation made with the southwest antenna also was noteworthy. As the first flight proceeded away from Avalon on the first day, voice transmissions from the aircraft had been monitored continuously at the ground terminal until a distance of 315 nmi was reached. The 25-watt airborne transmitter, Collins Type 17L7, operated at 123.4 MHz through the standard Collins Type 37R-2 VHF blade antenna on the topside centerline at station 237.

Structure of Test Message - Seven test messages were prepared in teletype format. Each message was composed of typical air traffic control information. The specially-modified equipment could not reproduce exactly the standard set of teletype characters but, for almost all cases, the letters followed the standard 5-unit teletype code. Available figures corresponded with Standard Type D code.

Each message was preceded on the tape by an identifying word group; e.g., either "MESSAGE 1 PHASE MODULATION" or "MESSAGE 1 AMPLITUDE MODULATION." Although the text of each message was different in detail from the others, all messages were much alike (see Appendix II, Figure II-2). The several different characters for each message and its identification included control signals for letters, letters shift, figures, figures shift, line feed, carriage return and spaces. The largest total number of characters, 152, was found in message #5; the smallest number, 143, was found in message #4. The average number of characters per message, to the nearest whole number, was 147.

On the average, teletype test messages contained 62 letters, 32 figures, and 55 control characters. Among the control characters, 10 were letters shift, 8 were figures shift, 10 were line feed, 4 were carriage return and 23 were space; some spaces appeared before and some followed the text. Since each of the characters included a space at the beginning and a mark at the end, the total number of possible mark and space bits per message was, on the average, 1029 bits.

Voice messages contained essentially the same information as the teletype messages.

There were some cases where fading lasted for most or all of a 20-second message.[8] However, most fading which reached carrier signal levels of -122 dBm lasted less than 5 seconds.

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[8]The exploratory data were not analyzed in respect to probability of fading, duration of fade, or depth of fade. This extremely small sample of the operating environment was considered too small to support worthwhile calculations of such characteristics.

Analysis of Exploratory Test Data

The several types of recordings taken during exploratory tests on paper charts, on teletype printout paper, and on note paper, were first reduced to tables in which values were adjusted for calibration-corrections, correlated with time and aircraft distance. The corrected data were plotted graphically and the graphs examined to guide the numerical analysis of teletype inaccuracies. Teletype messages were studied in detail; inaccuracies were analyzed according to several directions of flight and distances to the aircraft. Then, voice recordings on magnetic tape were listened to and some were related to fading by comparison with pen recordings of AGC voltage at the airborne receiver.

First the errors in teletype messages were simply counted because counting offered the possibility of an objective, quantitative comparison. A summary of the teletype data is given in Table II.

This tabulation of errors did not show clearly that either AM or PM was superior for teletype transmission at VHF; chance could have allowed more PM messages to occur during the turns. Each message was reexamined individually. However, detailed explanations of individual inaccuracies were not available. A complete analysis would have required a detailed comparison of the changing levels of noise, carrier power, and interference, as recorded during particular time intervals when each corresponding teletype character was being received. Furthermore, along the radial first and fourth flights, distance to the aircraft was less than 488 nmi during most of the simple counting so that averaging of errors was not appropriate.

Graphical Treatment of Teletype Data: Each exploratory flight produced an abundance of data. Plotting against distance was not practical because of the back and forth shuttle maneuvers, the lateral excursion, and the numerous turns. There was no convenient way to portray carrier signal level, signal-plus-noise to noise ratio, distance, direction of flight, time, missing characters, and wrong characters on a single graph. It was convenient to plot average carrier-signal level and the corresponding numbers of missing characters for each PM or AM teletype message against elapsed time on one graph for each flight along with distance and direction of the aircraft. On a companion graph, signal-plus-noise to noise ratio

TABLE II

SUMMARY OF EXPLORATORY TELETYPE DATA RECORDED AT AIRBORNE TERMINAL

Total Number of:	Carrier Modulation	Flight #1 Aug. 9, 1966	Flight #2 Aug. 10, 1966	Flight #3 Aug. 11, 1966	Flight #4 Aug. 11, 1966	TOTALS
Messages Sent	PM	41	67	44	23	175
	AM	41	67	43	24	175
Characters Sent (includes functions)	PM	6037	9859	6468	3381	25,745
	AM	6037	9859	6321	3531	25,748
Correct Characters Received	PM	5948	8302	5643	3085	22,978
	AM	5957	8350	5768	3318	23,293
Wrong Characters Received	PM	15	558	263	79	915
	AM	30	471	110	36	647
Two or More Adjacent errors	PM	1	21	9	1	32
	AM	1	18	3	2	24
Missing Characters	PM	74	999	562	217	1852
	AM	50	1138	443	175	1806
Figure 3 Missing after Space	PM	16	6	17	11	50
	AM	13	15	14	10	52
Teletype Pulses Sent, (1's)	PM	29,975	49,445	32,164	16,813	128,397
	AM	29,975	49,445	31,433	17,544	128,397
Teletype Bits Sent, (1's + 0's)	PM	42,189	68,943	45,276	23,667	180,075
	AM	42,189	68,943	44,347	24,696	180,175

and the corresponding number of wrong characters were plotted against elapsed time along with the same aircraft distance and direction information. Both types of graphs show the boundaries of flight distance, duration of successive frames of test messages, and relative time at which each teletype message started. Appendix VI contains eight graphical figures, two for each of the four test flights. Qualitative interpretations of the data were simplified by choosing elapsed time as the independent variable. The origin of the time base was assigned arbitrarily; true values of the time scale had no immediate bearing on interpretations of the character or interrelationships among the plotted data.

Numerical Analysis of Teletype Inaccuracies: Once the data had been plotted and examined qualitatively, it was easier to decide where the inaccuracies occurred at random and where systematically. By inspection of the graphs, segments of each flight were delimited so that several effects could be investigated separately in a straightforward numerical analysis. Radial courses, both outbound from Avalon and inbound toward Avalon, could be segregated from turns and lateral maneuvers. Similarly, the effects of direction of flight and distance from Avalon could be studied separately.

To organize the numerical data so that PM could be compared with AM, the data for each message, plotted along with aircraft distance against elapsed time in minutes, were marked off in straight flight segments and the error data reassembled, as shown in Table III. Outbound during Flight #1 the aircraft flew along a course of 145°T, and during Flights #2 and #3 along a course of 129°T. Inbound legs of Flights #2, #3, and #4 were along a course of 309°T. Errors during turns, and during tangential maneuvers between straight segments, were reassembled into Table IV. An inspection of the data in these tables suggested that the principal factors governing teletype performance were direction of flight and distance down range to the airborne receiver. Therefore, the data corresponding with straight radial flight segments were once again assembled into Tables V and VI.

At distances less than 440 nmi, the number of teletype inaccuracies was negligible. Beyond 440 nmi, inaccuracies increased with distance until beyond 520 nmi they virtually obliterated the message information.

The question whether AM or PM was superior was approached by a final summarization of data, Table VII.

TABLE III

INACCURACIES IN TELETYPE MESSAGES RECORDED DURING RADIAL/SEGMENTS OF EXPLORATORY FLIGHTS

Flight No.	Distance, Avalon to Aircraft, nmi		No. of Messages		No. of Missing Characters		No. of Wrong Characters		Total Missing & Wrong Characters		Direction Course of Aircraft
	Start	End	PM	AM	PM	AM	PM	AM	PM	AM	True Azimuth
1	380	406	2	2	4	0	0	0	4	0	145°
1	338	490	4	4	3	34	3	11	6	45	145°
1	491	520	2	3	45	42	5	32	50	74	145°
2	427	463	4	3	3	2	5	2	8	4	129°
2	409	485	6	7	76	68	46	48	122	116	129°
2	431	483	4	4	106	98	7	8	113	106	129°
2	484	508	2	2	15	97	19	19	34	116	129°
3	436	486	4	4	6	5	8	2	14	7	129°
3	416	476	4	4	4	2	3	1	7	3	129°
3	433	495	5	5	83	95	18	27	101	122	129°
3	496	550	5	4	162	87	65	25	227	112	129°
2	552	490	6	6	195	335	73	66	268	401	309°
2	489	421	6	6	106	106	88	53	194	159	309°
2	459	404	4	4	42	53	32	73	74	126	309°
2	477	424	5	5	4	39	5	20	9	59	309°
3	545	482	5	5	132	166	30	35	162	201	309°
3	462	427	3	3	1	13	0	5	1	18	309°
3	485	417	4	4	29	4	36	2	65	6	309°
3	480	427	4	4	49	12	28	6	77	18	309°
4	538	486	5	5	199	159	46	32	245	191	309°
4	485	429	5	5	10	3	32	0	42	3	309°
4	428	380	4	4	3	3	1	0	4	3	309°

TABLE IV

INACCURACIES IN TELETYPE MESSAGES RECORDED
DURING TURNS AND TANGENTIAL SEGMENTS OF EXPLORATORY FLIGHTS

Flight No.	Avalon to Aircraft, nmi		No. of Messages		No. of Missing Characters		No. of Wrong Characters		Total No. of Inaccuracies		Direction of Flight
	Start	End	PM	AM	PM	AM	PM	AM	PM	AM	True Azimuth
2	420	426	2	2	2	21	1	22	3	43	Turns from 129° to 309°
2	403	408	2	2	3	5	0	12	3	17	
3	426	430	2	2	2	3	0	0	2	3	
3	416	410	2	3	28	50	26	2	54	52	
3	426	426	2	2	18	1	28	0	46	1	
2	464	460	2	2	129	129	16	6	145	135	Turns from 309° to 129°
2	486	478	2	1	46	56	47	11	93	67	
3	487	486	2	1	56	1	21	0	77	1	
3	477	487	2	2	28	50	26	2	54	52	
2	423	441	11	11	107	84	100	84	207	168	219° 039°
2	441	423	11	12	145	45	108	46	253	91	

TABLE V

EFFECT OF DIRECTION OF FLIGHT ON AVERAGE NUMBER OF INACCURACIES PER TELETYPE MESSAGE

Total No. of Messages		Distance to Aircraft nmi		Characters Missing per Message		Characters Wrong per Message		Average No. of Inaccuracies per Message		Direction of Flight
PM	AM	Start	End	PM	AM	PM	AM	PM	AM	True Azimuth
8	9	436	472	6.5	8.4	1.0	4.8	7.5	13.2	145°
16	16	438	485	12.5	16.6	4.8	4.8	17.3	21.4	129°
18	17	440	502	14.2	11.1	5.2	3.2	19.4	14.3	129°
21	21	494	435	16.5	25.4	9.4	10.1	25.9	35.5	309°
16	16	493	436	13.3	12.3	5.9	3.0	19.2	15.3	309°
14	14	484	432	15.1	11.8	5.6	2.3	20.7	14.1	309°
11	11	423	441	10.7	8.4	10.0	8.4	20.7	16.8	219°
11	12	441	423	14.4	4.1	10.8	4.2	25.2	8.3	039°

TABLE VI

EFFECT OF DISTANCE UPON AVERAGE NUMBER OF INACCURACIES PER TELETYPE MESSAGE

Total No. of Messages		Distance to Aircraft, nmi		Characters Missing per Message		Characters Wrong per Message		Total Character Inaccuracies per Message		Direction of Flight
PM	AM	Start	End	PM	AM	PM	AM	PM	AM	True Azimuth
10	9	408	448	1.1	0.4	0.8	0.3	1.9	0.7	129°
16	16	456	404	3.1	6.7	2.7	6.1	5.8	12.8	309°
23	24	429	489	11.9	12.5	3.2	3.6	15.1	16.1	129°
18	18	485	423	10.4	6.9	3.4	8.5	13.8	15.4	309°
9	9	490	529	24.7	25.1	9.9	8.4	34.6	33.5	129°
16	16	545	486	32.9	41.4	9.3	8.3	42.2	49.7	309°

TABLE VII

SUMMARY ANALYSIS OF INACCURACIES IN TELETYPE MESSAGES RECORDED DURING EXPLORATORY FLIGHTS, AUGUST 9, 10, 11, 1966

Number of Runs each Flight	Average Distance to Aircraft, nmi		Messages Recorded Total		Number of Missing Characters, Totals		Incorrect Characters, Totals		Incorrect and Missing Characters	
	Start of Run	End of Run	PM	AM	PM	AM	PM	AM	PM	AM
Flight #2: 4	437	485	16	16	200	265	77	77	277	342
Flight #3: 4	440	502	18	17	255	189	94	55	349	244
Flight #1: 3	436	472	8	9	52	76	8	43	60	119
Totals: 11			42	42	507	530	179	175	686	705
Averages:	439	488								
Errors per message, outbound runs:					12.1	12.6	4.3	4.2	16.4	16.8
Flight #2: 4	494	435	21	21	347	533	190	212	537	745
Flight #3: 4	493	438	16	16	211	196	94	48	305	244
Flight #4: 3	484	432	14	14	212	165	79	32	291	197
Totals: 11			51	51	770	894	363	292	1133	1186
Averages:	491	435								
Errors per message, inbound runs:					15.1	17.5	7.1	5.7	22.2	23.2

Note: The course for Flight #1 was along a true bearing of 145° down range relative to the transmitter site. All other flights followed the Charlie Route along a true bearing of 127° when heading toward Bermuda (upper half of table) and a course of 307°T when heading inbound toward SHAD (lower half of table). Flights were at 19,000 to 20,000 feet in Grumman Model G-159 aircraft.

The data recorded in the aircraft during comparable legs of the several test flights away from Avalon were compared with the corresponding data recorded during legs of flights directed toward Avalon. The average number of characters missing from AM messages was nearly the average number missing from PM messages during flights away from Avalon. During the flight toward Avalon, the average number missing was somewhat higher for AM messages. The difference between the numbers of wrong characters received in AM messages and in PM messages was trivial during flights away from Avalon; during flights toward Avalon, the average number of wrong characters was more than 20 percent greater for PM messages. Whereas slightly more individual characters were missing from AM messages, regardless of direction of flight, PM messages contained slightly more erroneous characters during the flights toward Avalon.

Table VII shows that the total numbers of inaccuracies were almost identical, for both modes of modulation, during the flights away from Avalon; the average numbers per message were identical. Similarly, the overall total of 1133 inaccuracies in the PM messages received, and the 1186 in the AM messages, were almost identical results. The average inaccuracy per message during flights away from Avalon, as shown in the upper half of the table, was roughly 25 percent less than the corresponding average inaccuracy per message recorded during flight in the opposite direction.

The average total inaccuracy listed in the last two columns at the left of the table was noticeably larger during AM messages for three cases and noticeably larger during PM transmissions for the other three cases.

In summary, the data offered little or no basis to suggest that the AM system performed better or worse than the PM system. Data suggest that the effective radiation pattern of the airborne antenna, as installed on the project aircraft, substantially influenced the level of carrier signal measured at the airborne receiver.

Bit-by-Bit Analysis of Inaccuracies - All the erroneous characters recorded during Flight #3, including control signals such as line feed, carriage return, etc., were studied in a search for bit-error tendencies. Table VIII summarizes the number of bits dropped and the number of erroneous bits added for characters printed out in error at the airborne terminal. The total number of wrong characters recorded during PM transmission was 37; meanwhile, 29 wrong characters were recorded during AM transmission. The table shows that

TABLE VIII

SUMMARY OF BIT ERRORS IN TELETYPE MESSAGES RECORDED DURING FLIGHT #3, AUGUST 11, 1966

	No. of Bit Pulses Sent		No. of Bit Pulses Missing from Proper Level		No. of Spaces Sent		No. of Bit Pulses Added at Wrong Level	
	PM	AM	PM	AM	PM	AM	PM	AM
Code Level 1	11	9	3	4	26	20	4	5
Code Level 2	14	14	3	4	23	15	9	4
Code Level 3	16	17	5	3	21	12	5	4
Code Level 4	8	11	1	4	29	18	8	11
Code Level 5	14	12	5	2	23	17	17	10
Totals:	63	63	17	17	122	82	43	34

a slightly larger proportion of the AM characters were wrong because of extraneous bits entering where spaces should have been. This result suggests that the PM channel was somewhat less vulnerable to pulsed interference. Meanwhile, the proportion of bits dropped by the AM channel was exactly the same as the proportion dropped by the PM channel. This latter result suggests that both channels suffer comparably from drop-outs in the weak signal areas. However, this sample was considered very small.

Qualitative Analysis of Voice-Message Data: One Air Traffic Control Specialist (ATCS) listened to the voice messages[9] recorded on magnetic tape during Flight #3. Appendix VII gives the plain-language text of the voice messages. The playback was accomplished in a relatively quiet office. Thus, audio interference of an airborne acoustic environment was avoided along with other interference which might have been introduced by members of an operating flight crew.

After listening to each voice message, the ATCS first gave a general appraisal of quality in terms of adjectives such as good, clear, weak, fair, scratchy, intermittent. During another playback, the words found intelligible in each message were transcribed. Then, the ATCS listened to a final playback in order to confirm and refine the original comments.

The results of the qualitative examination by the ATCS were then reviewed while inspecting the record of AGC voltage for each message. Appendix VIII contains samples of the pen records of received audio and AGC voltages. Every comment was compared with corresponding carrier signal level; comments generally correlated with fading or apparent interference.

Voice messages reproduced from magnetic tape almost always became unreadable when the level of the received signal fell

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[9] Every oral communicator has characteristic patterns of inflection, diction, punctuation, and tone. To account for all these personal variations in a carefully controlled experiment would have been well beyond the scope of the project. The voice of one experienced communicator was assumed sufficient to this experiment for exploring the propagation of a carrier-frequency modulated by changing phase (PM) or changing amplitude (AM).

below -122 dBm. As signal level became higher than -122 dBm, background noise became less objectionable. There were no evident errors in reading words as long as the words were at all readable. Voice was very clear at levels above -115 dBm. Voice was of good quality, even though received carrier-signal power levels fluctuated as much as 10 dB during messages, provided the lowest carrier-signal level was above -115 dBm. During one message, several 1-second fades, from -115 dBm to -120 dBm, earned a rating of "Good, but occasionally intermittent."[10] When carrier-signal level rose to an average of -100 dBm, base tones were noticeably deeper which suggested that the system equalization was being modified by AGC level. The AGC system seemed to respond more to low frequencies in the audio baseband. At carrier-signal power levels of -113 dBm, the ATCS listener rated messages as clear, even though the presence of AGC voltage fluctuations suggested that there was some form of radio-frequency interference.

Some voice messages faded out at a carrier level of -117 dBm. The audio-frequency noise, which became noticeable at a carrier level of -117 dBm, made reading more and more difficult as carrier level was reduced toward the receiver threshold. At carrier levels of -121 dBm, signal generally was characterized as weak.

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10 An average value for carrier signal power was not computed separately for each voice message as it had been for each teletype message. Instead, the manner in which carrier power faded and revived with time and distance is indicated qualitatively by the reproduction of actual records, shown in Appendix IV, especially Figure IV-7 and IV-8.

SUMMARY OF RESULTS

Troposcatter Antennas

Noise temperature at the troposcatter antennas was observed only during a test period of less than 1 hour of the forenoon on March 21, 1966; the average value of noise temperature was 398°K.

Voltage standing wave ratio (VSWR) was measured at 1.6 or less for all frequencies in the band from 118 MHz to 136 MHz; at project frequencies 133.2 MHz and 133.4 MHz the VSWR was 1.2.

The main lobe in the forward sector of the horizontal radiation pattern from 70° T to 220°T with respect to Avalon, N. J., was shaped generally as planned and its major axis directed along a true azimuth of 145°.

Average back-lobe gain during one flight around the troposcatter antennas, in the sector from 220°T through 360°T to 70°T, was 35 dB or more below the maximum gain along the axis of the main forward lobe.

Back-lobe radiation was sufficient for preflight reception of teletype and voice messages at the airborne terminal in the project aircraft while it was parked on the NAFEC ramp about 25 statute miles away.

