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This Test Operation Procedure (TOP) describes procedures for conducting technical performance tests of land navigation and positioning systems. It is modeled around the Modular Azimuth Positioning System Hybrid (MAPS Hybrid) but is applicable to all land-based navigation systems including those using the Global Position System (GPS). This TOP incorporates procedures that require automated data collection instrumentation and a reference system that will provide medium-to-high position/attitude accuracy.

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LAND NAVIGATION AND POSITIONING SYSTEMS

			Page
PARAGRAPH	1.	SCOPE	2
	2.	FACILITIES AND INSTRUMENTATION	2
	2.1	Facilities	2
	2.2	Instrumentation	3
	3.	REQUIRED TEST CONDITIONS	3
	4.	TEST PROCEDURES	4
	4.1	Receipt Inspection and Inventory	4
	4.2	Electrical System	5
	4.3	Environmental	8
	4.4	Electromagnetic Interference/Compatibility	11
	4.5	Performance Accuracy	11
	4.6	Software	21
	4.7	Human Factors	22
	4.8	Safety and Health	24
	4.9	Reliability	24
	4.10	Integrated Logistic Supportability	25
	5.	DATA REQUIRED	26
	5.1	Receipt Inspection and Inventory	26
	5.2	Electrical System	26
	5.3	Environmental	26
	5.4	Electromagnetic Interference/Compatibility	27
	5.5	Performance Assessment	27
	5.6	Software	29
	5.7	Human Factors	29
	5.8	Safety and Health	30
	5.9	Reliability	30
	5.10	Integrated Logistic Supportability	30
	6.	MODELING AND SIMULATION CONSIDERATION	31
APPENDIX	A.	LAND NAVIGATION COURSE SURVEY DATA	A-1
	B.	AZIMUTH DETERMINATION BY THREE POINT RESECTION	B-1
	C.	ABBREVIATIONS	C-1
	D.	REFERENCES	D-1

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1. SCOPE.

This TOP describes procedures for conducting technical performance tests of inertial land navigation and positioning systems. It is modeled around the Modular Azimuth Positioning System Hybrid (MAPSH) but is applicable to all inertial land-based navigation systems including those aided by the Global Positioning System (GPS). The MAPSH comprises the Dynamic Reference Unit Hybrid (DRUH), a Precision Lightweight GPS Receiver (PLGR) and vehicle mount, a remote GPS antenna and mount, a Vehicle Motion Sensor (VMS), a Control and Display Unit (CDU) or CDU Simulator (CDUS), and interconnecting cabling.

This TOP does not completely cover position accuracy testing of GPS only systems or systems operated in a GPS only mode. Although much of the TOP can be used to test GPS systems, it essentially applies to inertial systems. GPS systems are not inertial systems and require a host of other considerations.

This TOP restricts position and attitude accuracy testing to static tests. There are currently no dynamic position/attitude requirements for land-based navigation systems.

This TOP incorporates procedures that require automated data collection instrumentation and a reference system that will provide medium-to-high position/attitude accuracy.

A listing of acronyms used within the TOP is presented as Appendix C.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Variable power supply	To conduct the power control tests of paragraph 4.2.2.
Environmental chambers	To perform the environmental tests of paragraph 4.3.
A shielded, enclosed anechoic chamber	To conduct the electromagnetic interference and compatibility tests of paragraph 4.4.
Navigation courses consisting of roads and trails with Survey Control Points (SCPs)	Position coordinates ±0.1 m. Azimuth reference ±0.1 mil.
Automated data collection system	To electronically record data from instrumentation with little or no action required from the operator.

2.2 Instrumentation.

Devices for Measuring	Measurement Accuracy
Physical dimensions	± 2 mm
Weight	± 0.2 kg
Center of gravity	± 25 mm
Temperature	± 1° C
Voltage, DC, 0 to 50 V	±1% full scale reading
Current, DC, 0 to 15 Amps	±1% full scale reading
Pitch (elevation) and cant	10% of required accuracy (typically ±0.1 mil)
Azimuth	10% of required accuracy (typically ±0.3 mil)
Universal Transverse Mercator (UTM) position coordinates	10% of required accuracy (typically ±1 m)

3. REQUIRED TEST CONDITIONS.

a. Perform a safety assessment to identify all safety hazards that may be present during testing. NOTE: If weapon system siting information is generated by the navigation system, then the system accuracy has a safety aspect. Use TOP 1-1-060[1*] for guidance. Ensure that Standing Operating Procedures (SOPs) are current and will provide adequate guidance to assure safety for personnel and equipment. Ensure that SOPs are posted at each test site where test operations will be conducted. Conduct a safety briefing at the beginning of each day's testing with all test personnel present who will be involved.

b. Ensure that environmental documentation has been prepared and approved by the installation environmental quality coordinator prior to initiation of test. Use Army Regulations 200-2[2] and 200-3[3] for guidance.

c. Ensure that energy conservation has been considered in the planning and execution of this test.

d. Establish and maintain a maintenance schedule for all test vehicles and appropriate equipment. Ensure that a corrosion control plan has been incorporated along with the maintenance schedule.

e. Establish a reliability, availability, maintainability (RAM) data base to record all test incidents and to provide for the organized and timely collection, analysis, use, systematic storage, and disposition of data. Provide RAM data and Test Incident Reports (TIRs) to the materiel developer, combat developer, testers, evaluators, logisticians, and others as directed in a timely and responsive manner.

* Superscript numbers correspond to those in Appendix D, References.

f. Ensure the availability of appropriate facilities and coordinate test support requirements, including technical documentation, training materials, personnel, vehicles, radios for mission communications, test equipment, maintenance facilities, spare parts, instrumentation, and test courses.

g. Verify the accuracy of instrumentation and test equipment used to control, monitor, or measure test parameters prior to testing. Ensure that test equipment meets and maintains calibration certification requirements.

4. TEST PROCEDURES.

4.1 Receipt Inspection and Inventory.

4.1.1 Method.

a. Inventory the test items and the system support package (SSP) against the packing list, SSP element list, or other applicable documentation.

b. Inspect the test items and the SSP for damage. Conduct nondestructive testing for suspected cracks and discontinuities.

c. Inspect the test items and the SSP for missing or inappropriate markings that caution the handlers.

d. Ensure that line replaceable units (LRUs) are properly code-marked for identification and reference throughout testing.

e. Assure conformance of LRUs to physical specifications stipulated in the requirements documents. Take measurements of physical dimensions, center of gravity, and weight.

f. Take characteristic photographs of the test items.

g. Conduct a pretest operational checkout to ensure that the system works properly.

4.1.2 Data Required.

a. Record the results of the inventory against the packing list, SSP element list, or other applicable documentation. Record and report all discrepancies. Record the nomenclature, serial numbers, manufacturer, and software version of each LRU.

b. Record the results of the receipt inspection. Document any damage and anomalies.

c. Record any missing or inappropriate markings on the test items or SSP that caution the handlers.

d. Compile a list that correlates LRUs with code-marks used for identification and reference.

e. Record the following physical measurements for each LRU.

(1) Weight (kg).

(2) Dimensions (cm x cm x cm).

(3) Center of gravity (cm).

f. Take characteristic, presentation-quality photographs of the test item.

g. Record the results of the pretest operational checkouts.

