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Materiel Test Procedure 6-2-075
Electronic Proving Ground

U. S. ARMY TEST AND EVALUATION COMMAND
COMMODITY ENGINEERING TEST PROCEDURE

3482

DISTANCE MEASURING EQUIPMENT (DME), GENERAL

1. OBJECTIVE

The objective of this materiel test procedure is to outline a series of engineering tests designed to determine the technical performance of distance measuring equipments.

2. BACKGROUND

Distance measuring equipment types fall into three major categories classified according to operational characteristics and concept of employment. These three categories are commonly referred to as (1) the VOR/TACAN/DME, (2) the VHF/FM-DME, and (3) tellurometers.

The VOR/TACAN/DME system is defined by MIL-STD-291A, (Ref 4B) ICAO Annex 10 (Ref 4C), and the RTCA Minimum Performance Standard (Ref 4D). It is a pulsed interrogator-transponder system operating in the 960-1215 MHz band, and is common to three rho-theta (ρ-θ) navigation systems: the military TACAN system, the VORTAC system, and the VOR/DME system (all depicted in Figure 1). Specifications for the TACAN system were established in 1951, for the VORTAC in 1956, and for the VOR/DME system in 1959.

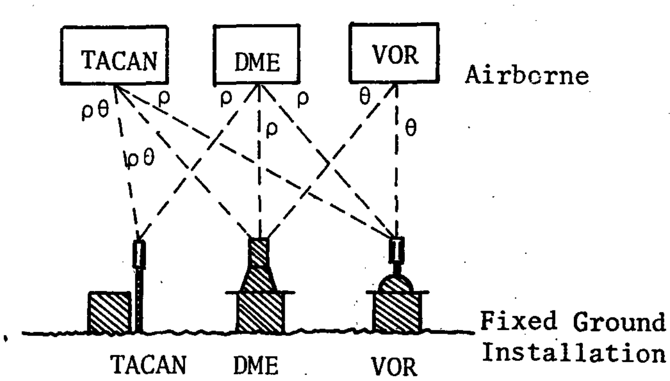

Figure 1. The VOR/TACAN/DME system.

The VHF/FM-DME is a system to provide distance measurements between aircraft and tactical ground radio sets (aircraft-to-ground). This equipment is used in conjunction with the homing capability of present aircraft VHF/FM radio sets and consists of two attachment type elements. One device, an applique unit designed for attachment to VHF/FM ground sets enables the sets to transpond omni-directional signals automatically (or manually at the option of the operator) in response from an aircraft VHF/FM-DME set. The other device, designed to function with aircraft VHF/DME sets, is capable of interrogation functions or transponding replies from other aircraft interrogation.

The multiple-frequency continuous wave (CW) radar technique has been applied to the accurate measurement of distance in surveying and in missile guidance. The tellurometer is the name given to portable electronic surveying instruments employing this principle. The tellurometer consists of a master unit at one end of the survey line and a remote unit at the other end. A typical master unit will transmit a carrier frequency of 3000 MHz with four single-sideband modulated frequencies separated from the carrier by 10.0, 1.0, 0.1 and 0.01 MHz. The 10 MHz difference frequency provides the basic accuracy measurement, while the difference frequencies of 1 MHz, 100 kHz permit the resolution of ambiguities.

The remote unit receives signals from the master unit and amplifies and re-transmits them. The phases of the returned signals at the master unit are compared with the phases of the outgoing signals, thereby obtaining a measure of signal distance covered.

It is necessary to perform engineering testing of general distance measuring equipment to (1) determine performance relative to test criteria, (2) define safety aspects, and (3) determine suitability for service testing.

A listing of textual terms and abbreviations peculiar to DME systems is presented in the glossary at the end of this MTP.

3. REQUIRED EQUIPMENT

a. Army aircraft including:

(1) Absolute altimeter
(2) Barometric altimeter
(3) RF tracking
(4) VOR equipment
(5) On-board instrumentation recording capabilities

b. Test range including:

(1) Radar or cinetheodolite tracking instrumentation
(2) VOR/DME or VORTAC ground station transponder

c. Bench test facilities
d. Photographic equipment
e. Meteorological support facility

4. REFERENCES

A. MIL-STD-449 (-), Radio Frequency Spectrum Characteristics, Measurement of
B. MIL-STD-291A, TACAN Signal, March 1958
C. Aeronautical Telecommunications, Annex 10, 7th edition, International Civil Aviation Organization