Space-Diversity

For more than 95 percent of the time during a flight at 20,000 feet to a radius of 350 nmi along the axis of their main forward lobes (145° T), reception at one antenna or the other was ample for air-to-ground communication despite deep fades observed at the SW antenna. Only during a few percent of total flight time was there coincident deep fading at both antennas. Slope of the trend line for troposcatter power beyond the radio horizon was estimated from the test data to be about -0.18 dB per nautical mile. About this line, fading varied the received power sometimes as much as 30 dB peak to adjacent peak.

Voice reception from the 250-W airborne terminal was observed to be excellent during both the outbound and inbound legs of an air-to-ground test. Extrapolation of results suggests that space-diversity reception to 450 nmi could have been achieved had the flight been extended.

Airborne Receiver Sensitivity

When an unmodulated VHF test signal was applied to the receiver input in the laboratory at a level of -127 dBm, automatic gain-control voltage increased just enough to be detected by the pen recorder. In the aircraft, indicated sensitivity was 3 dB less due to the airborne antenna, cable, and noise environment.

Fading of the received VHF carrier to power levels of -122 dBm and below resulted most of the time in missing teletype characters. However, short term fading which brought carrier power to -122 dBm usually lasted no more than 5 seconds whereas the intervals between fades were generally one or more orders of magnitude longer than the fade interval.

As heard during playback in a private office, voice messages recorded on the airborne tape recorder were very clear when received carrier power was at or above -115 dBm. Fading to -120 dBm during a voice message led the evaluator to rate the message "intermittent." Although some voice messages were not readable when received carrier power was observed to be -117 dBm, the evaluator characterized most voice messages as "weak" at carrier power of -120 dBm. At -122 dBm, voice messages generally were "unreadable."

Airborne Antenna Effects

The airborne antenna for the test was topside, aft of the operational VHF antenna, and several inches to the port side; this location made the horizontal radiation pattern asymmetrical, substantially favoring the port side with horizontal gain.

Maneuvers during turns, usually made to the left, increased the number of message inaccuracies; intermittent fading which occurred during turns corresponded with missing characters.

The average number of inaccuracies per message was roughly 25 percent greater during flight segments aimed toward the Avalon transmitter than during flight segments outbound toward Bermuda.

The character of transmission during the tangential excursion of Flight #2 was noticeably different according to whether the port or starboard airborne antenna patterns were directed toward the Avalon transmitter. While the port-side antenna pattern was directed toward Avalon, near the latter part of Flight #2, inaccuracies were about 300 percent more during PM than during AM transmission. While the

starboard-side pattern was directed toward Avalon, PM transmissions only suffered about 25 percent more inaccuracies than AM transmissions. During both outbound and return legs of the tangential excursion from the Victor Route during Flight #2, received carrier power fluctuated between -104 dBm and 124 dBm with periods typically less than 20 seconds and mostly about 3 to 5 seconds.

PM and AM Transmission

Both PM and AM transmissions were interrupted by fading of carrier power below receiver sensitivity levels.

Random inaccuracies in teletype messages occurred about as frequently during PM as during AM transmission when received VHF carrier was well above the level of receiver sensitivity. During a long flight within such a region, almost 12,000 characters were transmitted and all but eight were received correctly. Four of the inaccuracies occurred during three PM messages and the others during four AM messages.

At distances where carrier power approached the limits of receiver sensitivity, reception of PM and AM messages was characterized by almost identical frequency of inaccuracy. While on the average the total number of inaccuracies, made up partly of missing characters and partly of wrong characters, was about the same, the proportions shifted. As (S + N)/N fell to 30 dB, PM remained less likely to suffer wrong characters. However, as (S + N)/N fell still further to 20 dB, both modes of transmission produced wrong characters and since carrier level was also low, both suffered missing characters. However, PM suffered more missing characters as carrier decreased to threshold.

Both PM and AM systems produced essentially satisfactory teletype transmissions to distances between 440 and 520 nmi, within the half-power sector of the main-lobe coverage. At distances less than 440 nmi, transmission was essentially free of errors except for occasional effects of noise attributable to the data transfer equipment. Beyond 520 nmi, messages were often virtually obliterated.

Operational Factors

When transmitting at 2 kW from Avalon, the most efficient maneuvers were conducted so far out over the ocean that flight operations with the G-159 aircraft had to be based at Kindley Air Force Base, Bermuda. At shorter distances, received signals were strong and all modes of

modulation performed so well that no comparisons could be made. Similarly, when distance was so great that no carrier power could be received, no comparisons could be made. Thus operations had to be concentrated about the fringes of the effective radiation coverage.

Noise varied independently of carrier power for the most part. Measurement of signal power and noise power, therefore, should have been instrumented separately. However, the two values should also have been so measured that they could be related directly with each other and with significant parts of the several test messages. Data processing was complicated because of the sequential manual switching from (S + N) to N measurements between which fading often occurred.

Elapsed time was found to be a convenient common argument for plotting all the test data.

Available meteorological data were not adequate for convincing explanations of the maximum communications distances.

CONCLUSIONS

Based on exploratory tests conducted from a communication site established at Avalon, New Jersey, it is concluded that:

1. The two high-gain troposcatter antennas configured for space-diversity reception at the communication test site are suitable for experimentation with data transfer and automatic communications by VHF troposcatter to aircraft in an over-ocean environment.

2. High-gain troposcatter antennas will allow coastal sites to communicate with aircraft at substantial distances over the ocean, in some cases several hundred nautical miles beyond the radio horizon.

3. Performance of a data communication system in a noise-limited environment is likely to be changed very little by a simple application of phase modulation to the carrier frequency instead of amplitude modulation.

4. Performance of a troposcatter communication system designed for voice messages is likely to produce good-quality voice reception at substantially the same distances as it delivers error-free teletype messages when low-speed data modems are simply substituted for voice-frequency modulation and detection.

5. Aircraft maneuvers back and forth across the down-range threshold of reception offer an abundance of test data for comparison of various systems operating in a noise-limited environment.

RECOMMENDATIONS

Based on the results and experience derived from this project, it is recommended that:

1. The troposcatter antennas at Avalon, New Jersey, be accepted and utilized for experimentation to determine the characteristics of over-ocean data communications by tropospheric propagation at VHF.

2. An experiment be undertaken to ascertain the probable increase of operational coverage to be expected if coastal sites are equipped with high-gain troposcatter antennas without changing the VHF communications antennas of over-ocean aircraft.

3. In any long-term study of the over-ocean propagation medium, a simplified but complementary facility for reception and/or transmission be established at Bermuda so that, by monitoring of point-to-point reception and study of meteorological factors, effects due to phenomena of the medium may be separated from effects due to the airborne terminal or its movement.

4. A communicator be included among the airborne test crew to render "real-time" appraisals of the quality and readability of voice messages when the performance of a voice communications system is evaluated.

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ACKNOWLEDGMENTS

Preparation for the experiment was a team effort. The project manager was assisted by Mr. Lloyd Pearson who was responsible for engineering and supervision of the ground terminal. Engineering and supervision of the airborne station was largely the work of Mr. Thomas Barton. Messrs. Wayne Robinson, Robert Black and Albert Adams, in getting it ready, not only packaged the experimental system, but were indispensable throughout the test for its operation and maintenance. Messrs. Joseph Romei and John Worthington, both Air Traffic Control Specialists, assisted in detailing the operational plans, coordination of flight operations, test communications, and evaluation of voice recordings. The aircraft was flown through its special maneuvers by Messrs. Bernard Hughes, Alvan Bazer, Irving Budoff, and Theodore Billen.

APPENDIX I

DESCRIPTION OF TROPOSCATTER ANTENNAS FOR GROUND TERMINAL

Parts for the high-gain antennas had been taken from the eight-bay antenna structure recovered in 1965 from the experimental site at Barnstable, Massachusetts. Five vertical columns in each antenna structure were arranged at the apexes of three adjacent equilateral triangles each with one side open so that the plan view of the structure resembled the letter "W". Two vertical panels, 107 feet high by 12 feet wide, forming an angle at the center of the structure, were reflector panels which met at the center column where they intersected at an angle of 60°. Since the 12-foot side opposite this 60° angle was open, it became the aperture of the antenna through which radiation was directed from a vertical array of dipoles mounted within the central triangle. (Figure I-1).

The two reflecting panels behind the dipoles were strung from top to bottom with aluminum wire, AWG #10, spaced every 2 inches along the 12-foot width of the panels. Wires were 106.8 feet long, supported at 12-foot intervals by insulating grommets on horizontal crossbars. All the vertical wires were inter-connected electrically by jumpers at the bottom crossbar.

The vertical array of 16 colinear dipoles, suspended between the two reflecting panels, was 4 1/2 feet from the corner at the center column and rigidly supported in the plane which bisected the 60° aperture. Electrical distance vertically between vertically-polarized radiating elements was 0.775 wavelength. Energy was distributed among these elements by a binary harness of Heliax coaxial cable. Near each element, feeders were 7/8 inch in diameter while the main distribution cable was 1 5/8 inches in diameter. The calculated gain of the antenna through the front aperture was 24 dB.

The antenna was erected so that the principal axis of the antenna pattern would, as nearly as possible, be aimed toward the horizon along a true azimuth of 145°. The shape of the pattern was designed to be broad and flat with a horizontal angle of 30° between the half-power vectors of the major lobe. The half-power vector in the vertical plane along the principal axis was elevated 2° above the horizontal; a deep null was expected at an elevation angle of 4.6°. A secondary lobe above this null was pointed toward an elevation angle of 6.5°; its gain was about 14 dB less than that of the main lobe.

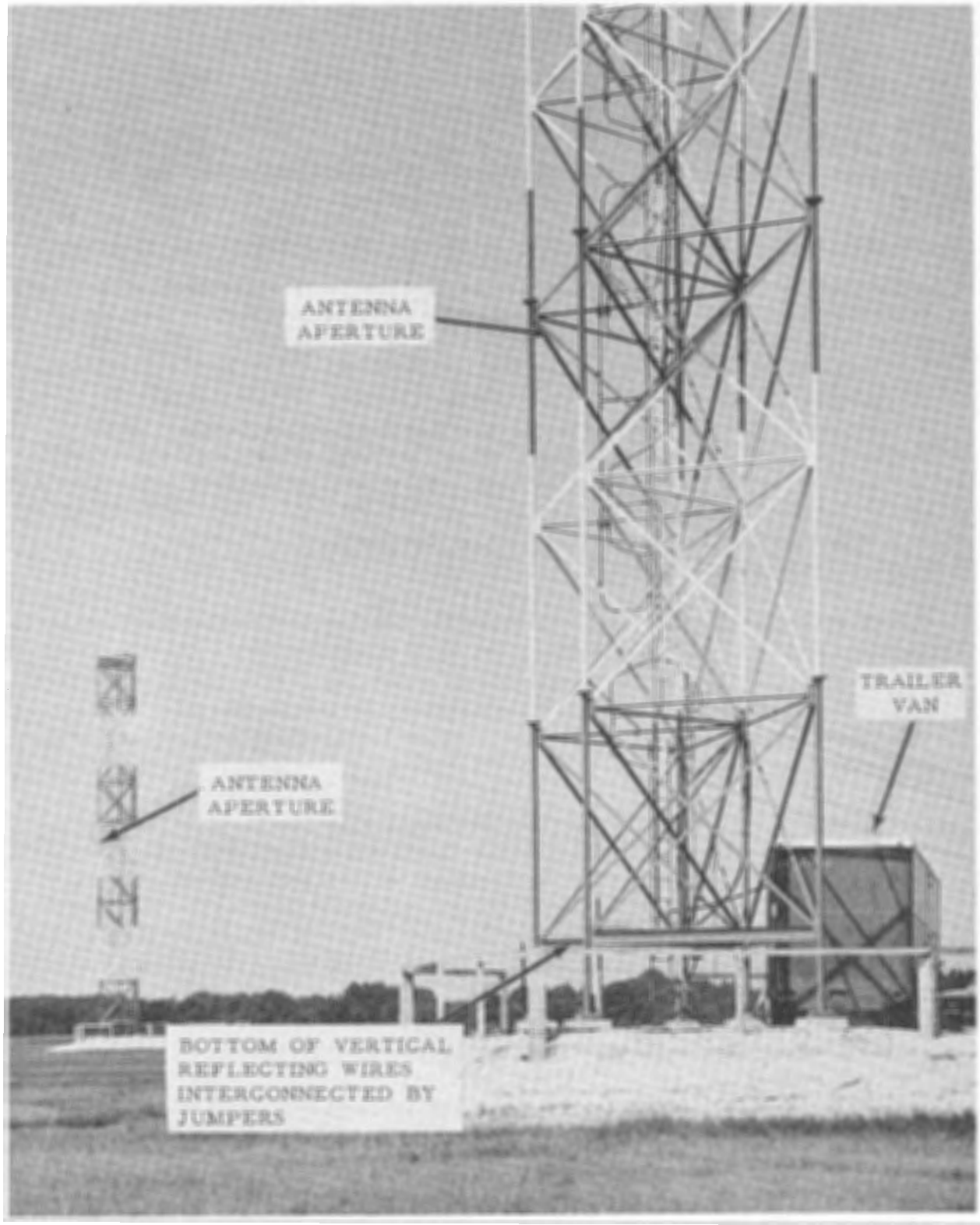

FIG. I-1 CLOSE-UP VIEW OF VHF TROPOSCATTER ANTENNAS AT AVALON, NEW JERSEY

The effective center of radiation was at or slightly above the center of the dipole array. The grade level at the base of the antenna structure was approximately 7 feet above mean sea level; the center of radiation was nominally 67 feet above mean sea level.

At the base of each tower, the pressurized Heliax coaxial cable harness was terminated with a standard pressurized fitting for a 1 5/8 inch coaxial cable. A pressure gage and valve were included at the end of the harness near the pressurized connector. Specifications for the harness required testing to a pressure of 8 psi with no more pressure leakage than 2 psi in 8 hours.

APPENDIX II

DESCRIPTION OF GROUND TERMINAL EQUIPMENT

Equipments comprising the major components of ground terminal assembled for the exploratory tests between July 25, 1966, through August 16, 1966, are listed in Table II-I.

A. Message Generating Facility

Several different message-generating units were interconnected with the other equipment of the ground terminal (Figure II-1).

A commercial audio oscillator, Telesignal Model 101, provided the constant-frequency test-tone modulation at 1615 Hz.

Standard teletype equipment generated the digital data at the normal teletype rate. Seven messages, typical of air traffic control copy, were prepared in advance on punched paper tape. The text of each of the seven messages was punched twice on the paper tape; the first message of each pair was preceded by an identification including the message number, and the words "PHASE MODULATION," and the next by the message number, and the words "AMPLITUDE MODULATION." Once all seven pairs of messages had been run through the paper-tape reader, the paper tape was recycled manually. The text of the seven teletype messages is presented in Figure II-2.

The teletype paper-tape reader delivered its data signals to an audio-frequency-shift keyed (AFSK) Data Modem, Collins Radio Company Type TE-204 A-4, through the modem, to a Teletype Model 28 ASR page printer, which was used at the ground station to monitor the outgoing messages.

Output of the data then was also delivered to a sequencer, which consisted of a manually-adjustable timer connected mechanically to a stepping relay. After passing through the stepping relay, output of the modem was amplified, regulated, and introduced either to the Phase Modulation (PM) exciter or the Amplitude Modulation (AM) exciter at regulated levels.

When the teletype message within a sequence came to an end, a hand-held microphone could control the exciter until the sequencer switched control about 10 seconds later to the output of a magnetic tape recorder/reproducer, the Webcor Viscount model. Last was information contained in the seven teletype messages, enunciated in corresponding plain language (Appendix V), by an experienced communicator, and recorded on an endless loop of 1/4-inch magnetic tape.

TABLE II-1

MAJOR COMPONENTS OF GROUND TERMINAL FOR EXPLORATORY TESTS

Equipment	Manufacturer	Type/Model
Paper Tape Reader	Teletype	Model 28ASR
Page Printer	Teletype	Model 28ASR
Magnetic Tape Recorder-Reproducer	Webcor	Viscount
Microphone	Electrovoice	25 ohm, Differential
Data Modem	Collins Radio	TE-204 A-4
Sequencer	(Local)	Special
Tone Oscillator	Telesignal	Model 101
Regulated Output Amplifier #1	Tritronics Laboratories, Inc.	Type CA-1762
Regulated Output Amplifier #2	Maxson Instrument Corp.	Type CA-1539A
VHF Transmitter	Collins Radio	
2000-Watt Linear Amplifier		TV-37X
50-Watt Power Amplifier		TV-36
AM Exciter		Special
PM Exciter		Special
Vertically-Polarized Antennas	Page Engineering	Special
Cycle Counter (Frequency Meter)	Hewlett Packard	Mod-52452
Oscilloscope	Tektronics	310-A
VHF Receiver with Power Supply	Bendix Corp.	RA-21
Audio Amplifier	Local	Special
Audio Loud Speaker	Local	Special

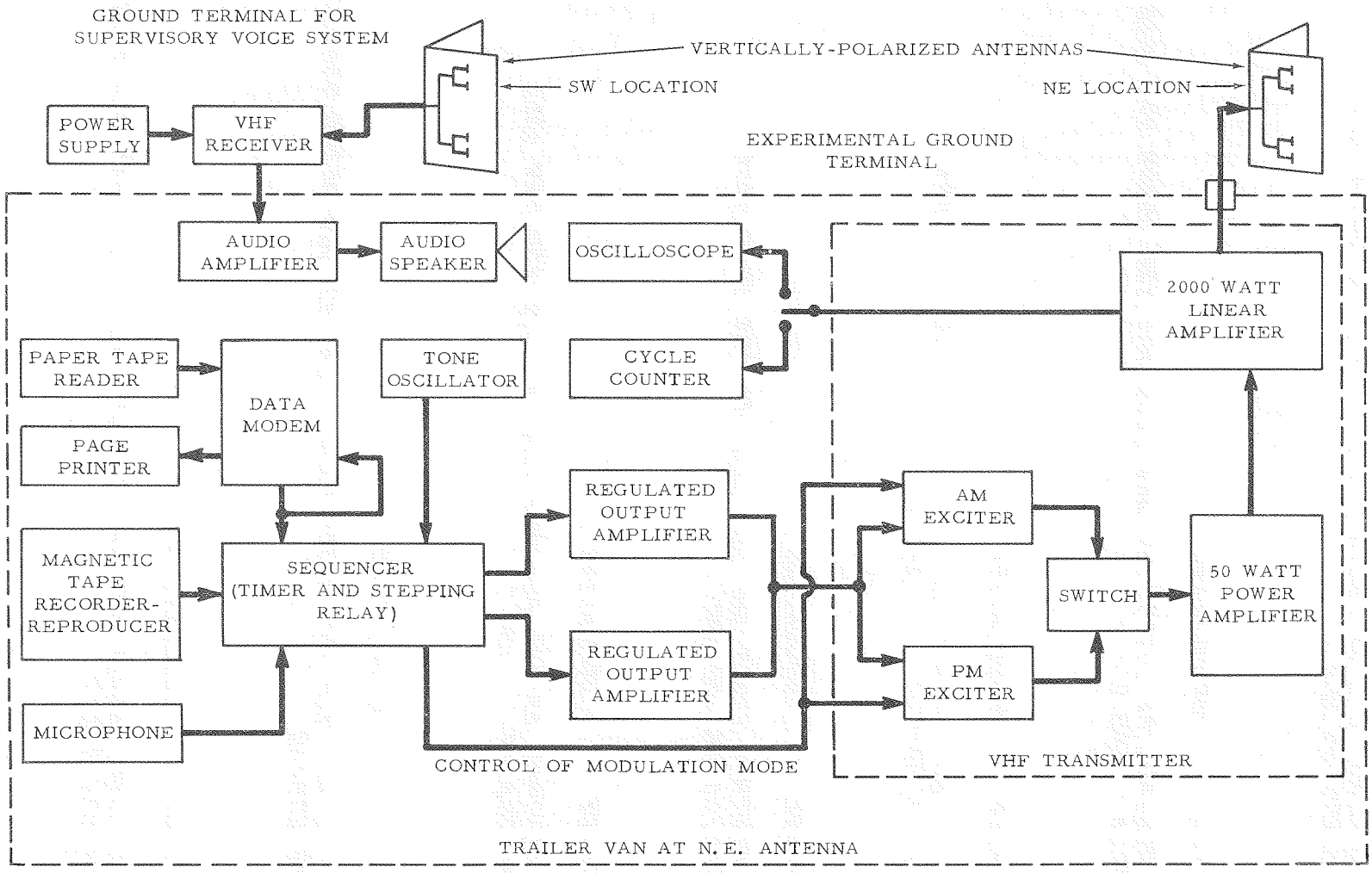

FIG. II-1 FUNCTIONAL BLOCK DIAGRAM OF GROUND TERMINAL FOR EXPLORATORY TESTS

MESSAGE 1 PHASE MODULATION

TROPO TEST CONTROL BOA GA 4945N 50W 1317 FL 190 5000N 40W 35
9HR 30 MS 18 255/35 END 1

MESSAGE 2 PHASE MODULATION

TROPO TEST CONTROL PA 101 5045N 20W 1536 ASC 120 4925N 25W 1621
10HR 45 355/30 END 2

MESSAGE 3 PHASE MODULATION

TROPO TEST CONTROL EA 451 ABM OC 1829 FL 210 C-1 1854
5HR PS 140 FT TURB MDT END 3

MESSAGE 4 PHASE MODULATION

TROPO TEST CONTROL FABDP ABM ACK 2031 FL 180 SHAD 2058
9HR MS 18 255/35 PS 290 END 4

MESSAGE 5 PHASE MODULATION

TROPO TEST CONTROL AA 491 42N 40W 2248 FL 310 43N 50W 2313
8HR 30 MS 45 300/60 END 5

MESSAGE 6 PHASE MODULATION

TROPO TEST CONTROL KLM 455 4530N 5245W 2145 FL 280 4630N 5345W 2210
7HR 30 MS 20 270/30

MESSAGE 7 PHASE MODULATION

TROPO TEST CONTROL AIREP SPECIAL KLM 601 ABM KBOS 1543 ALT 8000 FT
SALEM 01 ICE SEV END 7

FIG. II-2 TEXT OF SEVEN TELETYPE MESSAGES

To approximate random word sequences during the test, there was no synchronization of the magnetic tape; the free-running tape was sensed at random, whenever the sequencer ordered transmission of a taped voice message, and interrupted when the allowed time was up. Such voice messages typically contained 20 to 25 words.