4.2 Electrical System.

Conduct this procedure using TOP 2-2-601[4] to ensure that the battery system which will be adapted to provide electrical power to the test item during testing does not impose a safety hazard to test personnel or equipment. Two common configurations are:

a. Connecting the test item directly into the host vehicle electrical system.

b. Establishing an independent battery system for the test item. This system will normally be charged through the host vehicle electrical system.

4.2.1 Battery System.

4.2.1.1 Method.

a. Ensure that the battery system complies with appropriate schematics.

b. Inspect the battery system for any defects. Ensure that connections and workmanship are adequate.

c. Ascertain whether batteries and cabling are accessible for testing, maintaining, and simplicity of installation.

d. Ensure that the battery system has overload protection.

e. Ensure that the system has isolation circuitry to prevent the test item batteries from discharging through the vehicle electrical system.

f. Determine the amount of protection from contact with live electrical circuits that is provided to personnel.

4.2.1.2 Data Required.

a. Obtain a detailed description of the test item power system. Include schematics and photographs for each vehicle type.

b. Record any defects in workmanship, connections, overload protection, and isolation circuitry.

c. Note the effectiveness of personnel protection from contact with live electrical circuits.

d. Note any malfunctions and anomalies discovered in the test item battery system and the vehicle electrical systems.

4.2.2 Power Control. Perform the following procedures applicable to the test item. Bench mount the test item to allow observation of all connections. If sparking or excessive heat occurs, discontinue the test immediately. Use calibrated instrumentation to monitor voltage and current.

4.2.2.1 Method.

a. Turn-on. Perform this procedure if the test item is required to turn on within a range of voltages.

(1) Connect the test item to a variable power supply adjusted to deliver less than the minimum turn-on voltage stated in the test item specifications.

(2) Connect instrumentation to monitor the input voltage and current.

(3) Slowly increment the voltage to determine the voltage at which the test item activates.

(4) Turn the test item off.

CAUTION: Perform the following steps if the test item is required to turn on below a specified voltage. Application of over-voltage to unprotected equipment could result in damage to the test item.

(5) Adjust the variable power supply to deliver slightly more voltage (no more than 5%) than the maximum turn-on voltage stated in the test item specifications.

(6) Slowly decrease the voltage by increments to determine the voltage at which the test item activates.

b. Operation. Perform this procedure to ensure that the test item operates within its required range of voltage and current.

CAUTION: Some equipment that has electromagnetic pulse (emp) protection (like the druh) have transorbs between the power lines and chassis ground. These devices are high power zener diodes which clip the spikes around 60 volts. Use caution to protect test equipment from high current levels.

(1) Connect the test item to a variable power supply adjusted to deliver the minimum turn-on voltage stated in the specifications.

(2) Connect instrumentation to monitor voltage and current.

(3) Turn the test item on.

(4) Operate the test item to verify that all functions are performing in accordance with the requirements document.

(5) Adjust the variable voltage power supply to the maximum operating voltage stated in the requirements document.

(6) Operate the test item to verify that all functions are performing in accordance with the requirements document.

c. Turn-off. Perform this procedure if the test item is required to turn off outside a range of voltages.

(1) Connect the test item to a variable power supply adjusted to deliver more than the minimum turn-on voltage stated in the test item specifications.

(2) Connect instrumentation to monitor voltage and current.

(3) Turn the test item on.

(4) Slowly decrease the voltage by increments to determine the voltage at which the test item deactivates.

CAUTION: Perform the following steps if the test item is required to turn off above a specified voltage. Application of over-voltage to unprotected equipment could result in damage to the test item.

(5) Adjust the variable power supply to deliver less than the maximum operating voltage stated in the test item specifications.

(6) Turn on the test item.

CAUTION: When performing the following step, if the test item fails to turn off when the input voltage is increased beyond 5% of the maximum operating voltage (or as otherwise specified in the requirements document), discontinue this procedure. Application of over-voltage to unprotected equipment could result in damage to the test item.

(7) Slowly increment the voltage to determine the input voltage at which the test item deactivates.

d. Transient. Perform this test if the test item is required to operate in the presence of transient power surges.

(1) Connect the test item to a variable power supply adjusted to the nominal operating voltage stated in the test item specifications.

(2) Connect the test item to a signal generator capable of producing voltage spikes that simulate the power surges during which the test item is required to operate.

(3) Connect instrumentation to monitor the test item input voltage and current.

(4) Turn on the test item.

(5) While maintaining constant input voltage from the power supply, inject voltage anomalies from the signal generator to test the worst-case limits specified by MIL-STD-1275[5].

(6) Operate the test item to verify that all functions are performing in accordance with the requirements document.

(7) Perform steps (1) through (6) above over the full operating voltage range.

4.2.2.2 Data Required. Record any failures, erratic behavior, or other anomalous conditions observed during testing. Record the following data applicable to the test item.

a. Turn-on. Record the minimum and maximum voltage (±0.1 V) within which the test item will turn on. Record the observed current (±0.1 A) at these values.

b. Turn-off. Record the minimum and maximum voltage (±0.1 V) outside which the test item will turn off. Record the observed current (±0.1 A) at these values.

c. Operation. Record the minimum and maximum voltage (±0.1 V) within which the test item will operate. Record the observed current (±0.1 A) at these values.

d. Transient. Record the behavior of the test item when subjected to the worst-case limits of MIL-STD-1275.

4.3 Environmental.

4.3.1 Method.

4.3.1.1 General.

a. Land navigation and positioning system requirements documents typically specify the environmental tests included in this section. Conduct only those tests deemed necessary. For additional environmental tests, consult MIL-STD-810E[6].

b. Carefully consider the order in which the environmental tests are conducted if a particular test item undergoes a series of these tests. The test item can be favorably or unfavorably conditioned for a given test by a previous test.

c. Before and after each environmental test, inspect the test item for damage and physical integrity.

d. Before and after each environmental test, mount the test item in a vehicle and conduct a performance accuracy check in accordance with paragraph4.5. For a given test item, the post-test performance check can serve as the pretest performance check for the next environmental test.

e. Environmental chamber tests generally require operational checks before, during, and after exposure to the environmental conditions. When appropriate, vary the input voltage along its operational range during operational checks. The before and after exposure operational checks should consist of a complete checkout of all functions. Limited access to the test item often restricts operational checks during exposure to environments. This may require remote or unattended operation of the test item. During exposure, operational checks should consist of ensuring that the test item will at least:

(1) Turn on and off.

(2) Accept commands.

(3) Display built-in test (BIT) information.

(4) Display navigation and position data.

Land navigation systems often incorporate odometer aiding. Since chamber testing is static, conduct operational checks in the free inertial mode (or if available, in a GPS only mode using a remote GPS antenna or GPS simulator). Operational checks of odometer aiding devices such as the VMS can be performed separately by monitoring the VMS output signals (e.g., using an oscilloscope) while rotating the VMS input shaft with a calibrated electric motor.

4.3.1.2 Low Pressure (Altitude). Perform this test to determine if the test item can withstand, and operate in, a low-pressure environment. Bench mount the test item and subject it to altitude testing in accordance with MIL-STD-810E, method 500.3, procedures I and II.

4.3.1.3 High Temperature. Perform this test to determine if the test item can be stored and operated under hot climatic conditions without experiencing physical damage or deterioration in performance. Bench mount the test item and subject it to high temperature testing in accordance with MIL-STD-810E, method 501.3, procedures I and II.