D. Minimum Performance Standards for DME, RTCA Doc 40-64/DO-124, Radio Technical Commission for Aeronautics, May 1964
E. IEEE Transactions on Aerospace and Navigational Electronics, Volume ANE-12 No. 1, Special Issue on the VOR/DME Navigation System, March 1965
F. Principles and Features of DME, ITT Federal Labs, 1963
G. Skolnik, Introduction to Radar Systems, McGraw-Hill
H. MTP 6-1-003, Determination of Sample Size

5. SCOPE

5.1 SUMMARY

The following tests collectively constitute an engineering evaluation of the equipment under test.

a. Range and Accuracy - The objective of this test is to determine the average inbound lock-on and outbound unlock range limits and frequency distribution of errors within the range limits. This test is applicable to all DME types.

b. Warm-up - The objective of this test is to determine the time required for the test item to become operational after activation. This test is applicable to all DME types.

c. Warning and Restricting Devices- The objective of this test is to determine the characteristics and suitability of test item provisions for warning or preventing the operator from inadvertently attempting voice transmission during interrogation or reply. The test is applicable only to VHF/FM-DME types.

d. Influence of Weather - The objective of this test is to determine the effects of selected meteorological conditions on the performance of the test item.

5.2 LIMITATIONS

In order to provide general coverage, the procedures contained herein have been designed to provide for overall DME system tests and do not consider DME components in detail.

This materiel test procedure applies only to those distance measuring equipment types described in paragraph 2. Laser range finders and distance measuring equipments not employing interrogator-transponder principles are specifically excluded.

6. PROCEDURES

6.1 PREPARATION FOR TEST

a. Select test equipment having an accuracy of at least ten times that of the function to be measured.

b. Record the following information:

1) Nomenclature, serial number(s), and the manufacturer's

name of the test item(s)
2) Nomenclature, serial number, accuracy tolerances, calibration requirements, and last date calibrated of the test equipment selected for the tests

c. Assure that all test personnel are familiar with the required technical and operational characteristics of the item under test, such as stipulated in Qualitative Material Requirements (QMR), Small Development Requirements (SDR), and Technical Characteristics (TC).

d. Review all instructional material issued with the test item by the manufacturer, contractor, or government, as well as reports of previous similar tests conducted on the same type of items, and familiarize all test personnel with the contents of such documents. These documents shall be kept readily available for reference.

e. Thoroughly inspect the test items for obvious physical and electrical defects such as cracked or broken parts, loose connections, bare or broken wires, loose assemblies, bent relay and switch springs, corroded jacks and plugs, and bare or cracked insulation. All defects shall be noted on an applicable data form, and corrected before proceeding with the tests.

f. Prepare record forms for systematic entry of data, chronology of test, and analysis in final evaluation.

g. Prepare adequate safety precautions to provide safety for personnel and equipment, and ensure that all safety precautions are observed throughout the test.

h. Ensure that adequate maps and navigation charts (such as DOD FLIP or other navigation charts) are available for testing of airborne DME units.

i. Ensure that adequate test range radar support is available for all airborne testing.

j. Ensure that line-of-sight ranges with accurately measured distances between established points have been established and are available for tellurometer tests.

k. Mount the following equipment in the test aircraft:

1) Test item (DME interrogator)
2) Transponder beacon (such as the AN/DPN-31) to enhance the range radar's return signal
3) Cameras to record DME readout, altitude, and time
4) Very high frequency omnidirectional radio ranging equipment (VOR) for determining bearings

6.2 TEST CONDUCT

6.2.1 Range and Accuracy

6.2.1.1 VOR/TACAN/DME

NOTES: 1. The VOR/TACAN/DME range and accuracy test shall be conducted in a test area where range radar coverage is available and where a VOR/DME or VORTAC transponder can be used as the hub for the flight test courses.

2. The flight test courses shall consist of approximately six radial flight paths centered upon the ground transponder as illustrated in Figure 2. The radials shall be spaced at equal angles insofar as possible to minimize "siting" effects.

a. After selecting the test courses, determine (with the aid of the equation or nomographs given in Appendix A) the approximate maximum range at which testing shall be initiated.

b. Direct the aircraft containing the test item to fly over the test course at a velocity of approximately 50 per cent of the aircraft's rated ground speed and at an initial altitude of 1500 feet above the ground station.

c. Direct the test pilot to fly each leg of the test course in each direction. The pilot shall continuously interrogate the ground to determine the points at which inbound lock and outbound unlock occur. On-board recording equipment shall monitor and record DME readout, altitude, pitch, roll, yaw and time synchronization marks. The test pilot shall introduce varying degrees of aircraft pitch, roll and yaw during the test in order to evaluate test item performance as a function of aircraft attitude.

d. Record numerous readouts between the lock-unlock points to provide statistical data on the frequency distribution of DME error. The range radar station shall provide time correlated space positions of the aircraft.

e. Repeat the above procedure for aircraft altitudes of 3000, 6000, 9000, 12000, and 15000 feet and additional intermediate and extreme values as dictated by the test item's specifications.

f. Repeat the entire test sequence as necessary to provide a sufficient number of measurements for drawing statistically valid conclusions. The background document MTP 6-1-003, Determination of Sample Size, should be consulted for background information and details.