B. Modulator and Transmitter of Ground Terminal - A 50-watt Power Amplifier, Collins Radio Type TV-36 was mounted within the case of the 2-kilowatt Linear Amplifier, Collins Radio Type TV-37X (Figure II-3). The power amplifier had been modified so that its excitation could be switched from the standard AM module to a special added PM module. This equipment was located in a trailer van and connected to the antenna by means of flexible Heliax coaxial cable.

Message input to the AM and PM exciters was kept within manageable dynamic limits by means of two Regulated Output Amplifiers (ROA) one of which, Type CA-1589A, by Maxson Instruments Corp., regulated the teletype signals and the other, Type CA-1762, by Tritronics Laboratories, Inc., regulated the voice and tone signals. The levels of voice and teletype signals delivered by the ROA's were so balanced that the exciters could not be overdriven or underdriven as the sequencer switched signals from one source to another.

C. Receiving Equipment at Ground Terminal - During the preliminary measurements of the horizontal patterns for the airborne and ground antennas, the Defense Electronics, Inc., (DEI) Telemetry Receiver, Type TMR-5A, and a RIXON preamplifier and RV-9 receiver, each were connected to one of the ground antennas. Their automatic gain control (AGC) voltages, calibrated with laboratory signal generators, were recorded on paper charts either by Brush Instruments, model Mark II, or Esterline Angus pen recorders.

During the ground-to-air transmissions, a standard receiver Type RA-21, was located together with its power supply at the southwest antenna. Audio output of this receiver was amplified and monitored within the van at the other antenna. This channel was used to receive administrative messages transmitted from the aircraft via standard VHF communications equipment.

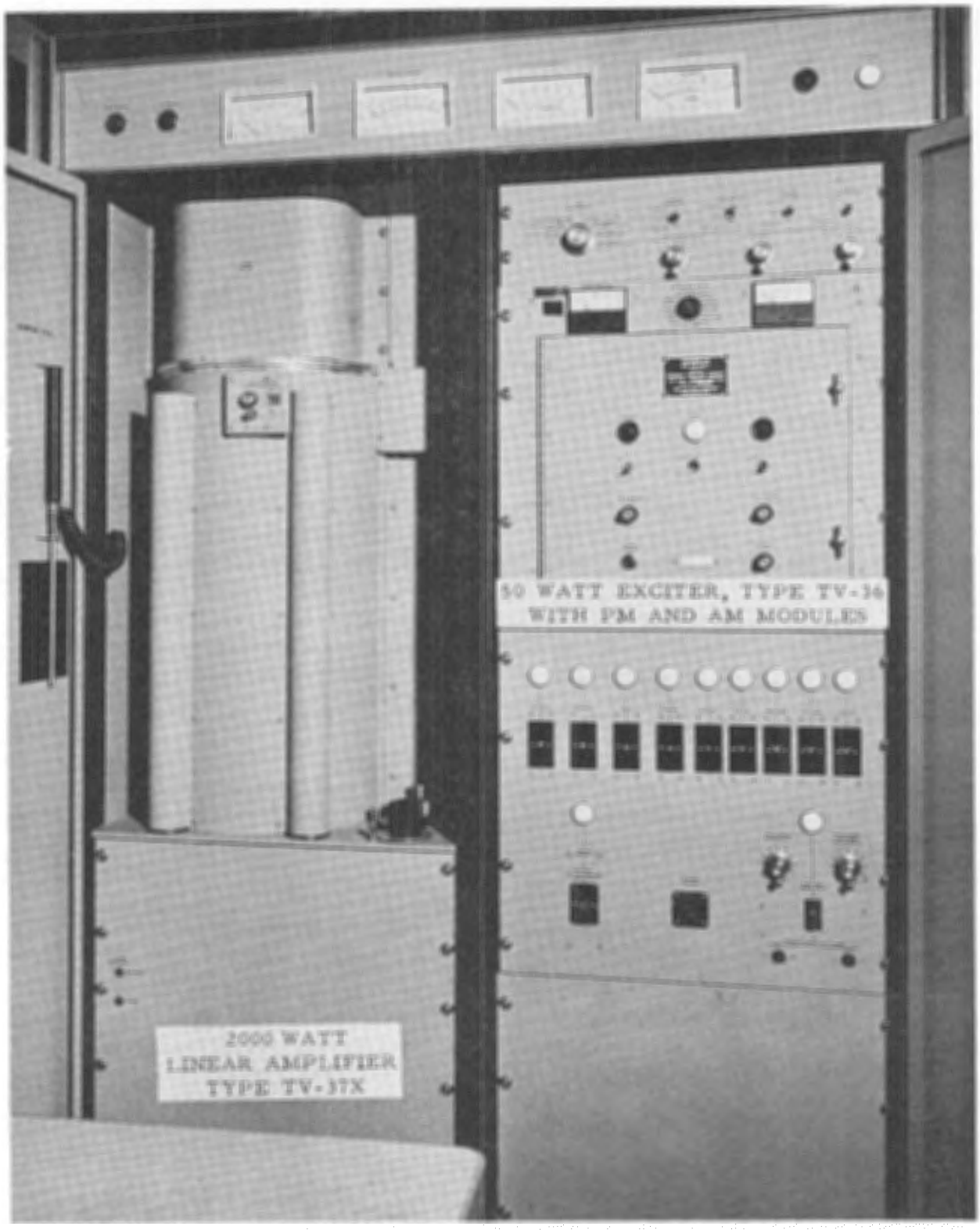

FIG. II-3 VIEW INSIDE FRONT PANEL OF LINEAR AMPLIFIER TYPE TV-37X

APPENDIX III

DESCRIPTION OF AIRBORNE TERMINAL EQUIPMENT

Equipment comprising the airborne terminal for the exploratory tests is listed in Table III-1. Interconnection of the components of the experimental airborne terminal is illustrated in Figure III-1 along with the operational airborne components employed for supervisory communications from air-to-ground.

A. Airborne Transmitters

During preliminary tests, a 25-watt airborne transmitter, Bendix Radio Type RTA-41A, was operated within line-of-sight distances of Avalon. The 250-watt VHF amplifier-modulator, Bendix Type RAA-204A, was operated while the aircraft maneuvered near and beyond the radio horizon.

B. Receiving Equipment and Instrumentation

The airborne antenna was connected, during the ground-to-air tests, through 12 feet of type RG-8 coaxial cable to a DEI Type TMR-5A telemetry receiver mounted in a standard airborne test rack along with several other components (Figure III-2).

After passing through a coaxial switch, Bird Electronics Corp. Model 72-2, the audio output of the receiver was filtered first by a bandpass filter, Kronhite Model 210-AB, whose bandpass was nominally from 300 to 3000 Hz.

After the first filtering, audio signals were recorded on magnetic tape and also passed through a pad-type voltage divider manually adjusted to keep the audio test-tone at a useful level for recording. Output audio from the voltage divider was connected to a Simpson Model 269 multimeter, which served as a visual monitor of the signal level, to the Data Modem Type TE-204 A-4 which demodulated the audio tones of the teletype messages, and continuously to the special narrow-band filter through which the signal noise levels were measured in order to secure the ratio of signal-plus-noise to noise. A vacuum tube voltmeter (VTVM) measured these voltages at the output of a special narrow-band filter, approximately 120 Hz in bandwidth, and tuned to the 1615 Hz audio tone. Audio output of the TMR-5A receiver was admitted continuously to this narrow-band filter.

AGC voltage from the receiver was recorded directly and continuously by one pen of a two-pen recorder, Brush Development Co., Mark II (Figure III-3). The other pen recorded short samples of

TABLE III-1

MAJOR COMPONENTS OF AIRBORNE TERMINAL FOR EXPLORATORY TESTS

Equipment	Manufacturer	Type/Model
Operational VHF Antenna	Collins Radio Co.	Type 37R-2
Operational VHF Transmitter	Collins Radio Co.	Type 17L7
Project VHF Antenna	Bendix Corp.	Type ANA-22A
Telemetry Receiver	Defense Electronics, Inc.	Type TMR-5A
Coaxial Switch	Bird Electronics Corp.	Model 22-2
Audio Bandpass Filter	Kronhite	Model 310-AB
Voltage Divider	(Local)	Special
Magnetic Tape Recorder	Webcor	Model Viscount
Data Modem	Collins Radio Co.	Type TE-204 A-4
Page Printer	Teletype Corp.	Model UA28RO
Multimeter (120 Hz)	Simpson	Model 269
Narrow-Band Filter	(Local)	Special
Vacuum Tube Voltmeter	Hewlett-Packard	Model 3400A (RMS)
Paper-Chart Pen Recorder (Two Channel)	Brush Instruments	Model Mark II
Sequencer	(Local)	Special
Monitor Loudspeaker	(Local)	Special

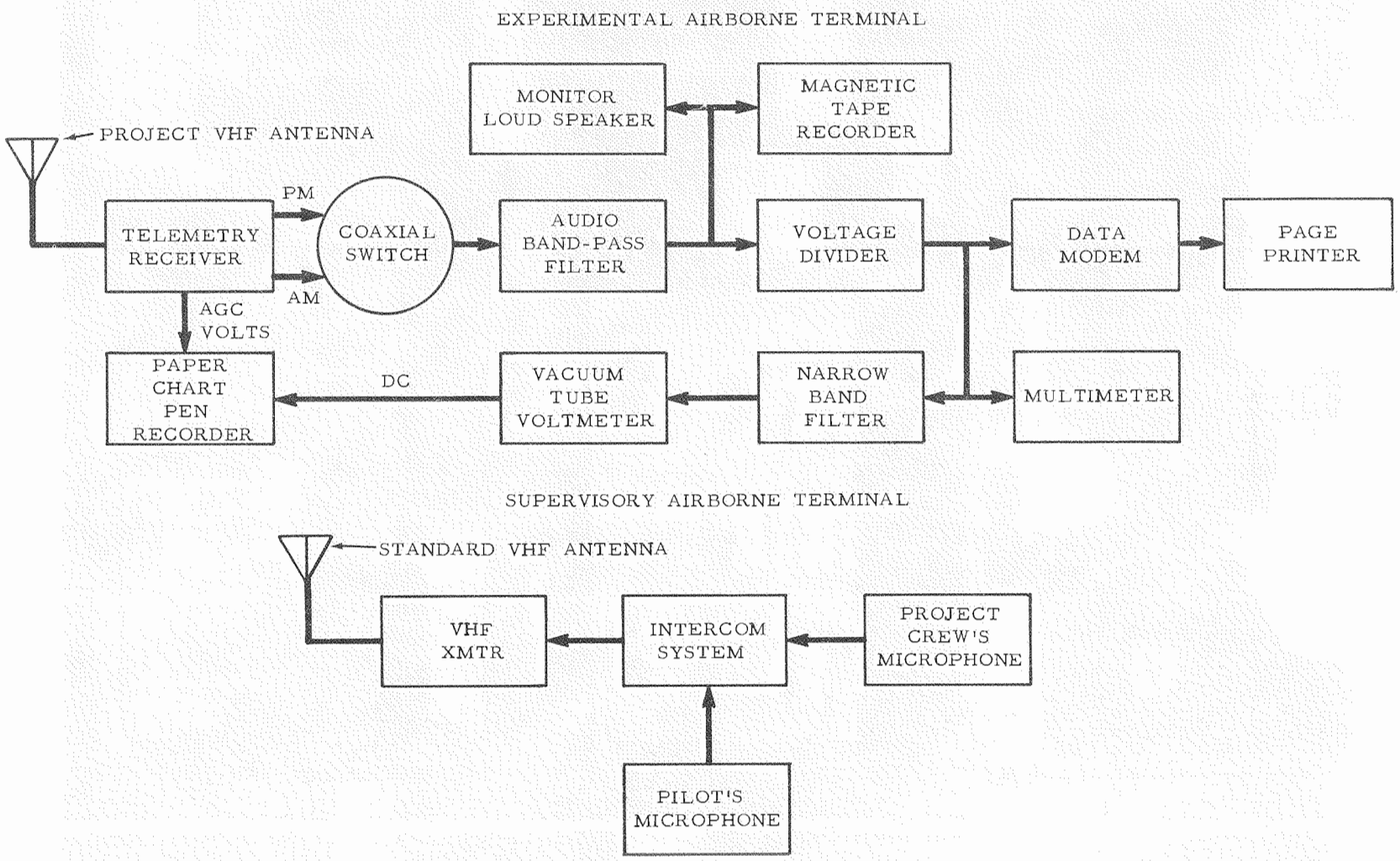

FIG. III-1 FUNCTIONAL BLOCK DIAGRAM OF AIRBORNE TERMINAL FOR EXPLORATORY TESTS

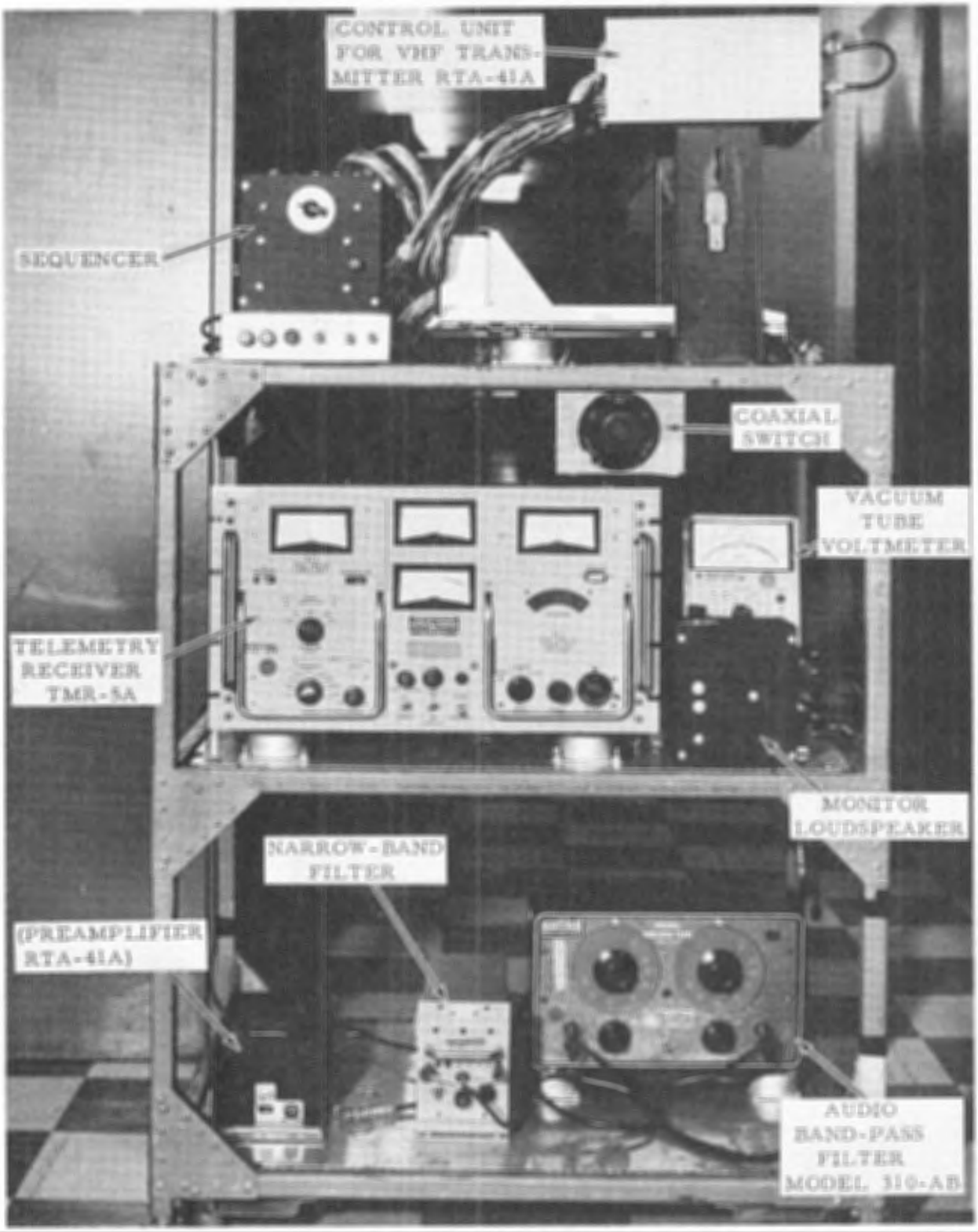

FIG. III-2 VIEW SHOWING AIRBORNE RECEIVER, MEASUREMENT AND CONTROL EQUIPMENT

FIG. III-3 VIEW SHOWING TELETYPE DATA MODEM AND RECORDING EQUIPMENT OF AIRBORNE TERMINAL

audio output voltages corresponding first to signal-plus-noise, and then to noise only. Since the linear speed of the paper chart was practically constant, length of the chart was relied upon to measure elapsed time.

All audio signals were recorded in flight with the airborne tape recorder, a Webcor Viscount model. In addition, the teletype signals, demodulated during the flight by the Collins Radio Data Modem Type TE-204A, were printed out directly on a specially-packaged Teletype Page Printer, Type UA 28RO. Meter readings taken by the airborne observer, and other notations, were manually recorded either on the teletype page printout or on the paper chart of the Brush Instruments recorder, or both.