4.3.1.4 Low Temperature. Perform this test to determine if the test item can be stored and operated under low temperature conditions without experiencing physical damage or deterioration in performance. Bench mount the test item and subject it to low temperature testing in accordance with MIL-STD-810E, method 502.3, procedures I and II.

4.3.1.5 Temperature Shock. Perform this test to determine if the test item can withstand sudden changes in the temperature of the surrounding atmosphere without experiencing physical damage or deterioration in performance. Bench mount the test item and subject it to temperature shock testing in accordance with MIL-STD-810E, method 503.3.

4.3.1.6 Solar Radiation (Sunshine). Perform this test to determine if the test item can withstand exposure to solar radiation without sustaining damage or deteriorated performance. Bench mount the test item and subject it to solar radiation testing in accordance with MIL-STD-810E, method 505.3, procedures I and II.

4.3.1.7 Rain. Perform this test to determine the following:

a. The effectiveness of the test item's protective cover and case in preventing the penetration of rain or high-pressure water washdown.

b. The capability of the test item to satisfy its performance requirements during and after exposure to rain.

c. The physical deterioration of the test item caused by rain.

Bench mount the test item and subject it to rain testing in accordance with MIL-STD-810E, method 506.3, procedures I and III.

4.3.1.8 Humidity. Perform this test to determine the resistance of the test item to the effects of warm, humid atmosphere. Bench mount the test item and subject it to humidity testing in accordance with MIL-STD-810E, method 507.3, procedure I or III.

4.3.1.9 Fungus. Perform this test to determine the extent to which the test item will support fungal growth or how fungal growth may affect performance or use of the test item. Bench mount the test item and subject it to fungus testing in accordance with MIL-STD-810E, method 508.4.

4.3.1.10 Salt Fog. Perform this test to determine the resistance of the test item to the effects of aqueous salt atmosphere. Bench mount the test item and subject it to salt fog testing in accordance with MIL-STD-810E, method 509.3.

4.3.1.11 Sand and Dust. Perform this test:

a. To determine the ability of the test item to resist the effects of dust particles which may penetrate into cracks, crevices, bearings, and joints.

b. To determine if the test item can be stored and operated under blowing sand conditions without experiencing degradation of its performance, effectiveness, reliability, and maintainability due to the abrasion (erosion) or clogging effect of large sharp-edged particles.

Bench mount the test item and subject it to sand and dust testing in accordance with MIL-STD-810E, method 510.3, procedures I and II.

4.3.1.12 Leakage (Immersion). Perform this test to determine if the test item can withstand immersion in water without leakage. Subject the test item to leakage testing in accordance with MIL-STD-810E, method 512.3.

4.3.1.13 Vibration. Perform this test to determine the resistance of the test item to vibrational stresses expected in its shipment and application environments. Subject the test item, along with mounting or support brackets, to vibration testing in accordance with MIL-STD-810E, method 514.4.

4.3.1.14 Shock. Perform this test to determine if the test item can withstand the relatively infrequent, nonrepetitive shocks or transient vibrations encountered in handling, transportation, and service environments. Subject the test item, along with mounting or support brackets, to shock testing in accordance with MIL-STD-810E, method 516.4.

4.3.1.15 Icing and Freezing Rain. Perform this test to determine the effect of icing produced by freezing rain, mist, or sea spray on the operational capability of the test item. Bench mount the test item and subject it to icing and freezing rain testing in accordance with MIL-STD-810E, method 521.1.

4.3.2 Data Required.

a. Take photographs of the test setup. Make notes and record observations at regular intervals. Take photographs of any damage noted on the test item.

b. Obtain the results of the pretest and post-test performance accuracy check in accordance with paragraph 4.5.2. For a given test item, the results of the post-test performance check can serve as the pretest performance check for the next environmental test.

c. Measure and record the data listed in MIL-STD-810E, section II-4, for each of the respective methods designated in paragraph 4.3.

d. Note any malfunctions and incidents (for both the test item and the test apparatus).

4.4 Electromagnetic Interference/Compatibility.

4.4.1 Method. Conduct electromagnetic interference and compatibility testing in accordance with TOPs 6-2-542[7] and 1-2-511[8], respectively.

4.4.2 Data Required. As stated in TOPs 6-2-542 and 1-2-511.

4.5 Performance Accuracy.

Perform this test to assess the accuracy and operability of the test item in wheeled and tracked vehicles when operated under various alignment conditions, operational modes, vehicle dynamics, and deployment conditions.

4.5.1 Method.

4.5.1.1 General. The stated accuracy of the test item will dictate the sophistication of the measurement devices and procedures used during performance accuracy testing. Since this TOP is modeled around the Modular Azimuth Positioning System Hybrid (MAPSH), the following items apply.

a. Use an electronic automated data collection system to measure, record, and control data for immediate reduction, presentation, or transferral to a data base. An automated data collection system is imperative to reduce human error and to decrease test time. In addition, an automated data collection system is usually necessary to minimize or eliminate effects of test measurements on the test item performance. In the case of MAPSH, the CDUS functions not only as a control and display unit, but as an automated data collection system. In fact, the CDUS has specific design requirements to function as an automated data collection system that will interface with the U.S. Army Aberdeen Test Center (ATC) data collection requirements for navigation testing.

b. Use digital inclinometers capable of providing the automated data collection system with pitch and cant measurements to within ±0.1 mil accuracy. Use a gunner's quadrant only if adequate digital inclinometers are not available.

c. Use an onboard device capable of providing the automated data collection system with reliable real-time azimuth orientation measurements to within ±0.3 mil accuracy during field testing. Use a one-second theodolite to measure the azimuth orientation of the test item if the onboard real-time device is not available.

d. Use a reliable position location measurement system (e.g., a differential GPS system) capable of providing the automated data collection system with real-time position coordinates accurate to within ±1.0 meter. Use high-order surveyed SCPs in conjunction with the position location measurement system to determine position coordinates.

4.5.1.2 Navigation Courses. A navigation course consists of roads and trails along which are survey control points (preferably on a level concrete pad) from which accurate position and azimuth orientation can be obtained for the test item. Use the following road courses (or those proposed as noted) for navigation testing.

a. General Navigation Courses (ATC). One course has up to 12 SCPs and is about 15 kilometers end-to-end. This course can be extended indefinitely by completing as many continuous iterations as needed. The general navigation course can be customized to include the Munson and Perryman test courses. Additionally, the firing ranges along the main front and Mulberry Point Road can be accessed for firing scenarios. For wheeled vehicles, an additional course measuring 25 kilometers, can be customized to extend from an SCP at U.S. Army Aberdeen Proving Ground (APG) to an SCP at the Churchville Site. This course offers the most diverse terrains and road surface types available for navigation testing.

b. 10-Kilometer Course (ATC). The 10-kilometer course is a subset of the general navigation course which has SCPs at 1-kilometer intervals. Although this course is not 10 kilometers from end-to-end, it does extend generally in a single direction for 10 kilometers of road travel. This course consists of a 3/7 ratio of paved/unpaved roads.

c. 3-Mile Straightaway (ATC). This 5-kilometer course has SCPs at 0, 250, 500, 1000, 2500, and 5000 meters. The road is straight over a level, paved road surface.

d. 14-Acres (ATC). The 14-acre test course has an 800-meter test track bounded by Jersey walls. This course consists of level, gravel road surfaces. It is highly suitable for safety testing of unmanned ground vehicles.