6.2.1.2 VHF/FM-DME

a. Conduct the VHF/FM-DME range and accuracy test in a manner similar to that indicated in paragraph 6.2.1.1 except substitute a tactical ground radio set equipped with the DME applique unit for the VOR/DME or VOTAC transponder.

6.2.1.3 Tellurometers

a. Place the master unit at a point which has been accurately "located" by conventional ground survey methods. This point shall have sufficient elevation to ensure line-of-sight to at least 10 surveyed positions at varying distances, directions, and elevations. At least one position shall be at a distance which is approximately 10 greater than the stated distance measuring capabilities of the test item.

b. Place the remote unit at one of the selected surveyed positions and, following the operating instructions of the appropriate instruction manual, obtain a measurement readout of the master unit-remote unit separation distance.

c. Repeat the measurement a sufficient number of times to simulate a number of units tested one time each (Ref MTP 6-1-003 Determination of Sample Size.)

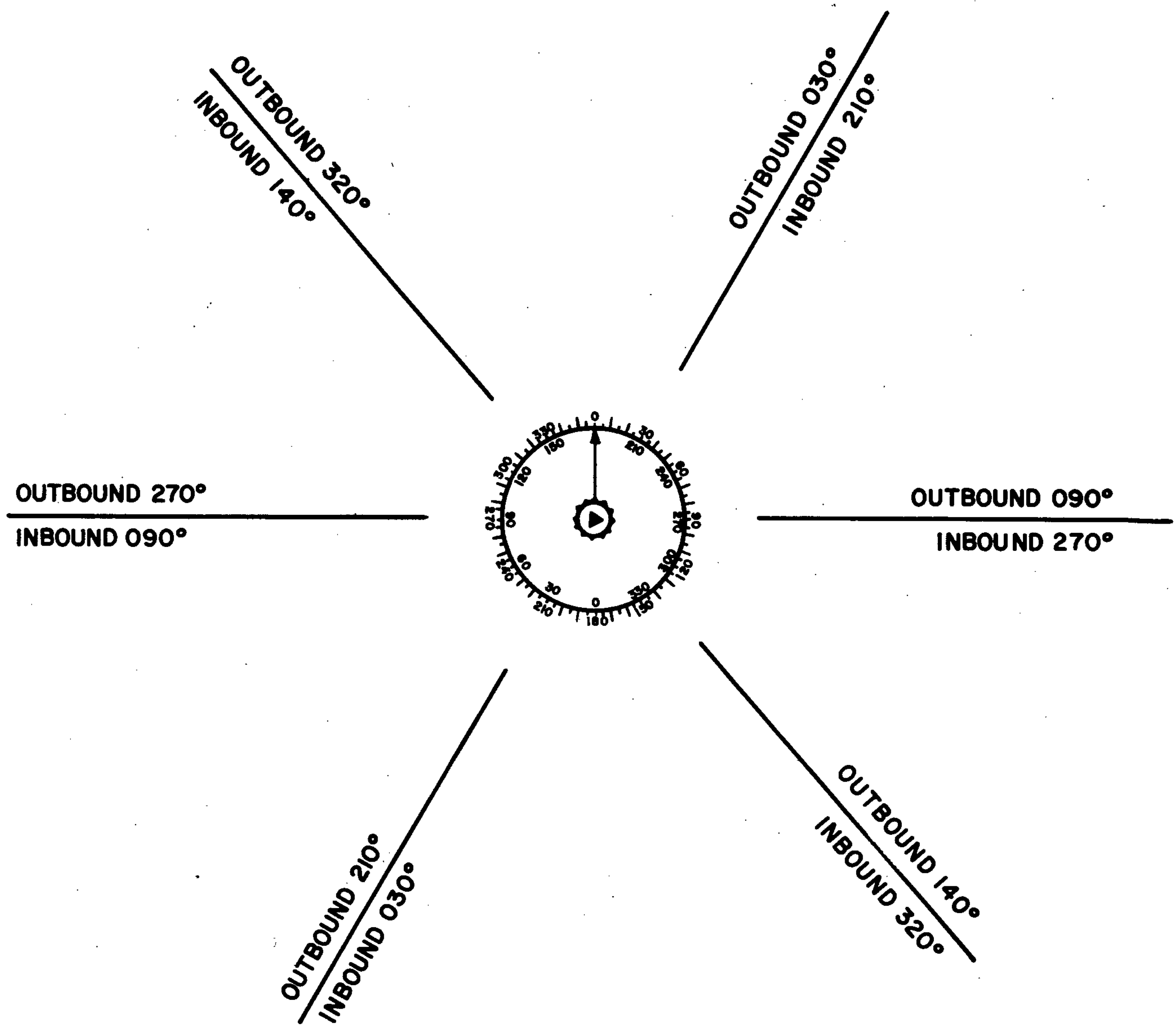

Figure 2.- Typical airborne DME test flight paths.

d. Successively place the remote unit at each of the remaining surveyed positions and obtain distance readings as indicated above.

6.2.2 Warm-Up

NOTE: The warm-up test shall be conducted in an open-field configuration with the interrogator/master unit bench mounted as convenient, and the transponder/remote unit located a sufficient distance away so as to achieve a convenient mid-scale distance reading.

a. Ensure that the interrogator/master unit has been in the "off" position a sufficient length of time for it to reach thermal equilibrium with the environment and, conversely, ensure that the transponder/remote unit has been in the "on" position a sufficient length of time to achieve stable operation.

b. Turn on the interrogator/master unit and note the elapsed time between equipment turn-on and achievement of stable distance measurement readout.

c. Repeat the above procedure a minimum of five times in order to be able to compute the mean warm-up time.

d. Repeat steps (a) through (c) above at the lowest and highest ambient temperatures available without the use of an environmental chamber.

e. Repeat the entire test sequence listed above in the following variations:

1) Ensure that the transponder/remote unit is in thermal equilibrium with the environment and the interrogator/master unit has achieved stable operation and thereby reverse the initial test conditions.
2) Ensure that both the transponder/remote unit and interrogator/master unit are in thermal equilibrium with the environment, and simultaneously turn on both units.

6.2.3 Warning and Restricting Devices