APPENDIX IV

TROPOSPHERIC PROPAGATION FACTORS

Several factors considered while planning the tests and interpreting the results were taken from the literature of tropospheric propagation theory. Of special interest were the concepts of the "common volume," scatter mechanisms, fading, ducting, and interference.

A. Common Volume - When the transmitting and receiving antennas are located beyond each other's radio horizon, their radiation patterns are generally directed toward each other so as to intersect in some "common volume" above the surface of the earth.[1] As the distance along the great circle is increased between the two antennas, the intersection of patterns must occur at higher and higher altitudes and at increasingly acute angles. As long as the common volume remains within the troposphere, the mechanism which supports beyond-the-horizon propagation is often called "tropospheric scatter" or "troposcatter." Whether the mechanism involves refraction, reflection, or both, its operation is affected by the ever-changing conditions of temperature, moisture content, pressure, and rates of change of the resulting permittivity within the common volume.

Not only are the contents of the common volume generally undergoing change at all times, but the shape and location of the effective pattern-intersection also change; the changing common volume embraces different scatterers in varying numbers, locations, and relative efficiency. When one terminal is airborne and moving, the common volume also moves, changes shape rapidly, and precludes any simple analysis.

If two terminals are sufficiently far apart, the bottom of the common volume can be well above moisture-laden levels of the troposphere at altitudes where the dielectric properties do not support useful scattering. Furthermore, as separation increases, radio energy scattered toward the receiving antenna will suffer increasing propagation losses.

B. Scatter Mechanisms - The theory of tropospheric propagation offers a concept of many scatterers in a volume of the troposphere. Scatterers within the "common volume" have been described both as

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[1] McClure, G.W., and Dute, J.C., "Survey and Analysis of Long Distance Communications Techniques," Final Report No. RD-7, Project No. FAA/ARDS-487, Radio Science Laboratory, Institute of Science and Technology, The University of Michigan, Ann Arbor, May 1964; Appendix A, General Propagation Background.

"spherical blobs" and as "flat pancakes" which either refract or internally-reflect radio waves. The presence of scatterers implies an inhomogeneous atmosphere. But, the irregularities which could cause "scattering" are essentially invisible and transitory. The concept of scattering requires a statistical framework adjusted by arbitrary assumptions regarding the size, number, and distribution of the irregularities. To the extent that scattering is due to reflections internal to each atmospheric irregularity, fading of received signals during point-to-point transmission would be associated with motion of the several scattering parcels. The average internal-reflection field received from each parcel would then be related to the rate of decrease of density with height within the parcel. Some of these fields would cancel and some reinforce at the receiver.

None of the early hypotheses has been entirely satisfactory. In 1963, K. Bullington wrote that:[2]

> "If the problem of inhomogeneous atmosphere could be solved rigorously, there would be no difference of opinion, but a rigorous solution that can be readily evaluated has not yet been achieved without significant approximation, and the relative accuracy of the different approximations is in question."

In an effort to bridge the gap between the earlier reflection concept and the scatter hypotheses, Bullington presented another method. In his method, it is assumed that:

a. Internal reflections occur within the atmosphere, whose dielectric permittivity (index of refraction squared equals the permittivity) varies as a smooth exponential function of altitude, but also has random variations superimposed on the exponential decrease;

b. Random variation of the differential dielectric permittivity from one given height to another has Gaussian distribution;

c. Between two heights within a common volume, the average reflection coefficient is derived as a function of the average exponential decrease in permittivity; and

d. The variance of the reflection coefficient is related to the variance of the dielectric permittivity by the same function that relates average reflection coefficient to the average permittivity.

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[2] Bullington, K., "Reflections from an Exponential Atmosphere," Bell System Technical Journal, Volume XLII, November 1963, pp. 2849-2867. The theory of tropospheric propagation beyond the horizon is relatively new. Bullington lists as his first of 18 references, a paper by W.E. Gordon dated January 1955.

C. Fading - Whether due to multipath interference, deflection of propagation, or other effects of the propagation medium, fading of VHF-radio carrier signal power received in the aircraft was expected to occur with changes of aircraft position and with time. Fading influenced by aircraft position in space could not be sorted out from fading due strictly to the propagation characteristics of the medium. This limitation was accepted for the exploratory tests.

D. Ducting - Where the gradient of refractive index is abnormal over a wide geographical area, propagation may be trapped within curved layers called ducts.[3] Energy so trapped can propagate over the ocean to distances of hundreds, even thousands, of miles before it escapes from the duct. A combination of ducting followed by scattering of the energy emerging from a break in the duct seems to explain many instances of extraordinary communication distance.

Stable meteorological conditions with large temperature inversions are often indicated over the ocean by widespread cloud cover. Ducts also can exist on cloudless days but they usually occur where a strong negative moisture gradient is coupled with a temperature inversion. Where the duct is broken as by the convective turbulence of a storm, or by some major change in tropospheric conditions, the emerging energy then proceeds to scatter. Ducting, therefore, modifies the location and shape of the "common volume."

E. Other Propagation Factors - In addition to those variations which occur because of changes in the common volume, changes in ducting, rotation of polarization,[4] and motion of the aircraft, received signals also are affected, usually to a far less extent, by scattering and reflections from the ionosphere and from meteor trails. Interference from many sources--such as galactic noise, sun's radiation, other radios--also interrupt the flow of digitized information or produce inaccuracies at the receiver.

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[3] See Randall, D. L., "Tropospheric Duct Meteorology at VHF and UHF in Theory and as Observed on a Trip Around the World, February 8 to March 15, 1962," U. S. Naval Research Laboratory, Wave Propagation Branch, Electronics Division, Washington, D. C., NRL Report 6404, May 31, 1966.

[4] In an Air Force Western Test Range technical report No. AFTWRT-TR-65-1 entitled "Power Transfer Between Two Antennas with Special Reference to Polarization," Beuhring W. Pike offers a general equation for calculating the power transfer between two widely-spaced antennas in free space. The polarization mismatch loss was expected to be a secondary effect during the tests reported herein.

Models are available from which the expected values of transmission loss can be predicted statistically as a function of path geometry and the long-term averages of atmospheric parameters.[2, 5] The value of test data taken in a particular environment is greatly enhanced if receiver carrier levels can be compared with predictions according to the methods prescribed for these models. After the early data offer a check on the applicability of specific prediction methods, the results can then be extrapolated to other propagation paths, or to other climatic areas to which the same model applies.

Prediction of transmission loss was not made for these exploratory tests according to the several recommended methods because the brief experiment was expected to be too limited for meaningful conclusions. Nevertheless, the results obtained seemed generally sufficient to suggest what other experiments might be undertaken.

Prediction of the performance of a communication link can be done for specific meteorological situations on a long-term average basis. Short-term correlation between meteorological and propagation parameters has usually been found to be small.

Extensive meteorological instrumentation, not available for the exploratory test, would be needed to determine a quantitative transfer function between meteorological conditions and VHF radio coverage beyond the radio horizon. Once such a transfer function had been developed, its use would probably be based on data also obtained with a similarly sophisticated system of instrumentation. At present, radar-observation (RAOB) balloons are launched from Bermuda, Ship E (35N48W), Ship D (44N41W), Argentia (Newfoundland), Sable Island (about 42N60W), Nantucket, New York City, Washington, (D.C.), Wallops Island, and Hatteras. This station network leaves a broad area east of Avalon, New Jersey, uncovered by meteorological soundings.

In the absence of surface meteorological information for the region between Avalon and Bermuda, day-to-day coverage predictions would have to be based on carefully conducted soundings. Air-to-ground

[5]See also Rice, P.L.; Langley, A.G; Norton, K.A.; and Barsis, A.P., "Transmission Loss for Tropospheric Communication Circuits," NBS Technical Note 101 (Revised), January 1967

soundings could be combined with point-to-point propagation monitoring between Avalon and Bermuda. A combination of fixed and changing paths should reduce the confounding of effects due to the medium alone from effects attributable solely to movement of the airborne terminal.

Cloud coverage photographs from satellites are not analyzed without difficulty; the work involves much experience, subjective judgment and patience. Although cloud analysis probably would not supply all the answers to questions about variable coverage, it is a developing field which, it seems, could be combined with VHF soundings to improve short-term coverage predictions.

APPENDIX V

TROPO TEST FLIGHT OPERATIONS PLAN
OVER-OCEAN DATA TRANSFER

Aircraft No. N 376
Type G 159 Gulfstream

Dates August 9, 10, 11, 1966

The following plan will be followed for "TROPO TESTS" on the above mentioned dates. The code names assigned to the routes are for Project test purposes only and are not to be confused with the regular Oceanic route names. Additionally they will permit speedy coordination between all parties and reduce verbiage or lengthy explanations. All Project Team personnel shall acquaint themselves with this plan. The N. Y. Center personnel will be requested to relay all messages between the Avalon test site and the aircraft, either in the air or on the ground at Bermuda Center and N. Y. ARTCC.

PLAN YANKEE (Figure V-1)

Course--proceed from ACY to ALPHA, thence to GOLF, thence to HOTEL

If it becomes expedient to go direct to HOTEL from some point enroute and before reaching GOLF, send this message to TROPO TEST CONTROL:

YANKEE ___ ___ ___ (GMT TIME)

The blanks would be filled in with the three digits necessary to give the distance down range on the track where we cut off. For example: If we decided to proceed direct to HOTEL from a point 457 miles down range from Avalon, we would send the signal YANKEE FOUR FIVE SEVEN. AT 1347ZEBRA

If it becomes expedient to return to ACY without proceeding any further the signal should be:

X-RAY ___ ___ ___ At ___ (GMT) ___

Again the three blanks would be filled in with the distance down range from AVALON. For example:

We are 326 miles from AVALON and the decision is made to return to ACY. The signal to be sent is:

X-RAY THREE TWO SIX AT 1445 ZEBRA

PLAN VICTOR (Figure V-2)

Course--proceed from KBV on VICTOR route for ACY until the desired test signal is received. Reverse course and proceed until the signal is lost. Reverse course again and repeat the procedure as many times as the planned endurance of the flight will allow. The decision whether to continue to ACY or return to KBV will be decided by the location of the "lost signal circle."

If the decision is to return to KBV the signal to be sent should be:

VICTOR KILO BRAVO VICTOR AT __(GMT)__

If the decision is to return to ACY, the signal to be sent should be:

VICTOR ALPHA CHARLIE YANKEE AT (GMT)

PLAN CHARLIE (Figure V-1)

Course--proceed from KBV on CHARLIE route to ACY. This will be the final flight of the series and no test maneuvers are planned or anticipated.

General Comments:

The Test Coordinator will be at TROPO TEST CONTROL, Avalon, N. J.

Phone: 609-465-7060

THE MISSIONS COORDINATOR IS THE COGNIZANT MAN IN NY ARTCC.

Phone: 516-588-1233

Bermuda Centre, (British, you know), has a direct line to NY ARTCC. This phone may be used from Base Operations at Kindley AFB.

Andrews Airways is capable of phone patching from aircraft to TROPO TEST CONTROL

If any difficulty is encountered in utilizing the direct line to NY ARTCC, do not hesitate to call the TROPO TEST CONTROL collect. Dial direct to the Test Control at Avalon.

ICAO flight plans will be filed and must be received in NY ARTCC no later than one hour prior to departure nor sooner than four hours.

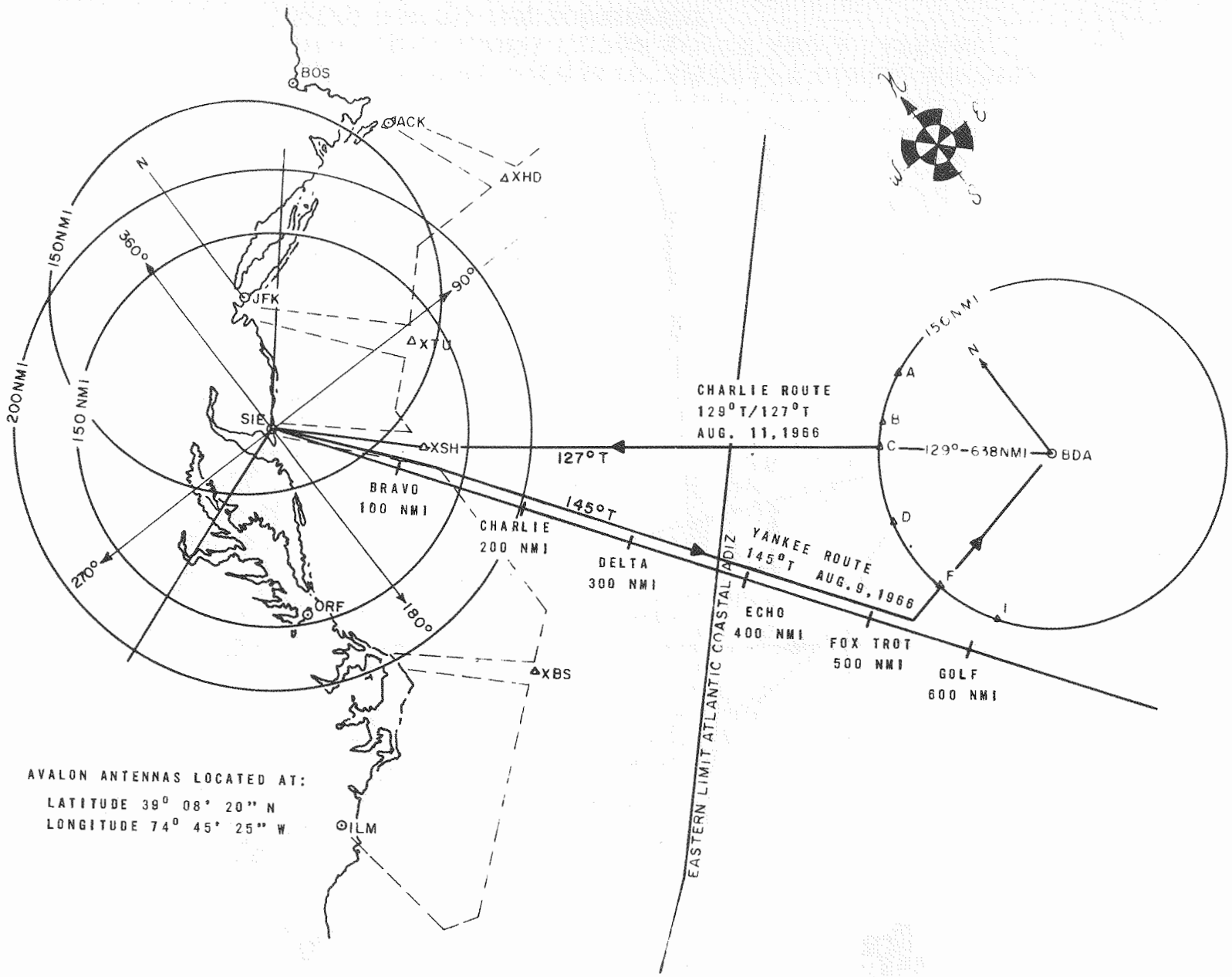

FIG. V-1 CHART SHOWING COURSES OF AIRCRAFT OUTBOUND FROM AVALON TOWARD BERMUDA AND INBOUND FROM BERMUDA TOWARD AVALON

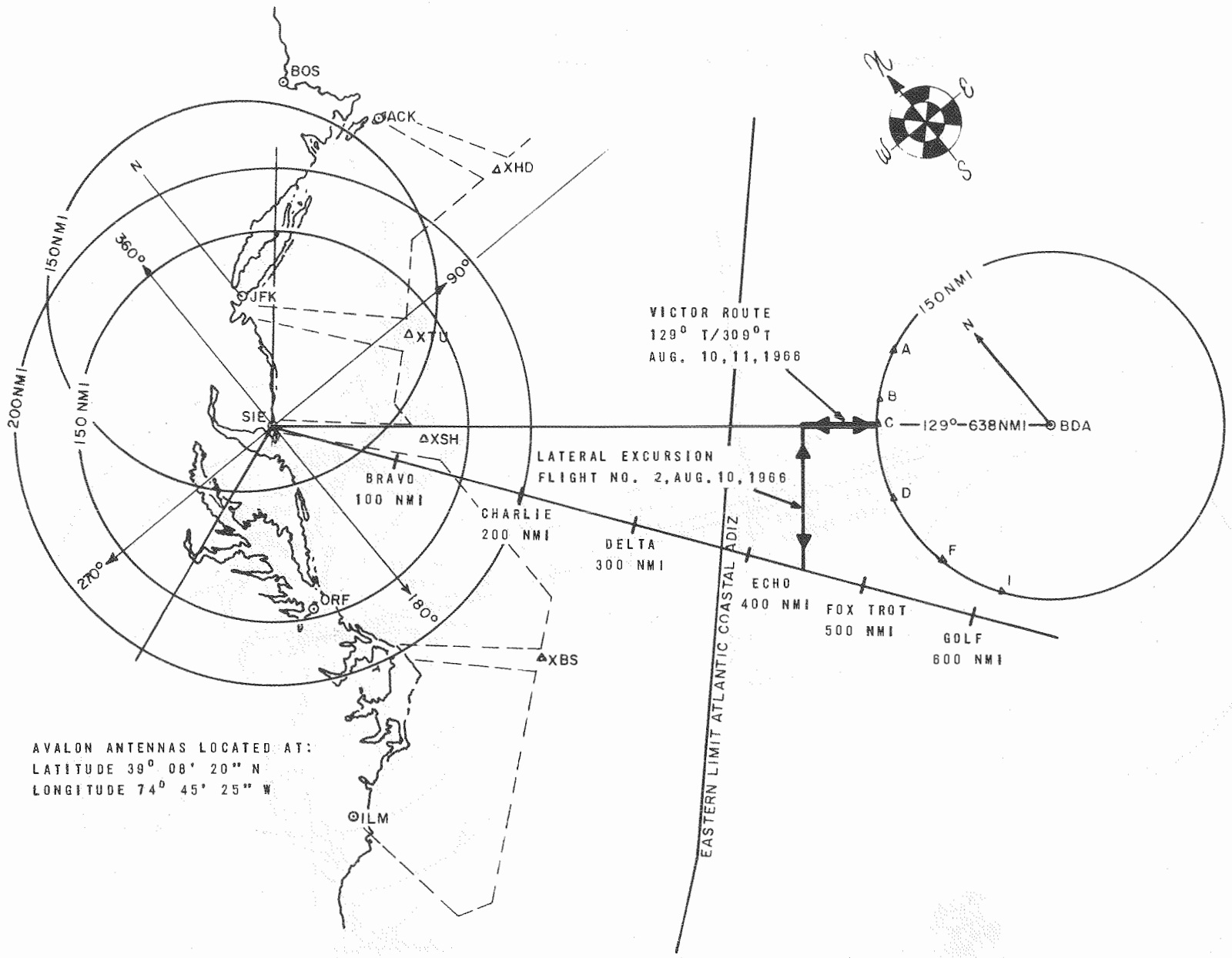

FIG. V-2 CHART SHOWING COURSE OF AIRCRAFT DURING SHUTTLE MANEUVERS ALONG VICTOR ROUTE AND A LATERAL EXCURSION TO THE SOUTHWEST

APPENDIX VI

GRAPHICAL TREATMENT AND ANALYSIS OF TELETYPE TEST DATA

Inaccuracies found in teletype messages, received during four test flights, were sorted into missing characters and wrong characters. Inaccuracies are plotted below for each teletype message, according to whether the VHF carrier was in the PM or AM mode. Numbers and missing characters are plotted on the same graphs with corresponding values of carrier signal level while numbers of wrong characters are plotted on the same graphs with corresponding values of signal-plus-noise to noise ratio. Two graphs therefore are presented for each of the four exploratory test flights.