e. General Navigation Course (ATC - Churchville). The Churchville course offers up to 200 meters of elevation change over 1.5 kilometers for tracked vehicles and 3 kilometers for wheeled vehicles. The Churchville courses are over smooth, dirt roads and hilly terrain.

f. Interstate-95 Course (proposed) (ATC). This course is planned to extend from the Fort McHenry Tunnel in Baltimore to the Aberdeen Proving Ground exit. This proposed 50-kilometer course will be available for test vehicles able to travel public highways at speeds from 64 to 88 km/hr.

g. High Latitude Course (U.S. Army Cold Regions Test Activity (CRTA)).

h. General Navigation Course (U.S. Army Yuma Proving Ground (YPG)). This course begins at Firing Point Road on the KOFA firing range and extends about 20 kilometers in an easterly direction. The course then turns to the north for 2kilometers and then turns easterly for another 17 kilometers. Approximately 80% of the course is over hard-packed gravel road. The remaining 20% is over paved roads. This course begins in UTM grid zone 11 and crosses into zone 12 after about 30 km of travel. SCPs (without concrete pads) are located at 5-kilometer intervals. Both wheeled and tracked vehicles may use this course.

i. Gravity Anomaly Course (YPG). The Topographic Engineering Center has identified a gravity anomaly between SCP 95-1 on "Old" Highway 95 and SCP TRH-1 on the Truck Rolling Hill Course. Road surfaces are hard-packed, gravel, sand, and concrete.

4.5.1.3 Mission Profile Table. Prepare a mission profile table. A mission profile table is a concise summary of the scope of performance accuracy testing. A typical mission profile table for a MAPSH test consists of rows with the following information.

a. Mission scenario (see para 4.5.1.4).

b. Test location (e.g., APG, CRTA, or YPG).

c. Navigation modes (GPS/odometer/inertial, odometer/inertial, GPS/inertial, inertial-only, or GPS-only).

d. Number of missions. Indicate the number of missions that will be run for each type of host test vehicle.

4.5.1.4 Mission Scenarios.

a. Design mission scenarios. Mission scenarios are detailed procedures designed to assess specific requirements of the test item in dynamic field environments or in static controlled environments. Test scenarios shall:

(1) Have an introduction stating the purpose and the scope.

(2) Be tailored to the test item and the test requirements.

(3) Be integrated into the mission profile table of paragraph 4.5.1.3 above.

(4) Contain detailed instructions for conducting the test scenario. Include required data and summary tables for navigation and firing sequences.

(5) Contain appropriate warning and cautions to safely execute the procedure.

b. General navigation scenarios. A general navigation scenario embodies as many operational conditions as possible that the test item would be expected to encounter in actual service. Some considerations are: mission duration, distance traveled, road surfaces, weather conditions, vehicle dynamics, and combat environments (excluding live firing). Avoid conditions that would not likely be encountered under realistic operational situations.

c. Firing scenarios. A firing scenario is a general navigation scenario that incorporates live or simulated firing sequences. Design the procedure to assess pointing accuracy if the test item is used to point the weapon for firing. When the primary purpose for live firing is exposure to gun fire shock, replace actual firing sequences with simulated firing sequences if an acceptable simulator is available.

d. Straight-line scenarios. Straight-line scenarios provide base line performance data. The course shall consist of reasonably straight, paved roads (or improved secondary roads) not oriented in a strictly north-south or east-westdirection. Tailor the scenarios for distances traveled specific to the test requirements.

e. Criteria-based scenarios. Criteria-based scenarios assess a limited number of criteria or conditions while minimizing the influence of other factors. Important criteria-based scenarios include:

(1) Zone-change scenario. Use a zone-change scenario to assess performance accuracy when the test item crosses UTM grid zone boundaries. A test course spanning a UTM grid zone has been established at YPG.

(2) High-latitude scenario. Design this scenario to assess the test item's performance accuracy at or near the highest latitude specified in the requirements documents. The accuracy (particularly azimuth accuracy) of navigation and positioning systems generally degrades at high latitudes. For testing outside 65° S to 65° N latitudes, the expected accuracy, A_e, for a given latitude LAT_e, is given by:

$$A_e = \frac{\cos(LAT_s)}{\cos(LAT_e)} A_s$$

where:

A_s is the required accuracy at the highest specified latitude, LAT_s.

(3) High-altitude scenario. Design this scenario to assess the test item through the full specified altitude range.

(4) Gravity-anomaly scenario. Perform this scenario to assess the accuracy and performance of the test item when operated at or near a gravity anomaly. The alignment of the orthogonal axes of the test item's inertial frame-of-reference with respect to the earth's coordinate axis is greatly influenced by the gravitation potential gradient at the location of the test item. A test course exhibiting a relatively large variation in the gravitation potential gradient has been established at YPG.

(5) Azimuth-drift scenario. Assess azimuth drift in a static environment. Mount the test item rigidly (preferably on a granite test table), prohibiting all movement. After initializing the system, monitor the displayed azimuth every 10 minutes or less, for four or more hours. This test is not applicable to systems that incorporate ring laser gyros (e.g., the MAPSH).

(6) Angular rate-of-change scenario. Assess angular rate-of-change in a static environment.

(a) Mount the test item on a rate table in a normal case orientation and rotate in accordance with the rates specified in the requirements documents. Monitor the displayed azimuth and angular rate at discrete time intervals.

(b) Perform the previous step with the test item mounted 90° offset in the pitch axis from the normal case orientation and again with the test item mounted 90° in the roll axis from the normal orientation.

4.5.1.5 Single Theodolite Azimuth Measurement Procedure. Numerous procedures are available for measuring the azimuth (heading) of the test item with respect to UTM grid north. This procedure employs one theodolite and is recommended for quick, accurate, and precise measurements. When reference is made to a theodolite reading or procedure, proper theodolite operating procedures (e.g., leveling) are implied.

a. The requirements for this procedure are:

(1) First order SCPs with position coordinates (northing, easting, altitude) at the vehicle stopping points and reference distant aiming points from the theodolite position.

(2) A 1-second theodolite.

(3) A porro prism that can be mounted on the test item or test fixture/mounting plate. A porro prism is a 90° prism mounted on a magnetic base with a magnetic switch and bubble levels. The purpose of a porro prism is to allow greater flexibility in measuring azimuth. To measure azimuth with a porro prism, it is necessary only to position the theodolite's sight axis perfectly normal to the transverse axis of the porro prism surface. Using a simple mirror would require positioning the theodolite normal to both the transverse and vertical axes of the mirror surface. A similar problem arises when measuring azimuth using scribe lines.

(4) A host vehicle configuration that permits the theodolite operator to position the theodolite over the theodolite position and sight to the porro prism installed on the test item. The vehicle or test item must be capable of being oriented in such a way to allow the theodolite operator to see his/her reverse image in the porro prism.

b. The following environmental considerations can adversely affect the quality of the azimuth measurement. Accordingly, the effects of the conditions must be minimized or eliminated.

(1) Vehicle movement due to wind buffeting, engine vibration, personnel movement, etc.

(2) Visual distortions due to hot, dry air (heat waves).

(3) Limited visibility due to inclement weather.

c. The following method shall be used.

(1) Stop the vehicle at an SCP with the vehicle alignment mark positioned as close to the vehicle stopping point (P_2, fig. 1) as possible.

(2) Install a porro prism on the test item, and level the bubble.