The engineering evaluation of the test item's warning and restricting devices shall be performed as an open-field test with the airborne interrogator unit either bench-mounted or mounted in a parked aircraft. The transponder unit shall be placed a sufficient distance from the integrator to achieve a convenient on-scale distance reading. The transponder unit operator shall (1) attempt voice transmission during interrogation and reply and (2) complete the following questionnaire following the attempt:

a. Does the transponder unit positively indicate when it is being interrogated?

Yes ( ) No ( ) Comment____________

b. Does the transponder unit positively indicate when it is replying to an interrogation?

Yes ( ) No ( ) Comment____________

c. Is the design of the transponder unit such that it prevents voice transmission during interrogation or reply?

Yes ( ) No ( ) Comment______________

d. If voice transmission is possible during interrogation or reply, is there a detrimental effect on the distance readout?

Yes ( ) No ( ) Comment______________

6.2.4 Influence of Weather

The influence of varying degrees of meteorological phenomena on the range and accuracy of the test item shall be determined by repeating the procedures outlined in paragraph 6.2.1 under the following weather conditions:

a. Heavy rainfall
b. Dust
c. Lightning
d. Operation over hot, sun-heated surfaces

NOTE: Quantitative assessment of the net effect of varying intensities of the above conditions will be difficult to achieve due to the inherent problem of locating the desired weather phenomenon within the test area. If this problem can be overcome, the very occurrence to which the test item is subjected, such as heavy rainfall, may obscure the aircraft from the tracking system. Because of these problems, collection of a sufficient number of data points to allow a statistical analysis may not be practicable and all airborne test items may have to be tested in a ground survey manner as indicated in paragraph 6.2.1.3.

6.3 TEST DATA

6.3.1 Preparation for Test

Data to be recorded prior to testing will include but not be limited to:

a. Nomenclature, serial number(s), and manufacturer's name(s) of the test item(s) and all components and accessories
b. Nomenclature, serial number, accuracy tolerances, calibration requirements, and last date calibrated of the test equipment selected for the tests
c. Defects noted as a result of pre-test inspection
d. Prevailing meteorological conditions prior to start of test as well as during test conduct, to include:

1) Temperature
2) Humidity, relative or absolute

3) Temperature gradient
4) Atmospheric pressure
5) Precipitation
6) Solar radiation
7) Wind speed and direction
8) Pibal data
9) Frequency of readings
10) Source of data