Straight and Level Outbound Flight - The carrier signal levels for adjacent PM and AM messages are presented in Figure VI-1 which pertains to the first flight, August 9, 1966. The carrier signal level, which dipped characteristically as the aircraft passed over the radio horizon en route to Bermuda, recovered somewhat and fluctuated thereafter with a profile resembling data published elsewhere for troposcatter propagation.[1] Here the received signals were attenuated, as distance increased, at a rate of approximately 0.18 dB per nautical mile.

During these messages, there was no deep fading. Nevertheless, as average carrier power drifted below -110 dBm toward the sensitivity limit at -124 dBm, missing characters were more frequent.

The ratio (S + N)/N together with wrong characters per message for the first flight are plotted in Figure VI-2. Values of (S + N)/N were not obtained for all test messages. The manually-operated instrumentation was unable to secure signal-plus-noise readings at the same time that noise was observed. The strip-chart record showed that a great change of carrier-power level could occur within a few seconds. (See Appendix VIII.) Some records had to be rejected as clearly not representative. Values of (S + N)/N were plotted as separate curves for PM and for AM messages. Nevertheless, in many cases, not only in Figure VI-2, but in corresponding figures showing data from the other flights, values of (S + N)/N for consecutive PM and AM messages were closely related.

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[1]See Figure 56, Session No. 7, Propagation, M.W. Gough, "Assessing Reliable Ranges in the VHF Aeronautical Band," Proceedings, Extended Range VHF Symposium, International Aeradio, Limited, Middlesex, England, 1963.

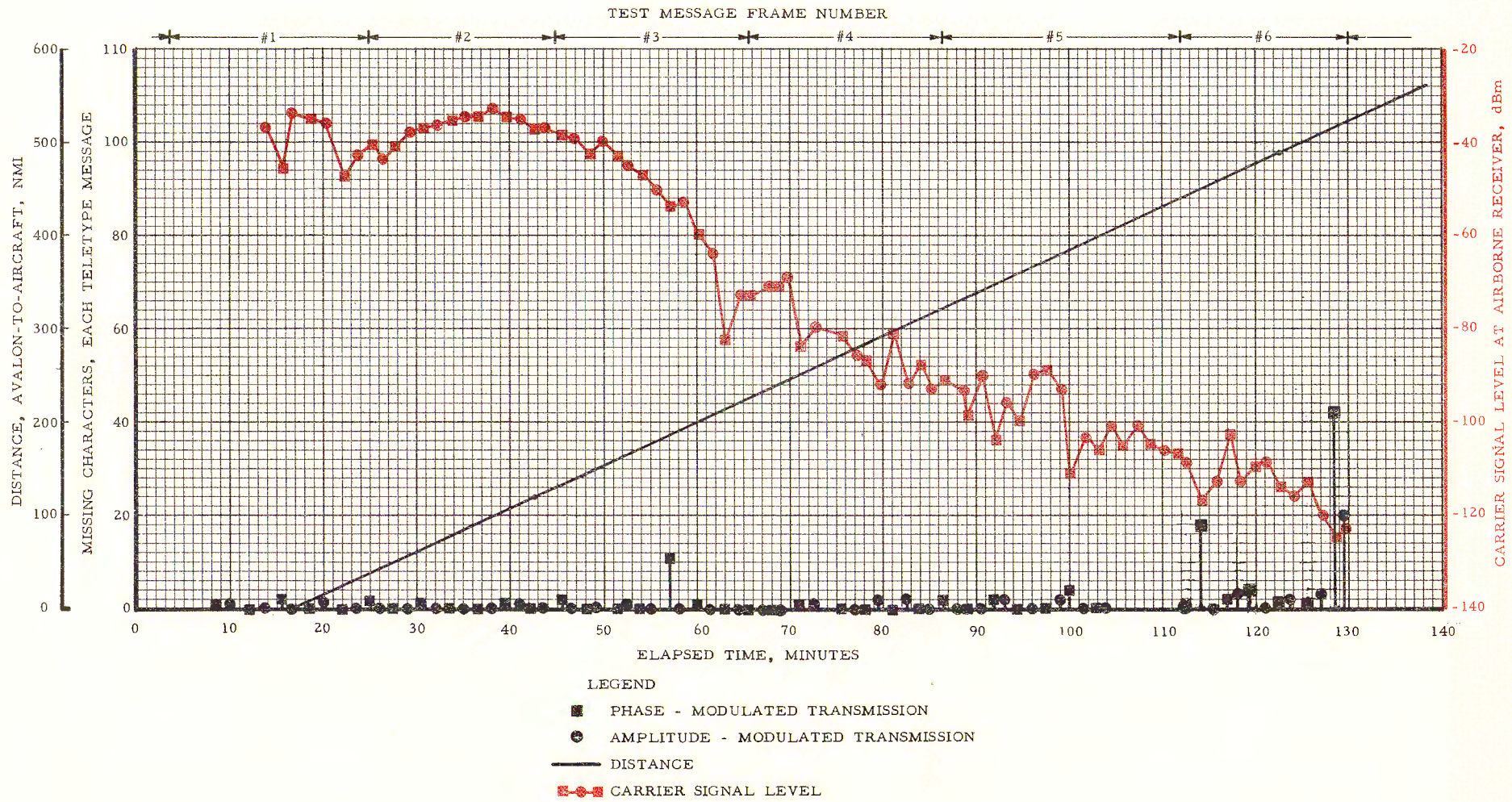

FIG. VI-1 DISTANCE, NUMBER OF MISSING TELETYPE CHARACTERS, AND CARRIER SIGNAL LEVEL DURING OUTBOUND EXPLORATORY FLIGHT AUGUST 9, 1966

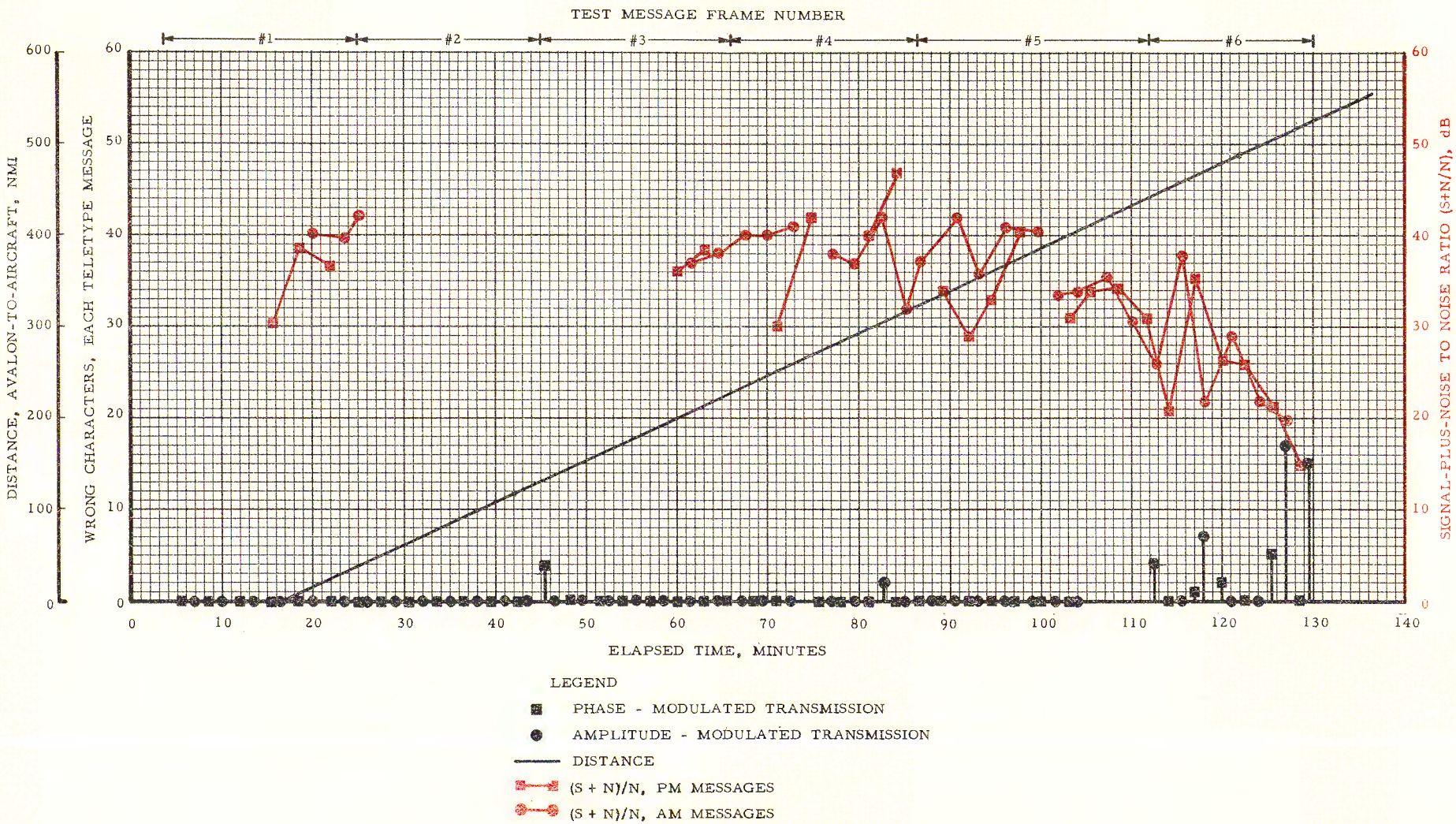

FIG. VI-2 DISTANCE, NUMBER OF WRONG TELETYPE CHARACTERS, AND SIGNAL-PLUS-NOISE TO NOISE RATIO DURING OUTBOUND EXPLORATORY FLIGHT AUGUST 9, 1966

Inspection of the graph over a brief portion of the first flight from 112 minutes to 130 minutes revealed that when (S + N)/N fell below 30 dB, some wrong characters were received. Furthermore, errors began to occur at higher values of (S + N)/N within AM messages than within PM messages.

Shuttle Maneuvers Down Range and Lateral Excursion - Figures VI-3 and VI-4 show data collected during the second flight, August 10, 1966. After the aircraft left Bermuda to fly over Point Charlie, some complete messages were recorded. One of these was received at an elapsed time of 6 minutes. Although the distance was about 550 nmi, carrier signal level was 120 dBm. Two minutes later, when carrier power was at a level of - 122 dBm, many characters were missing from the received message. The strip chart was examined at PM message No. 4 and the carrier level found to have been at - 124 dBm for about one-third of the message, - 123 dBm for about one-third, and at - 122 dBm for the other third. Mere inspection of the distribution of numbers of missing characters versus carrier level indicated that there was a threshold in the vicinity of - 122 dBm below which both PM and AM messages lose continuity.

Turns of the aircraft seemed to be accompanied by one or more incomplete messages.

The maneuver away from Victor Route toward the southwest and back, which started at 120 minutes and was completed at 180 minutes, provided an especially interesting graph of carrier signal level. At about 139 minutes, the average value of received carrier power during a message dropped below - 120 dBm, (S + N)/N fell below 20 dB, missing characters increased and wrong characters exceeded ten per message. Along this leg, the starboard side of the airborne antenna pattern was directed toward Avalon. After the 180° turn at about 153 minutes, the port side of the airborne pattern was directed toward Avalon. Average value of carrier level rose about 4 dB, and character inaccuracy disappeared for a few minutes. Along this leg back to the Victor Route, noticeably fewer characters were missing from AM than from PM messages. Also, the fluctuations of received PM carrier power coincided neatly with fluctuations in the number of missing PM characters.

The rest of the data for Flight #2 generally showed that received carrier power at a threshold of - 118 dBm, or stronger, supported accurate data transfer, but power levels 1 dB less were accompanied by noticeable discontinuities. A similar correspondence seemed to exist between bursts of errors and the noise levels which

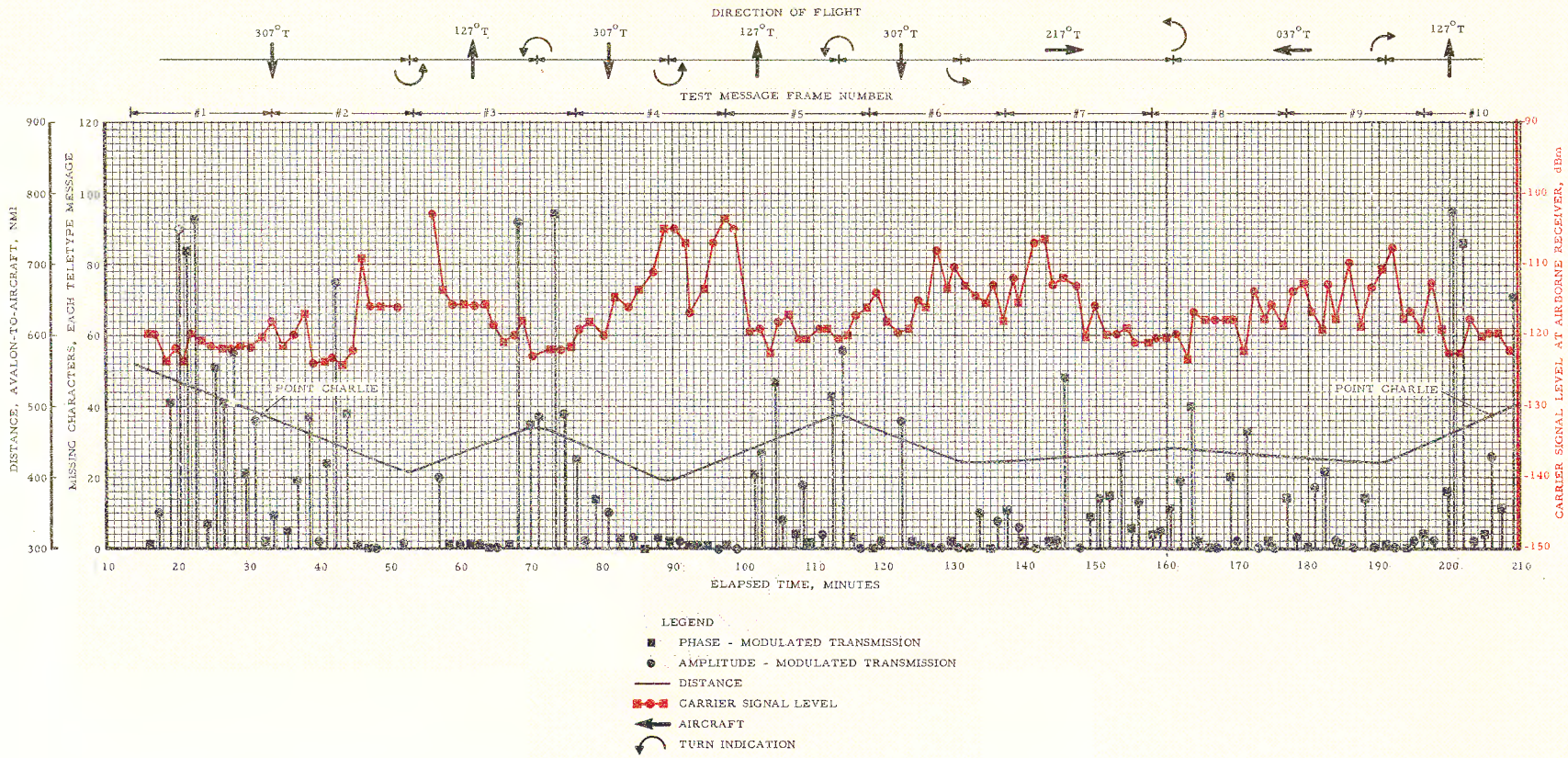

FIG. VI-3 DISTANCE, NUMBER OF MISSING TELETYPE CHARACTERS, AND CARRIER SIGNAL LEVEL DURING FIRST SHUTTLE FLIGHT AUGUST 10, 1966

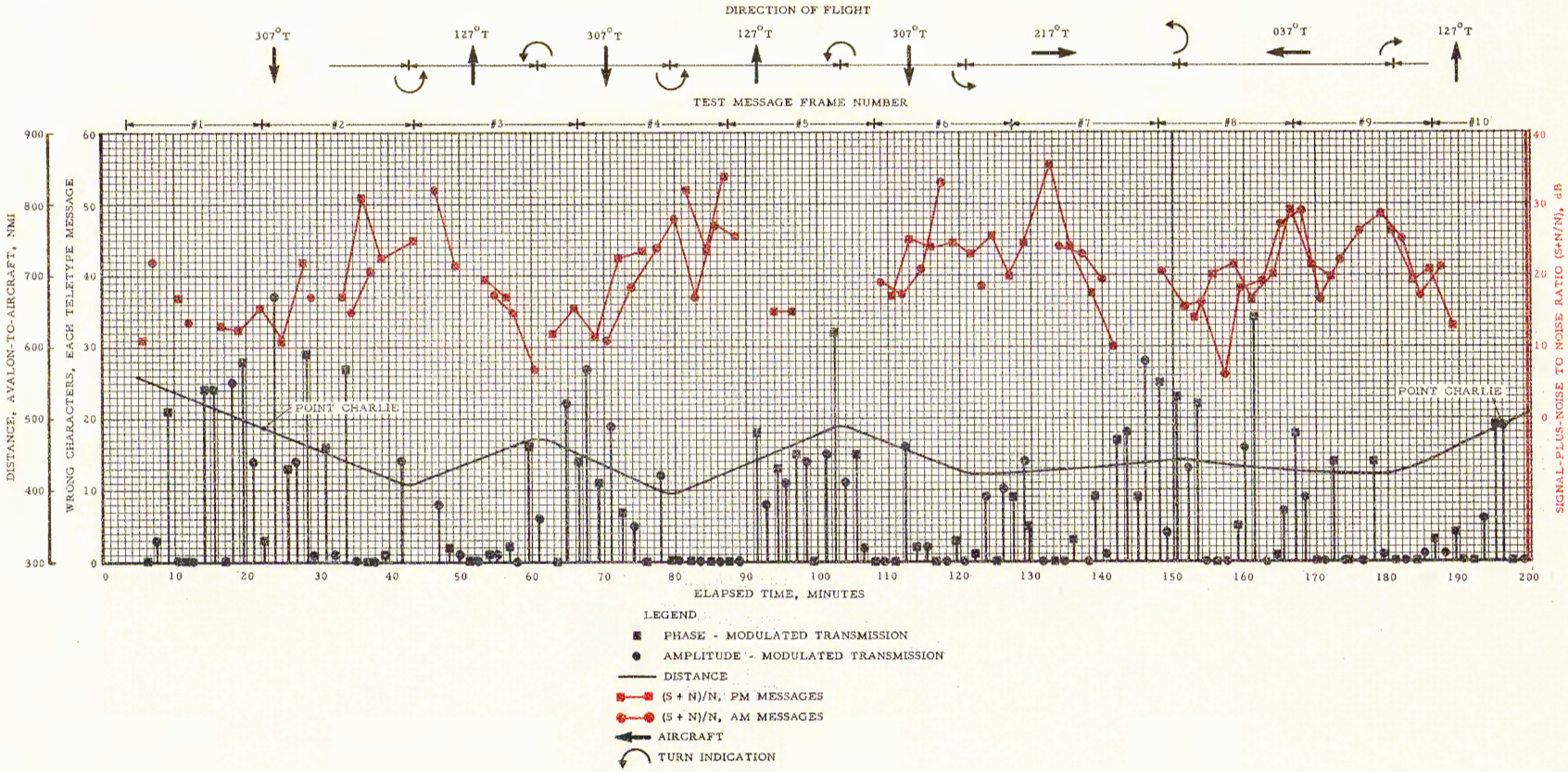

FIG. VI-4 DISTANCE, NUMBER OF WRONG TELETYPE CHARACTERS, AND SIGNAL-PLUS-NOISE TO NOISE RATIO DURING FIRST SHUTTLE FLIGHT AUGUST 10, 1966

dropped the (S + N)/N ratio below 20 dB while carrier level remained stronger than -120 dBm.