(3) Locate a theodolite directly over the SCP theodolite position, (T_1, fig. 1). The vehicle operator carefully jockeys the vehicle back and forth until the theodolite operator can see the reverse image of the theodolite in the porro prism. Ensure that the vehicle alignment mark remains near the vehicle stopping point. Relevel the porro prism bubble.

CAUTION: Ensure that test item azimuth outputs and the orienting line are both in the same north reference system (grid north or true north).

(4) Sight the theodolite along the orienting line (OL) (T_1 to P_1, fig.1), to a reference distant aiming point (P_1, fig. 1). Record the direct theodolite reading, D_1.

WARNING: Do not set the known ol azimuth on the theodolite. Setting the recording scale on a theodolite is a source of error and defeats the steps of this procedure which, if followed, insures accurate and precise measurements.

(5) Turn the theodolite telescope in a clockwise angle to the porro prism, and record the direct theodolite reading, D_2.

(6) Plunge the theodolite telescope and record the indirect theodolite reading, I_2, to the porro prism.

(7) Turn the theodolite telescope in a counterclockwise angle to the reference distant aiming point, P_1, and record the indirect theodolite reading, I_1.

(8) Calculate the test item azimuth (AZ_{tp}, fig. 1) from the known OL azimuth (AZ_{ol}) and the theodolite readings D_1, D_2, I_2, I_1, by:

Let AVE_ANGLE = $((D_2 - D_1 + C_1) + (I_2 - I_1 + C_2))/2$

where:

$C_1 = 360$ if $(D_2 - D_1) < 0$

$C_1 = 0$ if $(D_2 - D_1) \geq 0$

$C_2 = 360$ if $(I_2 - I_1) < 0$

$C_2 = 0$ (if $I_2 - I_1) \geq 0$

then:

$AZ_{tp} = AZ_{ol} + AVE_ANGLE - C_3$

where

$C_3 = 0$ if $(AZ_{ol} + AVE_ANGLE) < 360$

$C_3 = 360$ if $(AZ_{ol} + AVE_ANGLE) \geq 360$

NOTE: The preceding calculations assume that the measured angles and the reference OL azimuth are in degrees referenced from grid north. The range of possible values for D_1, D_2, I_1, and I_2 is from zero to less than 360 degrees.

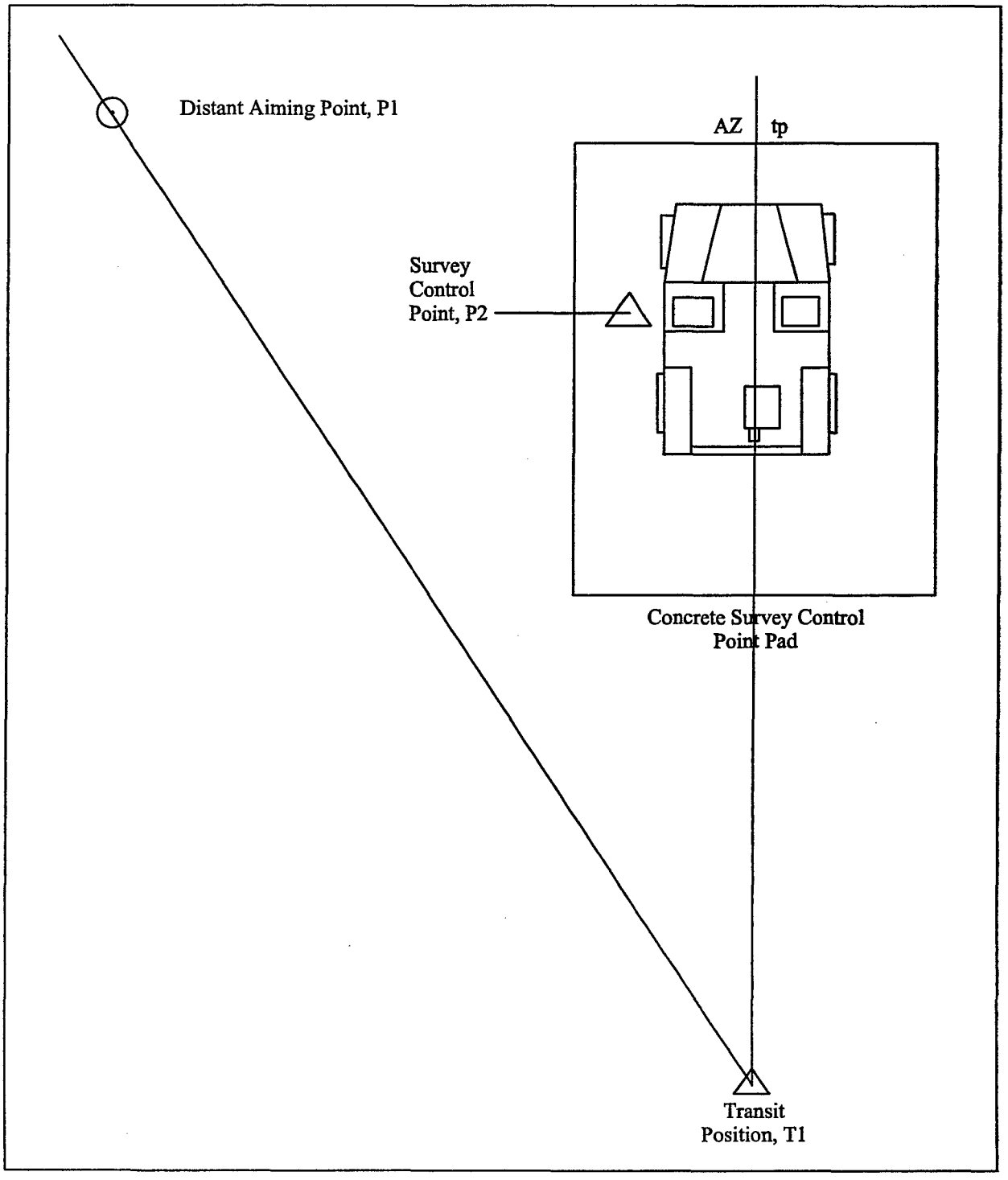


Figure 1. Single Theodolite Azimuth Measurement.

4.5.1.6 Azimuth Measurement Using Three-point Resection. This single theodolite survey procedure is recommended for quick, accurate, and precise azimuth measurements when it is not practical to position the theodolite over a known SCP. As before, when reference is made to a theodolite reading or procedure, proper theodolite operating procedures are implied.

a. The requirements for this procedure are:

(1) First order SCPs with position coordinates (northing, easting, altitude) at the vehicle stopping points and reference distant aiming points from the theodolite position.

(2) A one-second theodolite.

(3) A porro prism that can be mounted on the test item or test fixture/mounting plate.

(4) A host vehicle configuration that permits the theodolite operator to position the theodolite over the theodolite position and sight to the porro prism installed on the test item. The vehicle or test item must be capable of being oriented in such a way to allow the theodolite to see his/her reverse image in the porro prism.

b. The following environmental considerations can adversely affect the quality of the azimuth measurement. Accordingly, the effects of the conditions must be minimized or eliminated.

(1) Vehicle movement due to wind buffeting, engine vibration, personnel movement, etc.

(2) Visual distortions due to hot, dry air (heat waves).

(3) Limited visibility due to inclement weather.

c. The following method shall be used. Refer to the diagram in AppendixB.

(1) Locate the theodolite to sight along the desired azimuth, AZ_{tp}.

(2) Sight the theodolite to the resection point, B. Record the direct theodolite reading, D_1.