6.3.2 Test Conduct

Data to be recorded in addition to specific instructions listed for each individual subtest shall include:

a. An engineering log book containing in chronological order pertinent remarks and observations which would aid in a subsequent analysis of the test data. This information may consist of temperature, humidity, and other appropriate environmental data, or other description of equipment or components, and functions and deficiencies, as well as theoretical estimations, mathematical calculations, test conditions, intermittent or catastrophic failures, test parameters, etc., that were obtained during the test.
b. Instrumentation or measurement system mean error or stated accuracy
c. Test item sample size (number of measurement repetitions)
d. Test item control settings

6.3.2.1 Range and Accuracy Test Data

6.3.2.1.1 VOR/TACAN/DME

Range and accuracy test data for TOR/TACAN/DME test items shall consist of:

a. DME readout vs time
b. Time correlated space position data
c. Meteorological conditions
d. Aircraft altitude; degree of pitch, roll, and yaw
e. Test course identification

6.3.2.1.2 VHF/FM-DME

Range and accuracy test data for VHF/FM-DME test items shall be recorded as indicated in paragraph 6.3.2.1.1.

6.3.2.1.3 Tellurometers

Tellurometers range and accuracy test data shall consist of:

a. Distance (DME) readout
b. Ground survey data (distance, elevation, azimuth)
c. Meteorological conditions

6.3.2.2 Warm-up

Warm-up test data to be recorded shall be:

a. Ambient temperature
b. Interrogator/master unit warm-up time
c. Transponder/remote unit warm-up time
d. Simultaneous warm-up time

6.3.2.3 Warning and Restricting Devices

Warning and restricting devices test data shall consist of answers to the questionnaire given in paragraph 6.2.3, together with pertinent comments and/or clarifying remarks.

6.3.2.4 Influence of Weather

Influence of weather test data to be recorded shall consist of values of those parameters indicated in paragraph 6.3.2.1.

6.4 DATA REDUCTION AND PRESENTATION

Processing of raw test data shall, in general, consist of:

a. Reducing time correlated space position data to distance-to-go (slant range from interrogator/master unit to transponder/remote unit)
b. Applying statistical theory to: (1) determine mean values and frequency distribution of errors; and (2) account for error introduced by the measurement system
c. Organizing data into tabular and graphical form

All test data shall be properly marked for identification and correlation and grouped according to subtest title. Specific instructions for the reduction and presentation of individual subtest data are outlined in the succeeding paragraphs.

6.4.1 <u>Range and Accuracy</u>

6.4.1.1 VOR/TACAN/DME

Graphic presentations of the VOR/TACAN/DME range and accuracy test shall be made as follows:

a. Terrain map of test area showing:

(1) Latitude and longitude of ground transponder station
(2) Test flight courses
(3) Ground transponder identification and modulation information

b. Mean value inbound lock-on and outbound unlock curves as shown in Figure 3.