Distance to the aircraft at the -118 dBm level for carrier signal during Flight #2, most often was between 440 and 450 nmi during outbound legs and between 450 and 430 nmi during inbound legs. Bursts of missing and wrong characters generally accompanied turns; bursts were greater for the turns made further down range. (All turns were left-hand turns except for the turn at 180 minutes.)

Several general observations were made from the Flight #2 data:

a. Where large numbers of characters are missing, few, if any, wrong characters were logged;

b. Although the graph for (S + N)/N generally corresponded with the graph for carrier signal level, the two differed sufficiently to argue that noise and carrier signal level vary independently;

c. There were enough gaps in the (S + N)/N data to warn that for large-scale experiments depending on (S + N)/N, sequential measurements first of signal-plus-noise and then noise alone would not be satisfactory; instead, noise should be measured simultaneously with signal plus noise.

Flight #3 (Figures VI-5 and VI-6) covered almost the same shuttle path as Flight #2 along the Victor Route. Only beyond 520 nmi did average carrier signal level dip below -120 dBm, during the first inbound leg. Thereafter from 13 minutes to 114 minutes, average carrier signal for each 20-second message, was stronger than -120 dBm. PM messages at 53, 56, 66, and 73 minutes were affected by fades for several seconds to between -118 and -121 dBm. The AM message at 88 minutes had 50 characters missing. The corresponding average value for carrier signal level was -119 dBm. However, for 3 seconds, the carrier actually faded to -121 dBm during that portion of the received message which was missing. This case was typical of what happened at turns.[2]

Data transfer during Flight #3 was clearly superior to data transfer over the same region on the preceding day. Once again, however, a threshold appeared, near 500 nmi, within which data transfer was relatively free of inaccuracies. On the final leg heading toward Bermuda, carrier signal fell below -120 dBm at a distance of 460 nmi.

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[2]Throughout this flight, occasional inaccuracies occurred in bursts at random times. Bursts usually occurred at the turns; however, two burst-free turns were made at a distance of 420 nmi.

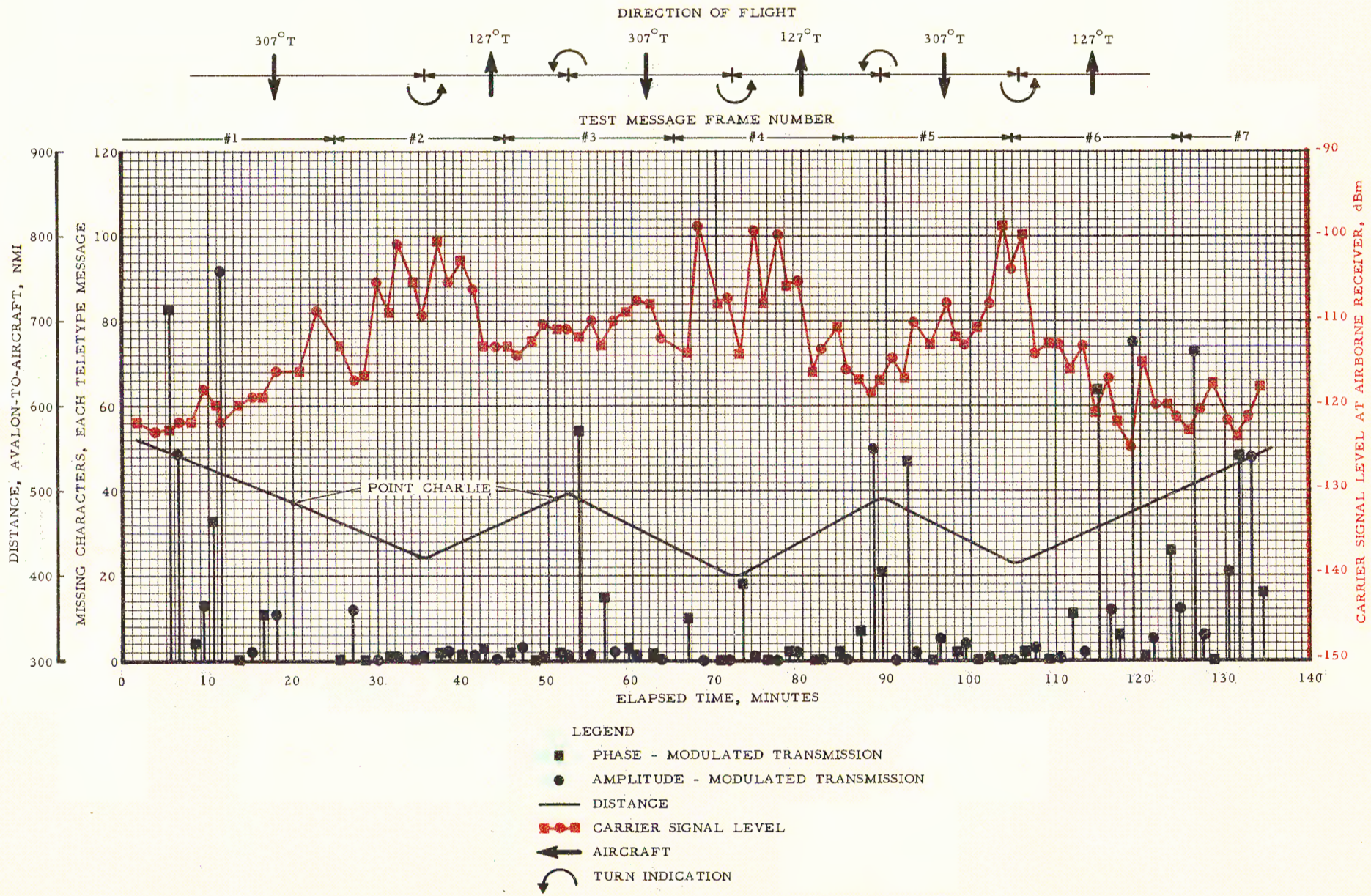

FIG. VI-5 DISTANCE, NUMBER OF MISSING TELETYPE CHARACTERS, AND CARRIER SIGNAL LEVEL DURING SECOND SHUTTLE FLIGHT AUGUST 11, 1966

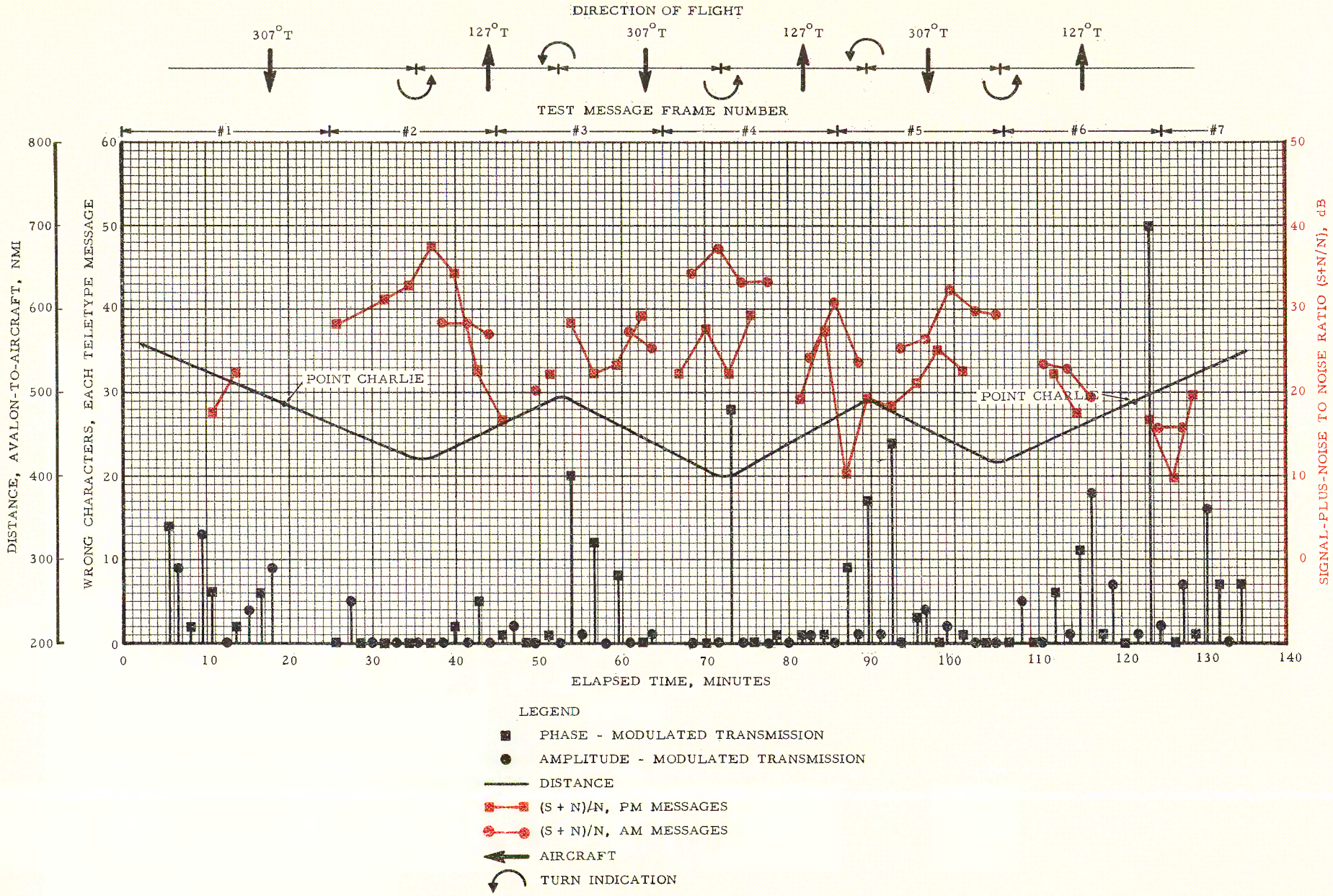

FIG. VI-6 DISTANCE, NUMBER OF WRONG TELETYPE CHARACTERS, AND SIGNAL-PLUS-NOISE TO NOISE RATIO DURING SECOND SHUTTLE FLIGHT AUGUST 11, 1966

While taxiing just before take-off on August 10 and 11, parts of some teletype messages were printed out correctly although the point-to-point distance from Avalon was some 628 nmi. Such long hauls usually imply ducting over part of the distance. It was interesting to note that while the aircraft was climbing to altitude after take-off from Kindley Air Force Base, few teletype signals were successfully received until the distance to Avalon became less than 550 nmi and the climb to 20,000 feet had been completed.

This incident brought attention to the possible effects of aircraft attitude and the vertical pattern of the airborne antenna which was tilted upward during the climb maneuver.

During the test period there had been no ready means for measuring the vertical pattern.

Straight and Level Return Flight - Figures VI-7 and VI-8 portray the results of data transfer observations during Flight #4. On crossing Point Charlie, the AM message suffered a loss of 46 characters as carrier level dipped temporarily below -120 dBm and then the PM message suffered 32 wrong characters. Subsequently, only a few random inaccuracies were observed throughout the return flight.

Review of graphs for these test flights suggested that only 15 to 20 minutes of Flight #1 and #4 were useful for comparative evaluation of AM and PM, whereas almost all of the flight time of Flight #2 and #3 supplied useful comparative data.

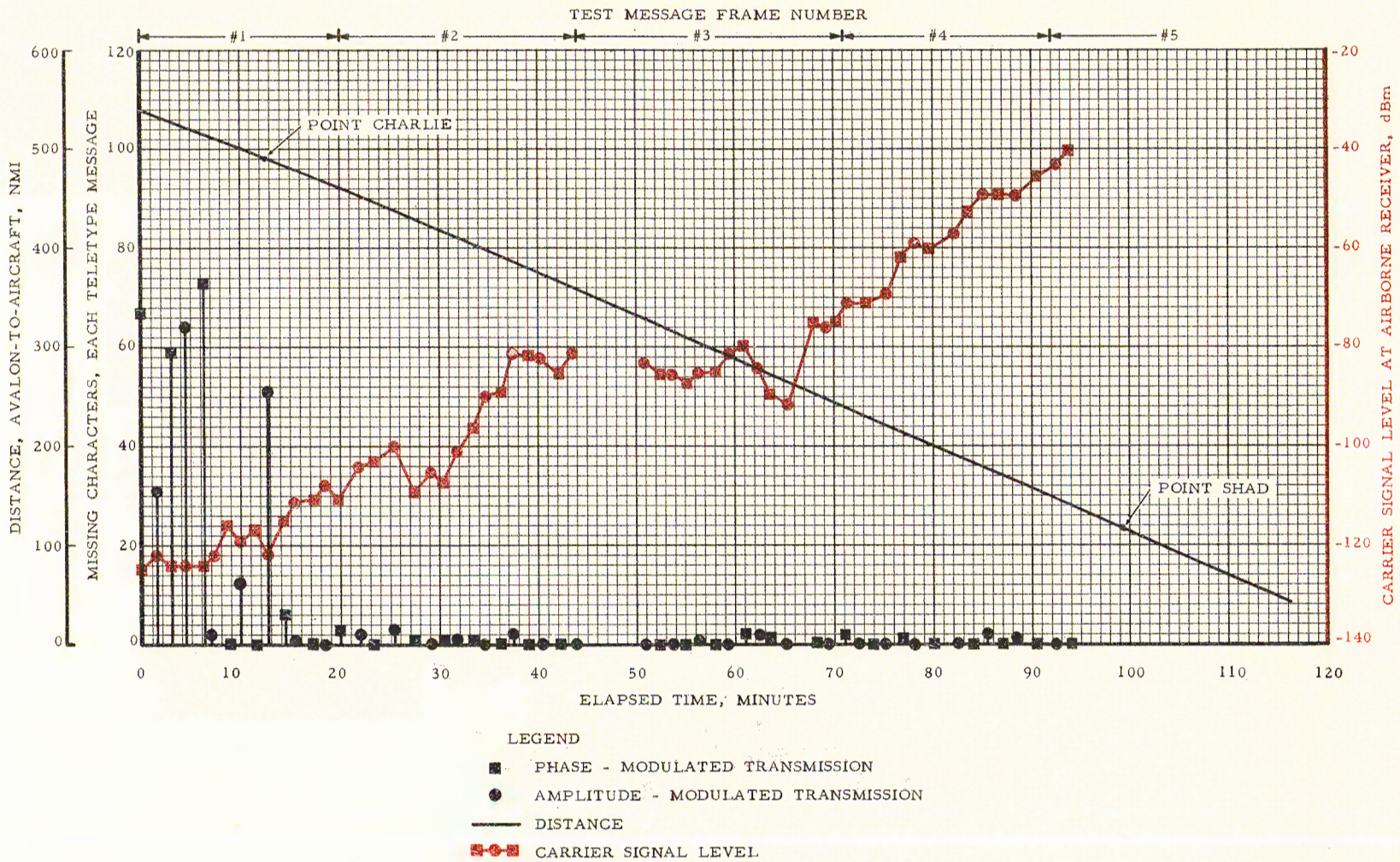

FIG. VI-7 DISTANCE, NUMBER OF MISSING TELETYPE CHARACTERS, AND CARRIER SIGNAL LEVEL DURING INBOUND EXPLORATORY FLIGHT AUGUST 11, 1966

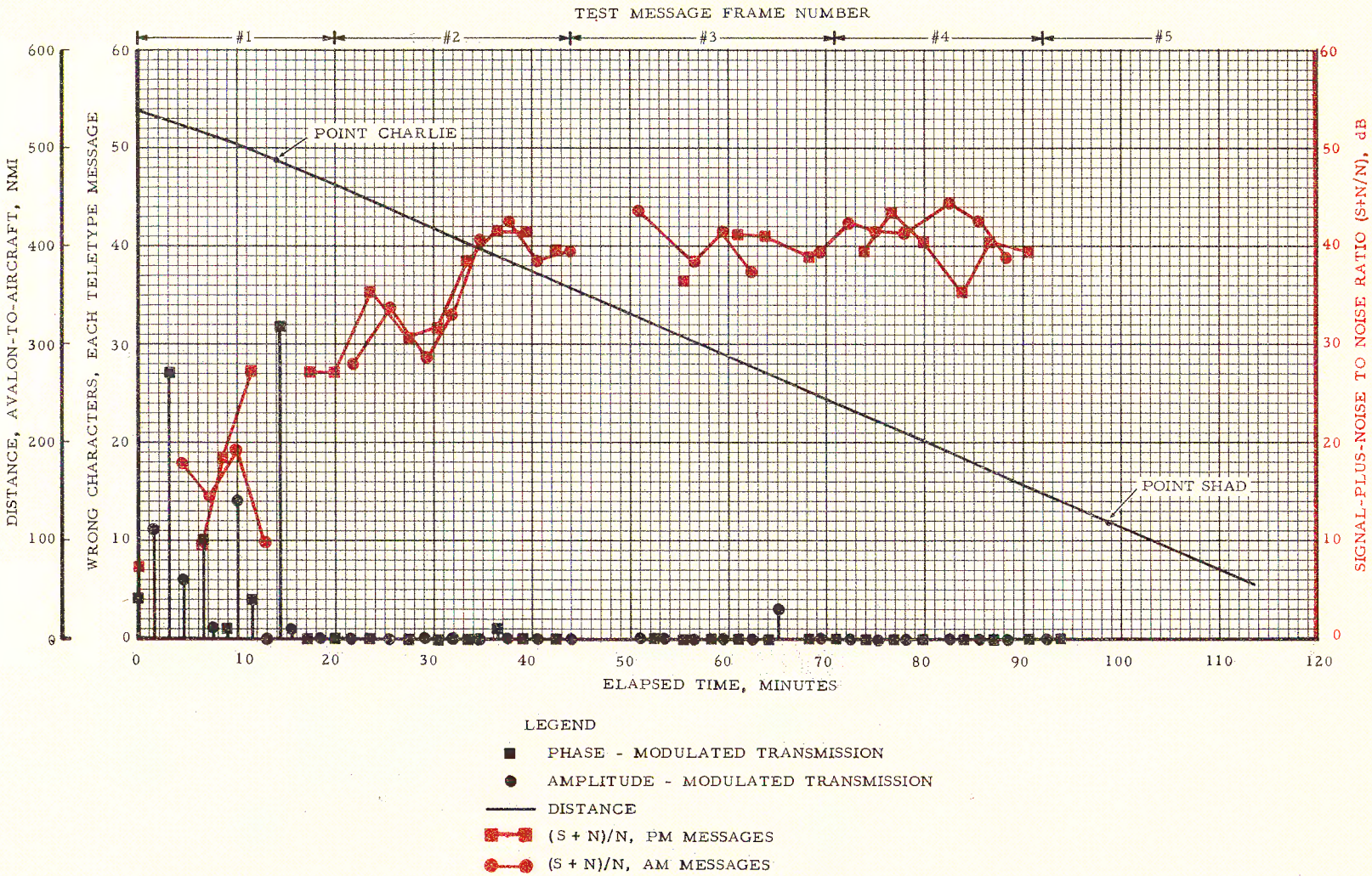

FIG. VI-8 DISTANCE, NUMBER OF WRONG TELETYPE CHARACTERS, AND SIGNAL-PLUS-NOISE TO NOISE RATIO DURING INBOUND EXPLORATORY FLIGHT AUGUST 11, 1966

APPENDIX VII

TEXT OF VOICE MESSAGES RECORDED ON MAGNETIC TAPE FOR AUTOMATIC SAMPLING AT RANDOM

TROPO TEST CONTROL/THIS IS SPEEDBIRD GOLF ALPHA/POSITION 49 45 NORTH/ 50 WEST AT 1317/ FLIGHT LEVEL ONE NINE ZERO/ NEXT POSITION 50 00 NORTH/40 WEST AT 35/ ENDURANCE 9 HOURS 30/ MINUS 18/255 35 END OF MESSAGE ONE