WARNING: Do not set the known ol azimuth on the theodolite. Setting the recording scale on a theodolite is a source of error and defeats the steps of this procedure which, if followed, insures accurate and precise measurements.

(3) Turn the theodolite telescope through clockwise angles to the second and third resection points (A and C), and record the corresponding direct theodolite readings, D_2 and D_3.

(4) Turn the theodolite through a clockwise angle to AZ_{tp} and record the direct theodolite reading, D_4.

(5) Plunge the theodolite telescope and record the indirect theodolite reading, I_4.

(6) Turn the theodolite telescope through counterclockwise angles back to the resection points: A, B, and C. Record the corresponding indirect theodolite readings: I_3, I_2, and I_1.

(7) Calculate angles, α, β , and γ (see fig. B-1), using the method of paragraph4.5.1.5c(8) in which:

α is the angle from B to A (using readings D_1, D_2, I_2, and I_1)

β is the angle from A to C (using readings D_2, D_3, I_3, and I_2)

γ is the angle from C to P (using readings D_3, D_4, I_4, and I_3)

(8) Using the method of Appendix B, calculate AZ_{tp} from the known resection data and the observed angles: α, β, and γ.

4.5.2 Data Required. If practical, implement an automated data collection system to electronically measure, record, and control data for immediate reduction or transferral to a data base. An automated data collection system is imperative for extensive tests to reduce human error and to decrease test time. In addition an automated data collection system is usually necessary to minimize the effects of test measurements on the test item.

4.5.2.1 General. Record the results of daily calibration checks. For example, the daily end-for-end micrometer test of gunner's quadrant or instrumented inclinometer.

4.5.2.2 Navigation Courses. Obtain a current trig list for all SCPs used throughout testing. Do not assume that the trig list contained in Appendix A is the most current. Maintain a time history of changes to the trig list throughout testing.

4.5.2.3 Mission Profile Table. Obtain the mission profile table from the test plan or as prepared prior to testing. Maintain a time history documenting the extent of completion of the testing described in the table.

4.5.2.4 Mission Scenarios. Record/obtain the following as is applicable:

a. Start-of-mission data consisting of:

(1) Date of mission.

(2) Test location (e.g., ATC or YPG).

(3) Name of mission scenario (e.g., general navigation scenario or gravity anomaly scenario).

(4) Test vehicle identification number (ID).

(5) Test item ID and serial number.

(6) Test equipment ID and serial number.

(7) Names of test personnel.

(8) Description of weather conditions.

(9) Description of road conditions.

b. Test data at each SCP consisting of:

(1) SCP ID.

(2) Time of day.

(3) Measured azimuth (and measured position coordinates when a high accuracy position location system is used in lieu of fixed SCPs).

(4) Test item displayed azimuth and position coordinates.

(5) Measured test item pitch and cant.

(6) Test item displayed pitch and roll.

(7) Number of rounds, type of rounds, and zone of propelling charge (for firing missions).

c. Test data throughout the mission consisting of:

(1) Temperature readings every hour at selected positions on or around the test item.

(2) Any unusual or anomalous alerts and messages displayed by the test item.

(3) Peak input voltage (VDC) to the test item.

(4) Distance traveled (km).

(5) Hours of operation.

d. Any failure data consisting of:

(1) Incident narrative description.

(2) Time of failure.

(3) How the failure was detected.

(4) Mode of operation and environment at time of failure.

(5) Nomenclature/description of failed item.

(6) Major item model number, serial number, and manufacturer.

(7) System life (hours, distance traveled, rounds) at time of incident or failure.

(8) Major part data, including: national stock number, drawing number, manufacturer's part number, serial number, and part test life.

(9) Action taken to correct failure.

(10) Incident classification.

(11) Weather and course conditions at time of failure.

4.5.2.5 Single Theodolite Azimuth Measurement Procedure. Record/obtain the following:

a. SCP numbers with position coordinates.

b. Reference distance aiming points from the theodolite position.

c. Direct and indirect theodolite readings.

d. Calculated and test item-generated azimuth.

4.5.2.6 Azimuth Measurement Using Three-Point Resection. Record/obtain the following:

a. SCP numbers with position coordinates.

b. Three resection aiming points.

c. Direct and indirect theodolite readings.

d. Calculated and test item-generated azimuth.

4.6 Software.

Perform the following procedure to determine if the test item's software meets system requirements.

4.6.1 Method.

4.6.1.1 General. Generate a system level software requirements matrix from the software requirements documents. Analyze the requirements matrix to determine if requirements are addressed elsewhere (e.g., as a performance requirement) or if a specific software test is needed. This rigorous approach will ensure that all software requirements are adequately addressed.

4.6.1.2 Software Requirements Matrix. Perform the following test using the software requirements matrix.

a. Verify that the test item properly handles operator-entered data. Monitor the test item's response to valid and invalid data items as well as data at boundary conditions.

b. Verify the interoperability of the test item with other systems. Verify that the test item's interfaces are in accordance with interface specifications. Monitor data busses as needed.

c. Verify software performance through system level performance testing. That is, exercise the system to insure that the test item's software properly handles every item in the software requirements matrix. Whenever possible, monitor the software response in real-time.

4.6.1.3 Software Maintainability. Analyze the test item software documentation for completeness and traceability.

4.6.1.4 Software Safety. Analyze each software requirement for system safety implications. Test software requirements having safety implications in accordance with MIL-STD-882C[9].

4.6.2 Data Required.

a. Software requirements matrix from the test plan or as prepared prior to testing.

b. Any unusual or anomalous responses to entered data (valid and invalid).

(1) Incident narrative description.

(2) Time of incident.

(3) How the incident was detected.

(4) Mode of operation and environment at time of incident.

(5) Nomenclature/description of item.

(6) System life (hours, distance traveled, rounds) at time of incident or failure.

(7) Action taken.

(8) Incident classification.

c. Degree of interoperability of the test item and its interfaces with other systems.

d. Completeness and traceability of software documentation.

e. Results of the software safety assessment in accordance with MIL-STD-882C.

4.7 Human Factors.

Conduct this test using TOPs1-1-059[10], 1-2-609[11], 1-2-610[12], MIL-STD-1472D[13], MIL-STD-1474C[14], and TECOM Pamphlet 602-1[15].

4.7.1 Method.

4.7.1.1 Demographic and Anthropometric. Collect demographic data for each military occupational specialty (MOS) qualified soldier-operator-maintainer test and evaluation (SOMTE) test participant using TOP1-2-610. Take anthropometric measurements of test personnel at the beginning of the test to ensure that they are in the 5th to 95th percentile specified in TOP1-2-610.

4.7.1.2 Workspace. Take workspace measurements at all crew stations inside the vehicle relative to the test item operation and maintenance.

4.7.1.3 Lighting. Take interior illumination measurements within the vehicle to determine light levels provided for test item operation or maintenance. Take brightness and contrast measurements on all displays, warning lights, and indicator lamps on the test item components.

4.7.1.4 Control and Display. Assess human factors engineering (HFE) characteristics of controls and displays through observations and measurements, using the checklist contained in MIL-STD-1472D. Take force measurements of all controls that test personnel determine require too much or too little force to operate. Also, measure any knob, crank, handwheel, lever, toggle switch, pushbutton, etc., that HFE personnel deem inadequate or detrimental to the man/machine interface. Take all measurements at least five times, and average them to obtain a mean value for each item.