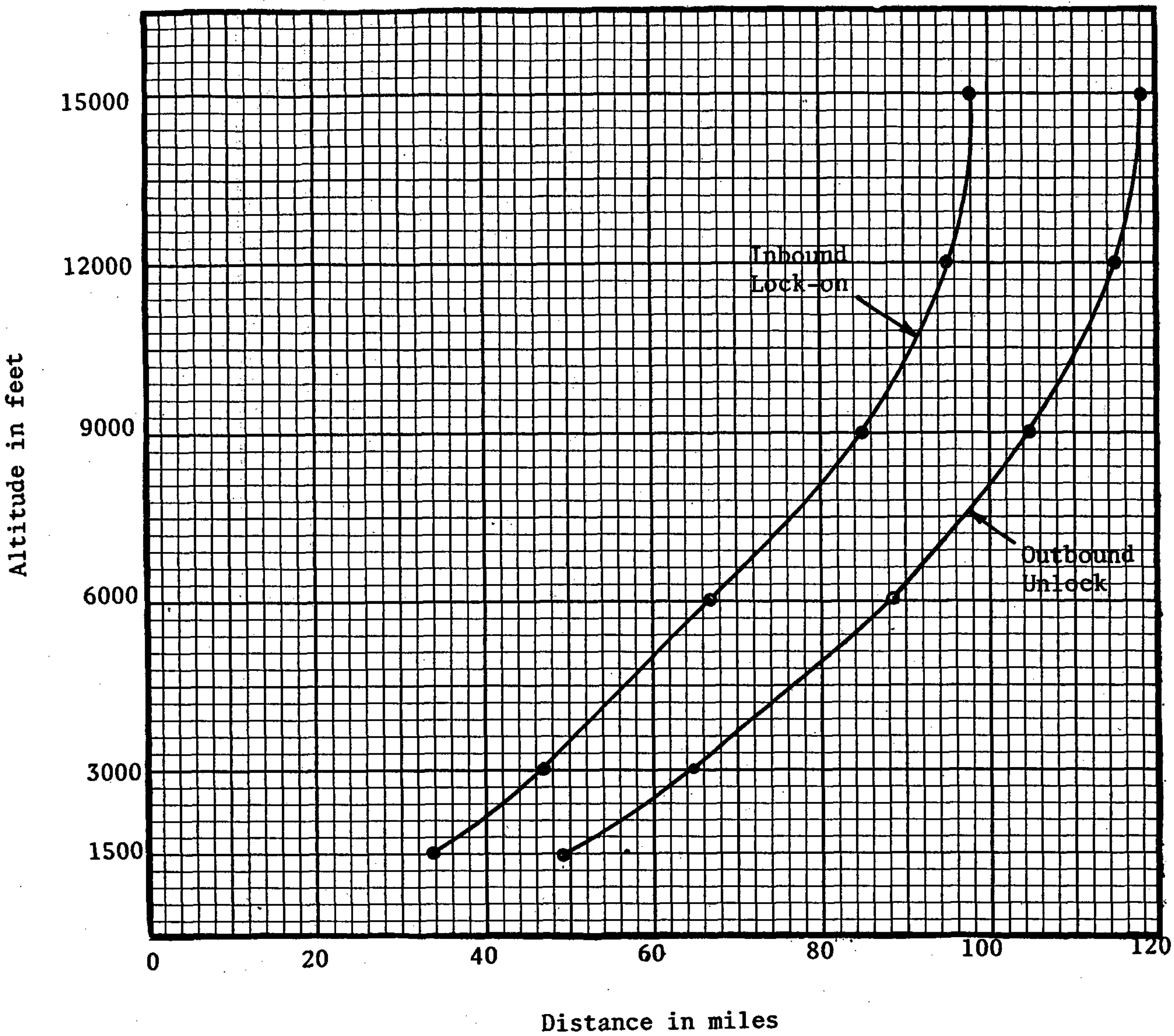

Figure 3. Mean value inbound lock-on and outbound unlock curves.