TROPO TEST CONTROL/ THIS IS CLIPPER 101/ POSITION 50 45 NORTH/ 20 WEST AT 1536/ CLIMBING TO FLIGHT LEVEL TWO TWO ZERO / NEXT POSITION 49 25 NORTH/ 25 WEST AT 1621/ ENDURANCE 10 HOURS END OF MESSAGE TWO

TROPO TEST CONTROL/ THIS IS EASTERN 451/ POSITION ABEAM OSCAR CHARLIE AT 1829/ FLIGHT LEVEL TWO ONE ZERO/ NEXT POSITION C-1 AT 1854 / ENDURANCE 5 HOURS/ PLUS ONE FOUR ZERO FEET/ TURBULENCE MODERATE END OF MESSAGE THREE

TROPO TEST CONTROL/ THIS IS FOXTROT ALPHA BRAVO PAPA DELTA/ POSITION ABEAM NANTUCKET AT 2031/ FLIGHT LEVEL ONE EIGHT ZERO/ NEXT POSITION PORPOISE AT 2058/ ENDURANCE 9 HOURS 30/ MINUS 18/ 255 35 AT 65 30/ PLUS TWO NINE ZERO FEET/ IN AND OUT BROKEN CUMILIFORM/ TOP THREE ZERO THOUSAND FEET/ TURBULENCE LIGHT/ FRONT 2025/ IN FRONT END OF MESSAGE FOUR

TROPO TEST CONTROL/ THIS IS AMERICAN 491/ POSITION 42 NORTH/ 40 WEST AT 2248/ FLIGHT LEVEL THREE ONE ZERO/ NEXT POSITION 43 NORTH/ 50 WEST AT 2313/ ENDURANCE 8 HOURS 30/ MINUS 45/ 300 60/ PLUS SEVEN FIVE ZERO FEET END OF MESSAGE FIVE

TROPO TEST CONTROL/ THIS IS KLM 455/ POSITION 45 30 NORTH/ 52 45 WEST AT 2145/ FLIGHT LEVEL TWO EIGHT ZERO/ NEXT POSITION 46 30 NORTH / 53 45 WEST AT 2210/ ENDURANCE 7 HOURS 30/MINUS 30/270 30/ PLUS THREE FOUR ZERO FEET END OF MESSAGE SIX

TROPO TEST CONTROL/ AIREP SPECIAL/ THIS IS KLM 601/ ABEAM BOSTON AT 1543/ ALTITUDE EIGHT THOUSAND FEET/ NEXT POSITION SALEM AT ZERO ONE/ ICING SEVERE END OF MESSAGE SEVEN

APPENDIX VIII

SAMPLE PEN RECORDINGS OF AUDIO SIGNALS AND AGC VOLTAGES AT AIRBORNE RECEIVER

Description of Illustrations - The first illustrations of this appendix, Figures VIII-1 and VIII-2, show samples of the pen recordings of audio signals, together with corresponding Automatic Gain Control (AGC) voltages, received during complete sequences of test messages. Each sequence of test signals started with Phase Modulation (PM) of the VHF carrier frequency. The same pattern of test signals was then repeated with Amplitude Modulation (AM) of the carrier frequency. Before the next sequence began, transmission of the carrier was interrupted for about 12 seconds.

Both sets of test signals started with a constant frequency tone which lasted for about 10 seconds. Receiver gain was adjusted manually until the recording pen reached a pre-arranged mark on the chart, usually the right-hand margin of the left portion of the record paper. This calibrated mark set the level of signal plus noise (S + N) for each change of carrier modulation.

Immediately following the (S + N) sounding, noise (N) alone was observed while the VHF carrier was unmodulated. The receiver audio was passed through a narrow-band filter the same as provided for S + N. For those cases where the (N) level was very low, attenuation was altered until the recording pen moved to a readable portion of the chart. With these two levels established, (S + N)/N could be computed at the beginning of each modulation sequence.

Next, the carrier was modulated by the teletype (TTY) message prescribed for the particular frame. This message, which lasted for 18 to 20 seconds, was easily identified as a pedestal rising from the left-hand margin to the first heavy line of the chart.

Following the TTY message, provision was made for injection of messages spoken into a microphone at the transmitter. Normally, there was no such message transmitted.

Finally, the taped voice message modulated the carrier completing the set for each of the PM and AM modes.

On the right-hand chart calibrated AGC voltage was recorded. Because of the dynamic range of the AGC, audio signals were not much dependent upon its actual value. The changes in carrier-frequency

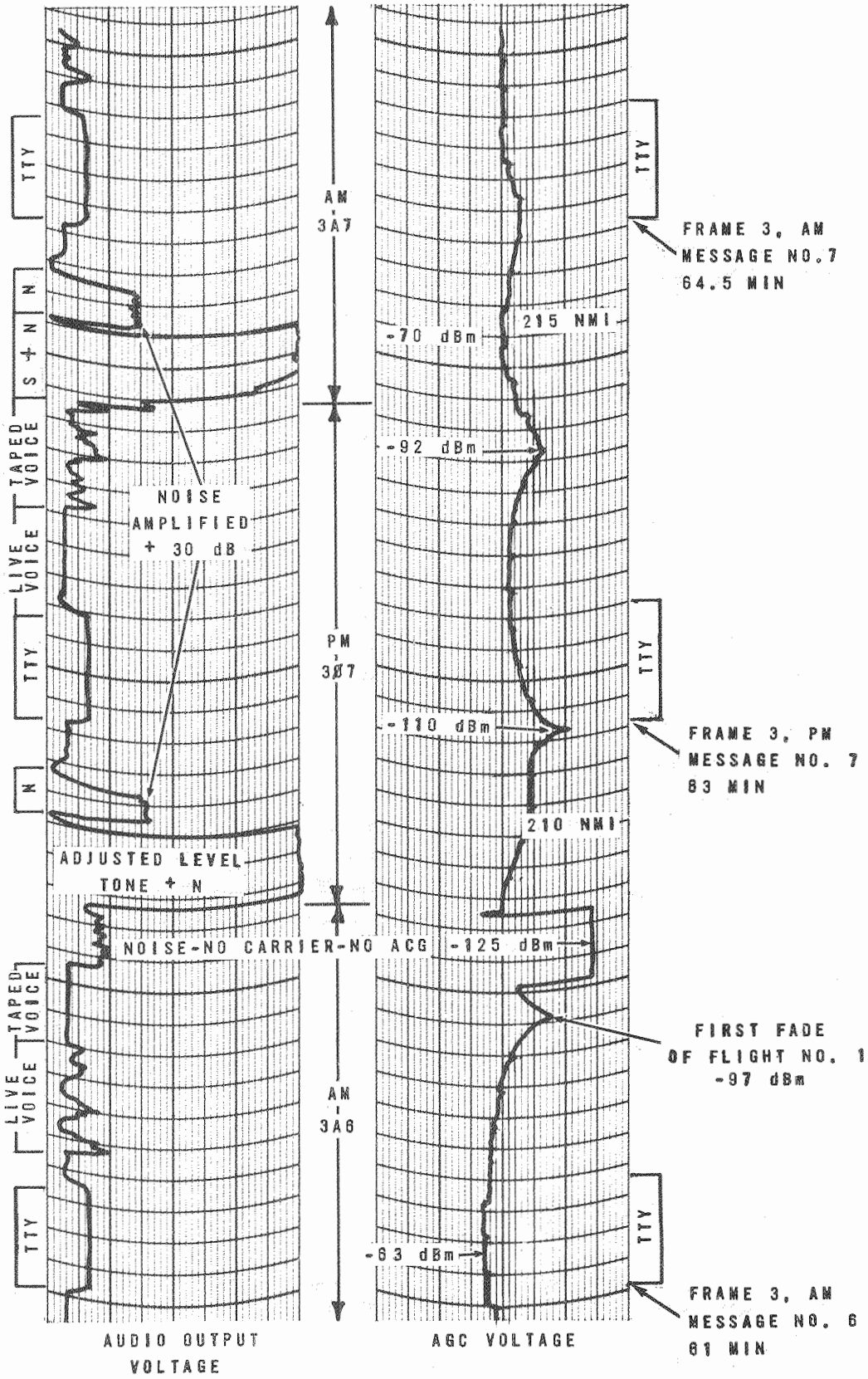

FIG. VIII-1 SAMPLE RECORD OF AUDIO OUTPUT AND AGC VOLTAGE RECORDED JUST BEYOND RADIO HORIZON, FLIGHT #1

power at the airborne receiver were directly represented by AGC voltage. At the end of each sequence, while the carrier was interrupted, a pedestal is found at a level representing the receiver sensitivity for each record. Calibration of other levels was accomplished before and after flights by substituting calibrated carrier-frequency output for a laboratory signal-generator at the usual antenna-input connection to the receiver. Occasionally, the AGC voltage connection was interrupted for a zero-signal reference check of the pen recording system; with no AGC voltage, the properly adjusted pen moved to the right margin of the record chart. Speed of the paper was such that 1 inch of record corresponds to 25.95 seconds of elapsed time. Curved graduations are 0.2 inch apart and therefore represent 5.19 seconds of elapsed time.

Dimension lines along the chart samples contain three symbols of which the first symbol designates the frame number, the second symbol identifies PM (Ø) from AM (A) of the carrier, and the third symbol designates which of seven teletype messages was transmitted during the set.

Some of the high and low levels of received carrier signal are marked in terms of -dBm at the corresponding AGC voltage.

Distance of the aircraft in nautical miles (nmi) from the ground transmitter is marked at several places on the records and so is elapsed time in minutes (min). With these references, some qualitative correlation may be obtained with the corresponding frequencies of erroneous and missing characters presented elsewhere in the report.

Sample Pen Records of AGC Voltage From Flight #1 - Fading of carrier-frequency power during the outbound flight along 145° T from Avalon was characterized by several sharp dips just after the radio horizon was passed. These may be seen in Figure VIII-1. Later variations of received carrier may be traced in successive sequences shown in Figures VIII-2 to VIII-4. Soon after test message 6A5 was received when the distance was about 515 nautical miles, test recordings were discontinued.

Variation of AGC Voltage at Turning Maneuvers - During the shuttle-flight operation of Flight #2, the aircraft made a number of 180° turns to the left. Figure VIII-5 illustrates the behavior of AGC voltage for several minutes from just before to just after four of these maneuvers. Flat turns were generally attempted. The two lower chart samples were recorded about 400 nmi from Avalon and the two upper samples were recorded at 470 to 490 nmi from Avalon.