4.7.1.5 Noise. Measure steady-state noise levels at crew stations or other operations/maintenance areas in order to determine hearing protection requirements in accordance with MIL-STD-1474C. Activate all vehicle components that are required to be operating in conjunction with test item operations or maintenance. Record sound pressure levels with the vehicle stationary and operating, as appropriate.

4.7.1.6 Manual Readability. Determine the reading grade level of the test item operator and maintenance manuals, using the guidelines in TOP1-2-609.

4.7.1.7 Crew Performance. Determine the ability of personnel to perform critical operational and maintenance tasks while outfitted in battle dress uniform (BDU), arctic gear, and NBC protective ensembles by comparing performance times required to complete tasks. Use SOMTE personnel with appropriate experience for operational and maintenance testing of the test item.

4.7.1.8 Questionnaires and Interviews. Administer HFE questionnaires to all test participants assigned to operate or maintain the test item, using TECOM PAM602-1 as a guide. Subjectively, determine the adequacy of new equipment training (NET) using the NET questionnaire at the beginning of the test.

Document comments and informal interviews, with respect to HFE observations, throughout all testing. Use these interviews, comments, and observations to augment the data from this HFE subtest.

4.7.2 Data Required. Record/obtain the following as required in applicable guidance documents:

a. Demographic and anthropometric data of all test participants.

b. Dimensions and weights of all test item components measured during initial inspection.

c. Workspace measurements at the crew areas and at selected areas relevant to the test item operability/maintainability.

d. Brightness and contrast measurements of lighted dials and gages; illumination measurements from work stations.

e. Observations on the legibility of all labels and displays.

f. Results of control and display assessment.

g. Results of operational and maintenance tasks by MOS-qualified SOMTE personnel wearing arctic and NBC protective clothing.

h. Results of steady-state noise tests.

i. Results of readability tests conducted on the operation and maintenance manuals.

j. Results of crew performance tests.

k. Summaries of questionnaires and checklists.

l. Observations and comments by HFE test personnel.

4.8 Safety and Health.

4.8.1 Method.

a. Before testing begins, review the developer's safety assessment report (SAR) and Health Hazards Assessment Report (HHAR). Identify all potential hazards to determine what testing must be conducted or what restrictions must be applied to safely operate the test item or host vehicle.

b. Throughout testing, document observations relative to any existing or potential safety hazard.

c. Periodically, throughout the test, assess the test item using TOPs3-2-503[16] and 10-2-508[17] as guides. Review the results of all other subtests for safety and health related issues.

4.8.2 Data Required. Record/obtain the following:

a. Observations and comments about any existing or potential safety hazard.

b. Any performance limitations of the test item or the host vehicle that are imposed due to the test item safety considerations.

c. The results of the review of all other test results for safety and health related issues.

d. Review of technical manual instructions for adequacy of safety instructions, cautions, etc.

4.9 Reliability.

Perform this test to collect:

a. Data to determine the capability of the test item to accomplish its specified mission in a supportable manner and to determine the nature of failures that occur during operations.

b. Data to verify that reliability failure modes identified during previous technical testing have been corrected and no further degradation of reliability has occurred.

c. All reliability data generated on the test item, and based on these data, to compute various indices with respect to hours of operation.

d. Data for other subtests such as performance, safety, HFE, and integrated logistics supportability.

NOTE: Use Army Regulation 702-3[18] and AMC Regulation 70-13[19] as general guidelines for reporting reliability data.

4.9.1 Method.

a. Prior to testing, establish a TECOM Automated Data Collection System (ADACS) reliability data base. Design forms and data entry software to collect reliability data.

b. Observe and record all test item operations and maintenance. Record test item hours of operation and mileage operated over each test course throughout all phases of testing. Document and maintain a complete history and description of all failures, unscheduled maintenance actions, and repairs.

c. During the course of testing, closely monitor and record changes made to the test item software and hardware. Cross reference all data recorded throughout testing with the configuration existing at the time data were observed.

4.9.2 Data Required. Record/obtain the following data:

a. Observations of the capability of the test item to accomplish its specified mission in a supportable manner and data to determine the nature of failures that occur during operations.

b. Results of verification that reliability failure modes identified during previous technical testing have been corrected and no further degradation of reliability has occurred.

c. All reliability data generated on the test item.

d. Data from other subtests such as performance, safety, HFE, and integrated logistics supportability.

e. Observations and records of all test item operations and maintenance. Record test item hours of operation and mileage operated over each test course throughout all phases of testing. Document and maintain a complete history and description of any failures, unscheduled maintenance actions, and repairs.

f. Record of changes made to the test item software and hardware, cross referencing all data recorded throughout testing with the configuration existing at the time data were observed.

4.10 Integrated Logistic Supportability.

Perform this test to collect maintenance data and, based on these data, compute various maintainability indices to support logistic supportability issues. Use TECOM Supplement 1 to AMC Regulation 700-15[20] as a guide for collecting and reporting maintenance data.

4.10.1 Method.

a. Observe and record all scheduled and unscheduled maintenance operations. Record what maintenance tasks were performed and total man-hours and clock hours expended. Perform all maintenance using applicable maintenance manuals. Perform all scheduled maintenance at the specified intervals. Obtain representative times to perform daily checks and services to the test item.

b. Maintain a log of all BIT and related alerts messages displayed throughout all testing.

c. Identify all parts repaired or replaced by nomenclature, manufacturer's part number, and functional group.

d. During each maintenance task, observe and comment on the adequacy of tools, test measurement and diagnostic equipment (TMDE), equipment publications, and repair parts.

4.10.2 Data Required. Use TECOM Supplement 1 to AMC Regulation 700-15 as a guide for reporting maintenance data. Record/obtain the following data.

a. Observations and records of all scheduled and unscheduled maintenance operations.

b. Records of what maintenance tasks were performed and total man-hours and clock hours expended.

c. Representative times for performing operator's daily checks and services.

d. Log of all BIT and related alerts messages displayed throughout all testing.

e. List of all parts repaired or replaced by nomenclature, manufacturer's part number, and functional group.

f. Comments and observations on the adequacy of tools, test measurement and diagnostic equipment, equipment publications, and repair parts used during each maintenance task.

5. PRESENTATION OF DATA.

5.1 Receipt Inspection and Inventory.

a. Compare the measurements of weight, dimensions, and center of gravity with the criteria of the requirements documents.

b. Report any damage, missing items, and other discrepancies discovered during the receipt inspection using TIRs in accordance with AMC Regulation 70-13 and the TECOM Supplement thereto. Include thorough narratives and photographs as appropriate.

c. Provide sorted lists of all incidents, malfunctions, or discrepancies reported by TIRs as needed from the ADACS data base.

5.2 Electrical System.

a. Compare voltage, amperage, and power measurements with the criteria of the requirements documents.

b. Report any malfunctions, erratic behavior, or other anomalous conditions observed during the electrical systems checkouts using Test Incident Reports (TIRs) in accordance with AMC Regulation 70-13 and the TECOM Supplement thereto. Include thorough narratives and photographs as appropriate.

c. Provide sorted lists of all incidents, malfunctions, or discrepancies reported by TIRs as needed from the ADACS data base.