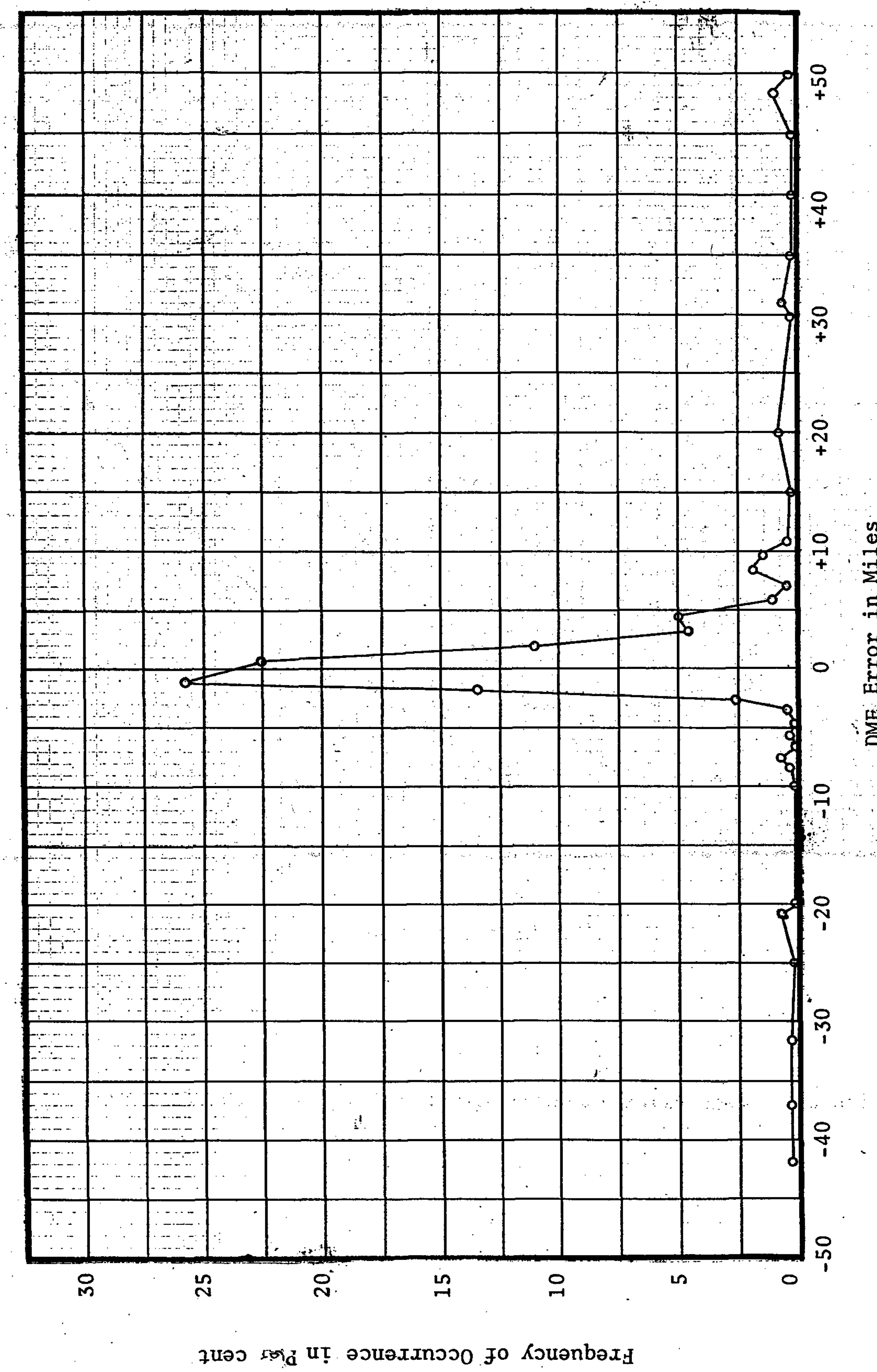

Figure 4. Frequency Distribution of Errors of All DME Interrogations

c. Standard deviation from mean value inbound lock-on and out-bound unlock curves either plotted on the same graph as the mean value curves or on a similar graph as indicated in Figure 3

d. Extreme value inbound lock-on and outbound unlock curves similar to that shown in Figure 3

e. Frequency distribution of errors curve as shown in Figure 4

Numerical range and accuracy data shall be reduced to and presented as tabular listings similar to the sample in Figure 5.

Test Course: (e.g. 320° outbound radial)

Altitude:

Meteorological Conditions:

DME Reading (NMI)	Slant Range (NMI)	Difference ±	Specified Tolerance (NMI)	Aircraft Altitude Pitch, Roll, & Yaw

Figure 5. Numerical Range and Accuracy Data

6.4.1.2 VHF/FM-DME

Graphic and numerical presentations of the VHF/FM-DME range and accuracy test shall be made as indicated in 6.4.1.1, with the exception that distances will be expressed in kilometers.

6.4.1.3 Tellurometers

Tellurometer range and accuracy test data shall be reduced to and presented in the general tabular form indicated in Figure 6.

Master Station Coordinates ______________________

Meteorolgocial Conditions ______________________

Remote Station Coordinates	Tellurometer Reading	Actual Distance	Difference ±

Figure 6. Tellurometer Range and Accuracy Data

Graphic presentations of the tellurometer range and accuracy data shall consist of (1) a terrain map of the test area showing equipment locations (2) a terrain profile chart for each test survey line and (3) a frequency distribution of errors curve similar to that shown in Figure 4.

6.4.2 Warm-up

Test data relative to warm-up shall be reduced to mean values of time for each of the three conditions indicated in paragraph 6.3.2.2 and presented as a numerical value that can be correlated to ambient temperature.

6.4.3 Warning and Restricting Devices

The test data collected from the warning and restricting devices shall be an organized presentation of the data as recorded under paragraph 6.3.2.3.

6.4.4 Influence of Weather

Test data from the influence of weather test shall be presented according to paragraph 6.4.1.

A written report shall accompany all test data and shall consist of conclusions and recommendations drawn from test results. The test engineer's opinion, concerning the success or failure of any of the functions evaluated, shall also be included. In addition, equipment specifications that will serve as the model for a comparison of the actual test results should be included.

Equipment evaluation usually will be limited to comparing the actual test results to the equipment specifications and the requirements as imposed by the intended usage. The results may also be compared to data gathered from previous tests of similar equipment.

APPENDIX A

APPROXIMATION OF MAXIMUM DME RANGE

The point at which a radio wave traveling directly from a transmitter to a receiver first touches the surface of the earth may be calculated and used as an approximation of maximum DME range. This maximum radius for testing is determined by the expression:

$$d_L = \sqrt{2h_1} + \sqrt{2h_2}$$ (the bending of the ray due to atmospheric refraction is accounted for)

where h_1 = transmitting antenna height in feet

h_2 = receiving antenna height in feet (aircraft altitude)

and d_L = radio line of sight distance between antennas in miles (radio horizon)

A nomograph for this calculation is shown in Figure A-1.