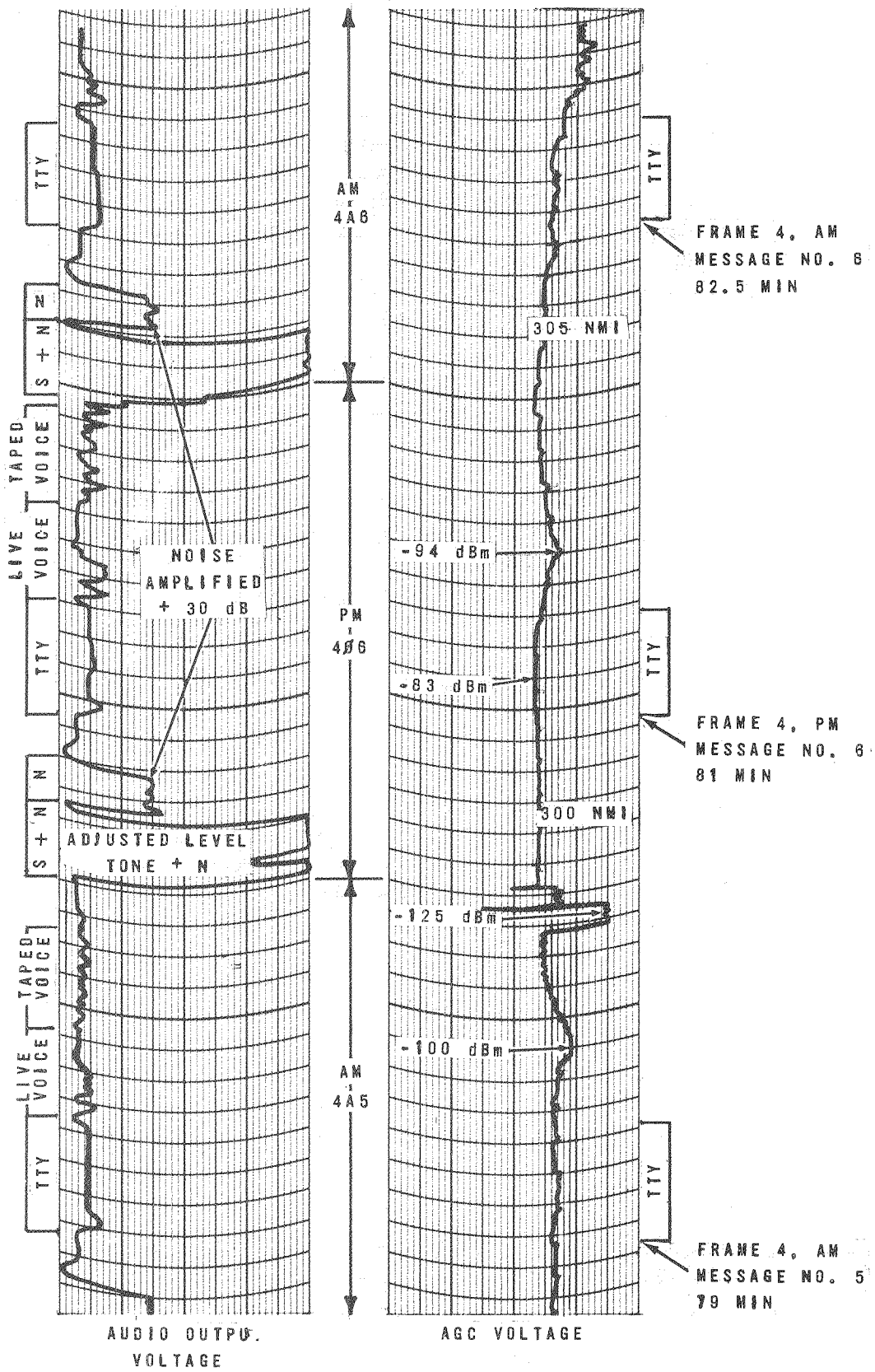

FIG. VIII-2 SAMPLE RECORD OF AUDIO OUTPUT AND AGC VOLTAGES RECORDED BEYOND RADIO HORIZON AND DIFFRACTION ZONE, FLIGHT #1

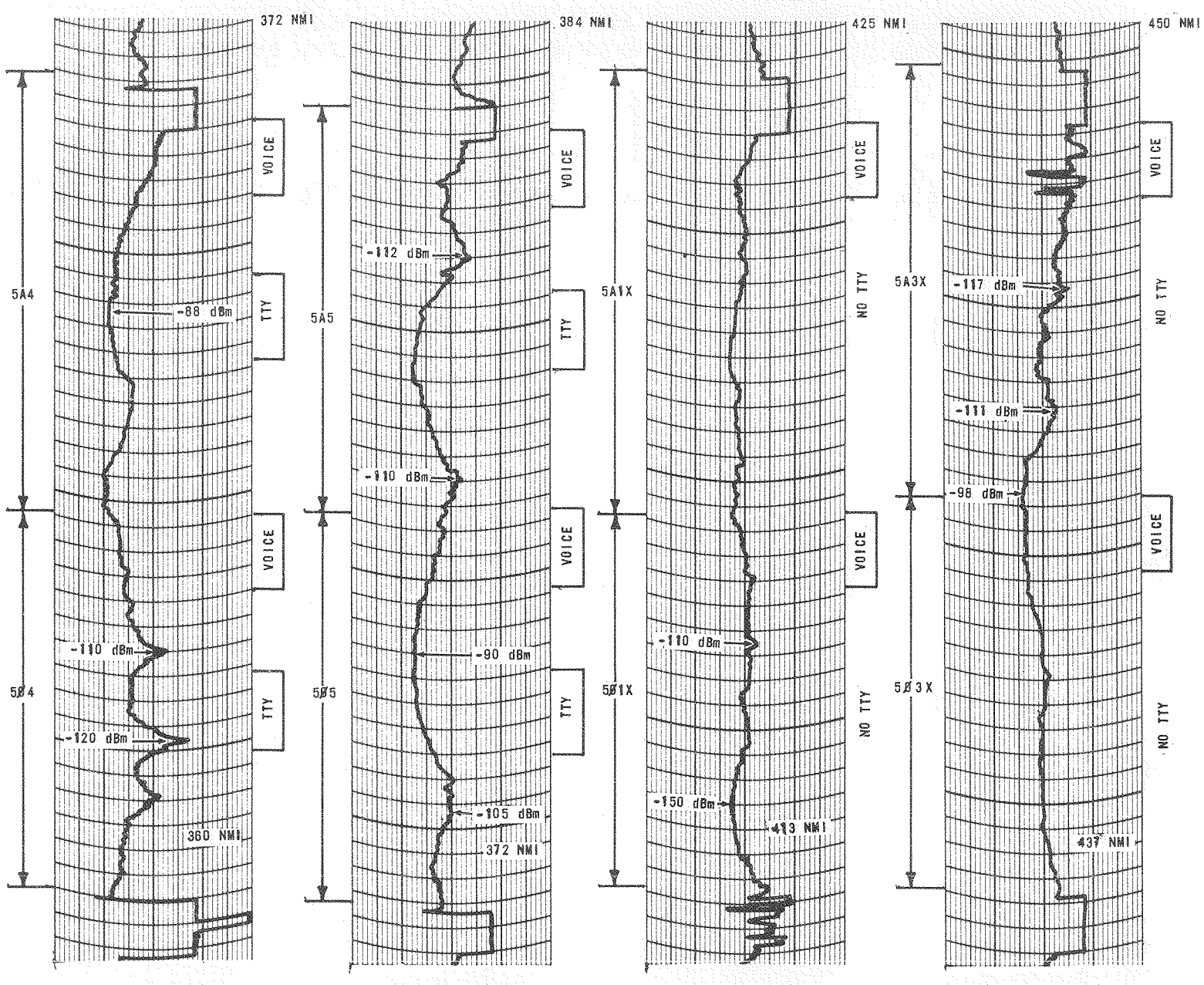

FIG. VIII-3 FADING OF CARRIER AS INDICATED BY AGC VOLTAGES DURING FLIGHT #1, FROM 358 nmi TO 450 nmi

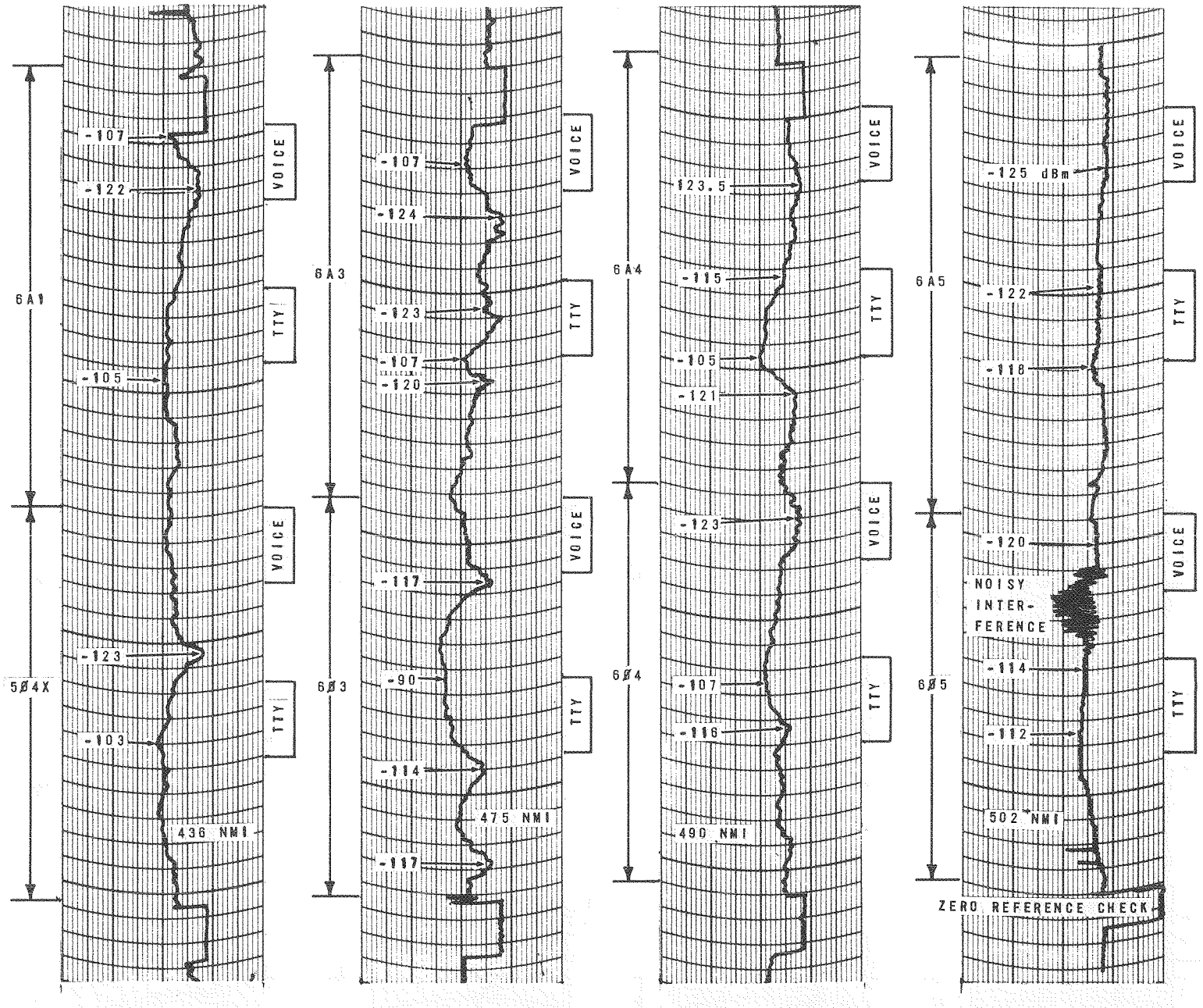

FIG. VIII-4 FADING OF CARRIER AS INDICATED BY AGC VOLTAGES APPROACHING THE LIMIT OF RECEPTION AT THE END OF FLIGHT #1

Variation of AGC Voltage During Lateral Excursion at Nearly Constant Distance - Figure VIII-6 presents sample AGC voltage records taken during the lateral excursion of Flight #2. At the upper right corner, message interval 6Ø5 is represented as the airplane was heading toward Avalon. A 90° left turn started during interval 6A5 was completed at 423 nmi by the start of interval 6Ø6. The next lower sample was recorded during the straight and level flight toward the Southwest. The sample at the center spans the 180° turn over the axis of the main beam (145°T from Avalon, N. J.). Next to the bottom, the chart samples the AGC voltage variation during the return straight-and-level flight back to the Victor route; this time, however, the antenna pattern to the port side of the aircraft was directed toward Avalon. The character of the variations seemed to be substantially different than during flight with the starboard pattern directed toward Avalon. In the lowest sample on Figure VIII-6 the AGC voltage after the 90° turn back to the Bermuda began to assume the same character as exhibited at the beginning of the illustration during interval 6Ø5.

Variation of AGC Voltage during Voice Messages - Figure VIII-7 and VIII-8 illustrate the effects of dynamic variation of carrier-signal during test voice messages. Comments by the reader of the voice messages recorded during Flight #3 are presented alongside the records of AGC voltage which correspond with the time of taped-voice transmission. When the AGC voltage dipped to the "no-carrier" levels, comments were unfavorable.

During message interval 2Ø5 the voice message sounded intermittent. The actual record of AGC voltage showed that the carrier signal dipped twice to low levels near the beginning of the voice transmission and then rose by more than 20 dB before the end of the same brief message.

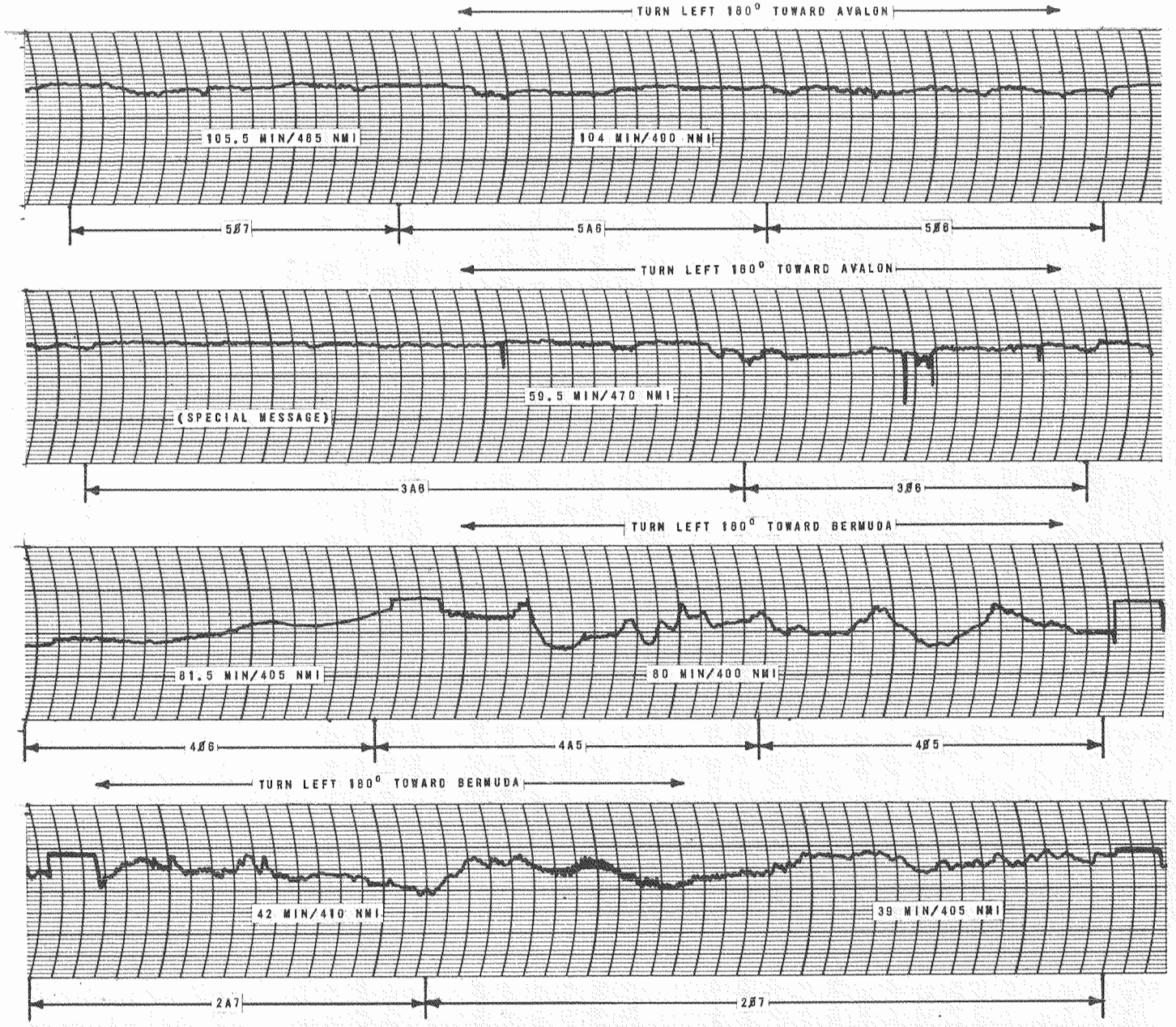

FIG. VIII-5 AGC VOLTAGE VARIATIONS IN THE VICINITY OF FOUR 180° LEFT TURNS DURING FLIGHT #2

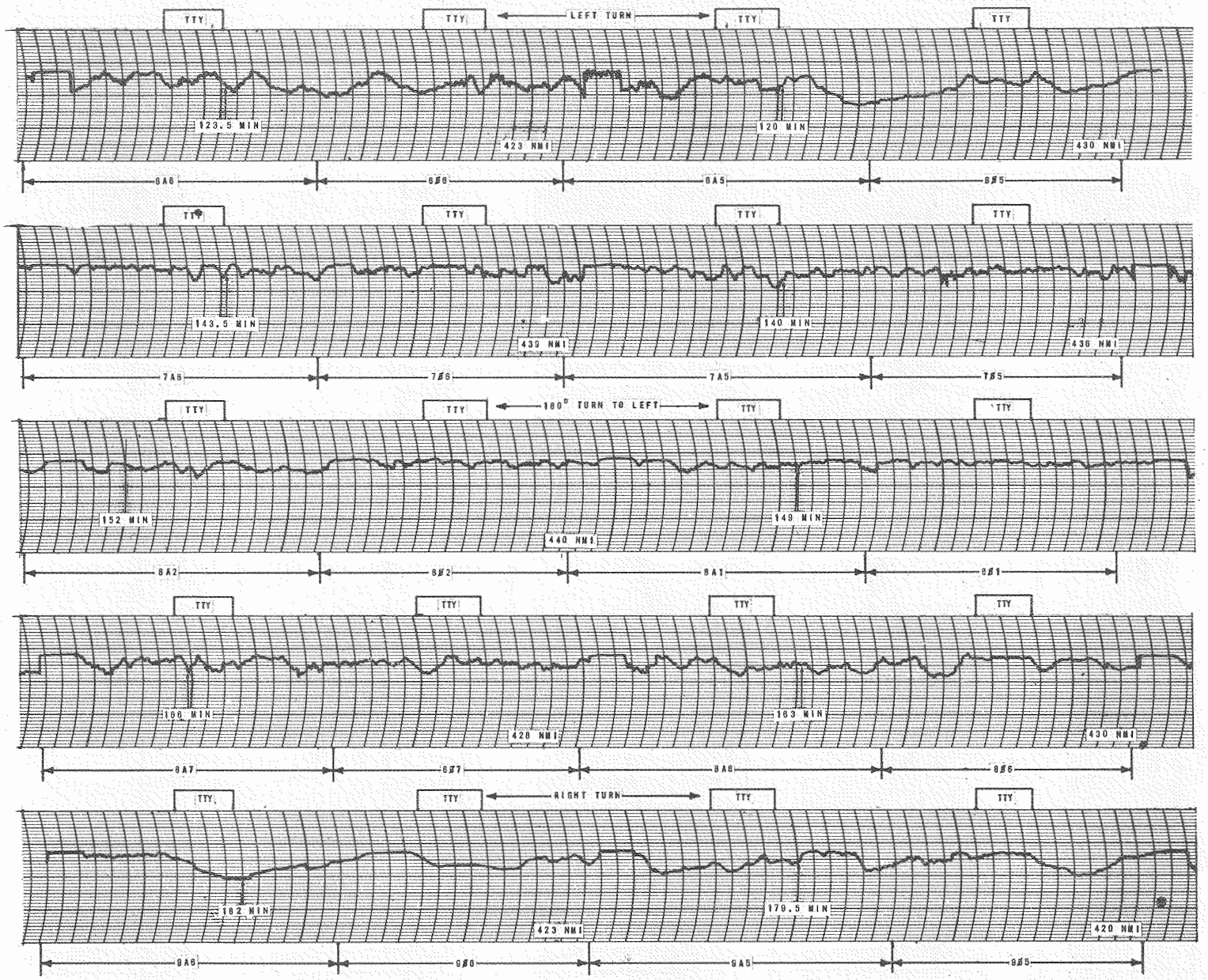

FIG. VIII-6 AGC VOLTAGE VARIATIONS DURING LATERAL EXCURSION TO THE SOUTHWEST OF NEARLY CONSTANT DISTANCE DURING FLIGHT #2

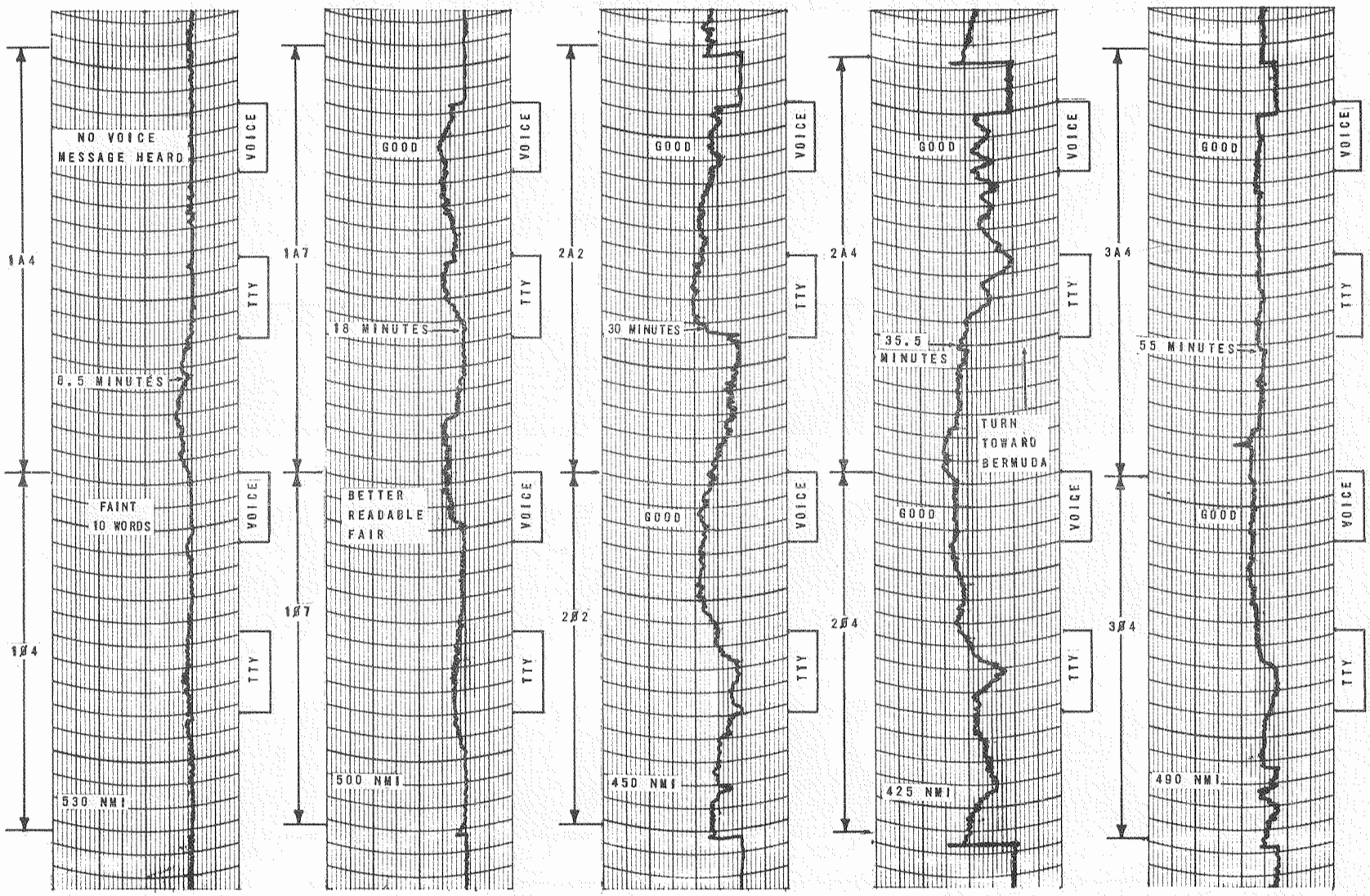

FIG. VIII-7 AGC VOLTAGE VARIATIONS WITH COMMENTS ABOUT SEVERAL VOICE TRANSMISSIONS DURING FLIGHT #3

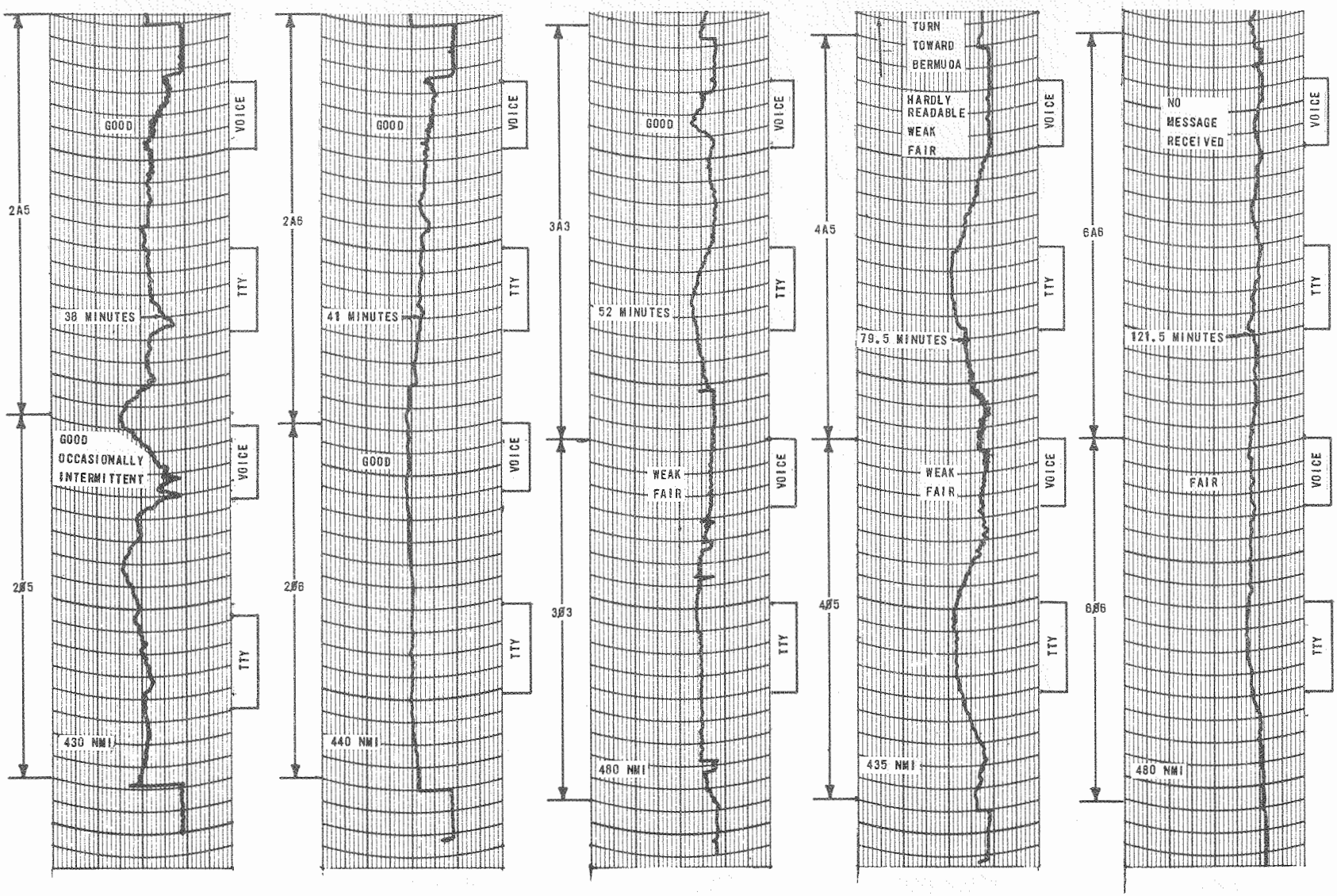

FIG. VIII-8 AGC VOLTAGE VARIATIONS WITH COMMENTS ABOUT VOICE TRANSMISSIONS DURING FLIGHT #3

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