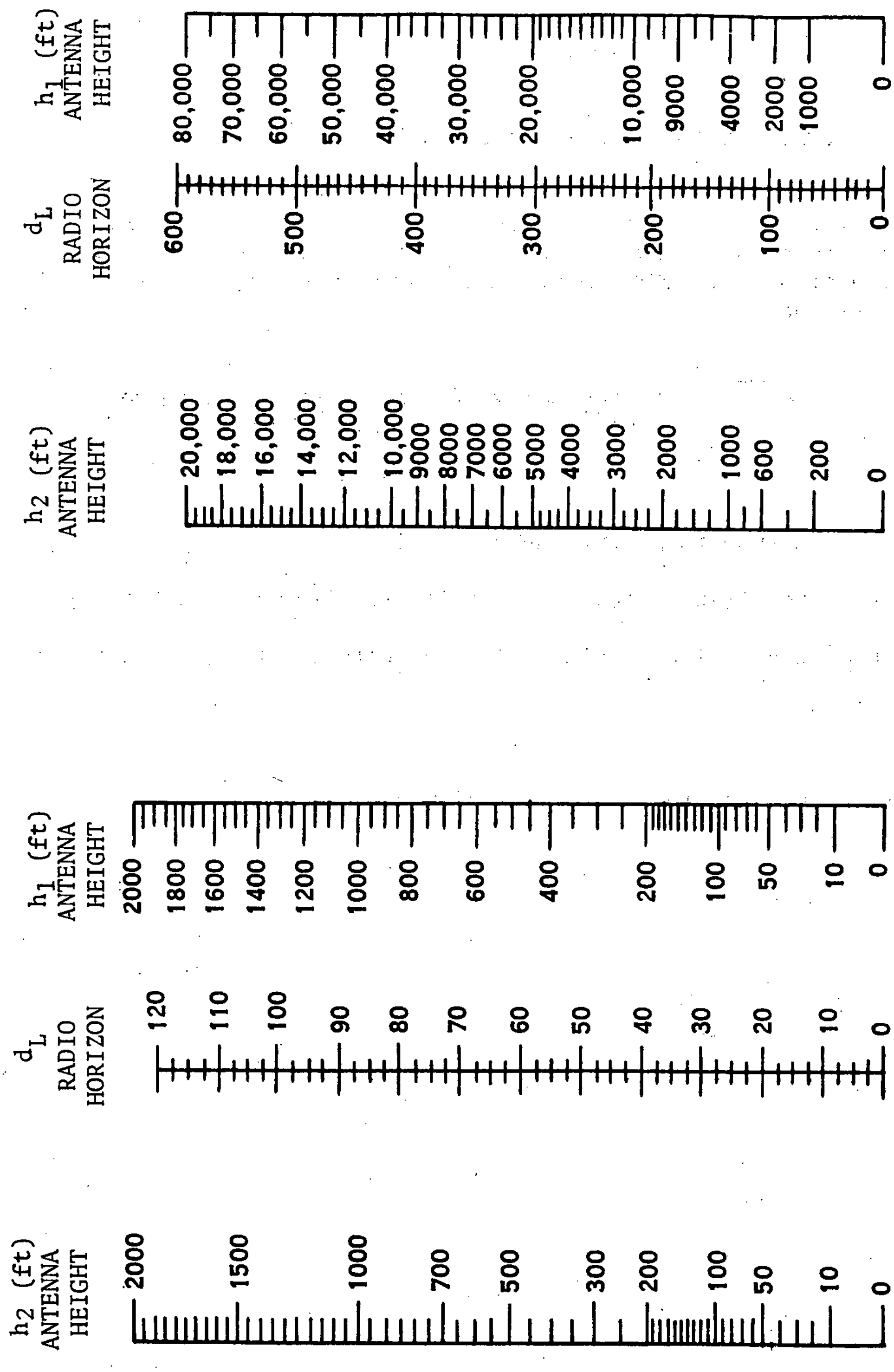

Figure A-1. Nomographs Giving Radio Horizon Distance

GLOSSARY

DME: Distance measuring equipment

VOR: Very high frequency omnidirectional radio range

TACAN: Tactical air navigation

VHF: Very high frequency

FM: Frequency modulation

ICAO: International Civil Aviation Organization

RTCA: Radio Technical Commission for Aeronautics

Rho-Theta: (ρ-θ) range - bearing

Interrogator: The airborne portion of the VOR/TACAN and VHF-FM distance measuring equipments

Transponder: The ground station portion of the VOR/TACAN and VHF-FM distance measuring equipments

Master Unit: That portion of the tellurometer distance measuring system which supplies the initial measuring frequency and the final distance readout

Remote Unit: That portion of the tellurometer distance measuring system which relays the initial measuring frequency back to the master unit