5.3 Environmental.

a. Present test chamber parameter data as graphs plotted for selected parameters, accompanied with tabular data. Indicate test item specifications or test criteria on the presentation to facilitate analysis and assessment.

b. Present evidence of any damage or physical deterioration of the test item as a chronological series of photographs and correlating narrative descriptions.

c. Report any malfunctions, damage, and other incidents, occurring as a result of environmental testing, using Test Incident Reports (TIRs) in accordance with AMC Regulation 70-13 and the TECOM Supplement thereto. Include thorough narratives and photographs as appropriate.

d. Provide sorted lists of all incidents, malfunctions, or discrepancies reported by TIRs as needed from the ADACS data base.

5.4 Electromagnetic Interference/Compatibility.

As stated in TOPs 6-2-542 and 1-2-511.

5.5 Performance Assessment.

Summarize data obtained from each performance parameter in tabular or graphical form, and compute the appropriate statistics defined in the following paragraph.

5.5.1 Error Definitions. Use the following error definitions unless otherwise specified in the requirements documents.

a. Radial error (RE), also referred to as linear error. RE is the linear difference in horizontal position between the measured and reference values for a single position measurement. Compute RE by:

$$RE = \sqrt{(m_n - M_n)^2 + (m_e - M_e)^2}$$

where m_n and m_e are the measured northing and easting, respectively and M_n and M_e are the reference northing and easting, respectively.

b. Root mean square (RMS) error. RMS error is the square root of the mean of the squared errors, relative to the reference value(s), for all measurements in the sample. Compute RMS by:

$$RMS = \sqrt{\frac{\sum_{i=1}^{N} (X_i)^2}{N}}$$

where: N is the total number of measurements in the sample.

X_i is the error in the i^{th} measurement with respect to the reference value.

$X_i = m_i - M_i$ for linear or angular errors.

$$X_i = 100 \frac{m_i - M_i}{S_i - S_o}$$ for percentage of distance traveled errors.

$$X_i = \frac{(m_i - M_i) + (m_0 - M_0)}{T_i - T_o}$$ for drift errors.

m_i is the i^{th} measurement in the sample

m_o is the initial measurement).

M_i is the reference value associated with the i^{th} measurement.

$S_i - S_o$ is the odometer distance traveled since the last position update.

$T_i - T_o$ is the travel time since the last alignment.

c. Probable error (PE). PE is the equally likely deviation (50% probability) of a set of linear measurements about the true (reference) value. Compute PE by:

$$PE = 0.6745 \times RMS_x$$

where RMS_x is the RMS of the sample set represented by x.

d. Circular error probable (CEP). CEP is the radius of a circle centered about true so that any measured position has a 50% probability of lying inside the circle. Compute CEP by:

$$CEP = 1.1774 \frac{RMS_n + RMS_e}{2}$$

where:

RMS_n and RMS_e are the RMS errors in northing and easting, respectively.

e. 2DRMS. 2DRMS is a frequently used measure of accuracy computed by:

$$2DRMS = 2\sqrt{\sigma^2_n + \sigma^2_e}$$

where:

σ_n and σ_e are the northing and easting standard deviations, respectively.

A circle of radius 2DRMS will contain the true horizontal position with a certain probability. However, this probability varies with the error ellipse from 95.4% to 98.2%. In the sense of the DOD usage of this term, 95% of the horizontal errors are less than 2DRMS. Assuming an unbiased, uncorrelated normal distribution with equal standard deviation (σ) in all directions:

$$2DRMS = \sigma\, 2\ln(20) = 2.448\sigma$$

5.5.2 Adjustment of Data.

a. Do not adjust data recorded from the test item.

b. Correct measured cant and elevation for any gunner's quadrant errors noted during quadrant calibration. Should a significant change in inherent error arise in the gunner's quadrant during periodic calibration checks, review the data taken since the previous calibration to determine when and under what circumstances the change occurred and what additional corrections, if any, should be applied to the actual cant and elevation readings recorded during this period.

c. Correct measured tube azimuth for the inherent error formed when a theodolite sights on a taped surface which is canted. This error is called the theodolite (transit) angle T error. Apply the following theodolite angle T error calculation algebraically to the theodolite reading.

$$T = \tan^{-1}\left(\frac{\sin E}{\left(\frac{L\cos^2 E}{R-r}\right) - \sin E\sqrt{\cos^2 E - \sin^2 K}}\right)$$

where:

T = theodolite angle error, the sign of which is the same as the sign of the howitzer cant.

E = corrected cant of the howitzer.

L = distance between the scribe lines used along the centerline of the gun tube, defined as $L_S \cos Z$.

$$Z = \sin^{-1}\left(\frac{R - r}{L_S}\right)$$

L_S = length between scribe lines on gun tube.

R = radius of the gun tube at the scribe line nearest the breech end of the gun tube.

r = radius of the gun tube at the scribe line nearest the muzzle end of the gun tube.

5.6 Software.

Present any software discrepancies, failures, and defects using TIRs in accordance with AMC regulation 70-13 and the TECOM supplement thereto. Discuss in detailed narrative any incidents that impact on safety and human factors.

5.7 Human Factors.

a. Present in narrative form the degree to which the test item conforms to HFE standards and requirements. Support instances of non-conformance with regard to the effect on system and mission performance.

b. Discuss any degradation of the human/machine interface with regard to safety. Summarize the results of observations, checklists, interviews, and questionnaires in tabular form. Objectively assess the results of structured

c. Present all quantitative measurements (anthropometric, workspace, force, etc.) in tabular and graphical form for direct comparison to specific criteria of appropriate HFE guidance documents to show the degree of compliance. These documents include:

(1) MIL-STD-1472D.

(2) MIL-HDBK-759[21].

(3) MIL-STD-1474C.

(4) TOP 1-2-610.

5.8 Safety and Health.

Review the results of all subtests to determine which are significant to safety and health assessment of the test item. Present these results in narrative form, and discuss their impact on safety and health.

5.9 Reliability.

a. Calculate point estimates and lower 90% (or other specified) confidence limits for mean-time-between-failures (MTBF), mean-rounds-between-failures (MRBF), and mean-miles-between-failures (MMBF) in terms of those failures which would causea mission to be terminated or degraded performance below required levels specified in the requirements document. Assess mission and system reliability in accordance with the failure definition and scoring criteria and the failure decision flow charts provided by the developer.

b. Any failures will be identified and assessed to isolate recurrent failure modes. Failure modes and corrective actions will be analyzed for their effect on the mission reliability and performance.

5.10 Integrated Logistic Supportability.

Present all data generated during preventive and corrective maintenance operations in support of the system during testing on Supportability Analysis Charts (SACs). Compute the following maintainability indices based on data accumulated throughout testing.

a. Maintenance ratio (MR). Compute for each level of maintenance and overall maintenance:

$$MR = \frac{\text{Total scheduled and unscheduled active maintenance man - hours}}{\text{Total operating time}}$$

b. Mean-time-to-repair (MTTR). Compute for each level of maintenance and overall maintenance:

$$MTTR = \frac{\text{Total corrective maintenance time}}{\text{Total number of corrective maintenance tasks}}$$

c. Achieved availability (A_a). Compute achieved availability by:

$$A_a = \frac{\text{Total operating time}}{\text{Total operating time} + \text{Total active maintenance time}}$$

6. MODELING AND SIMULATION CONSIDERATION.

The US Department Of Defense (DOD) is relying more and more on Modeling and Simulation (M&S) of systems. The goal of this section is to feed real Navigation test data into the early stages of the system design and development process.

6.1 M&S Development.

Within testing and customer constraints, attempt to gather and disseminate data to organizations that can utilize these data for the future development of models and simulations.

6.2 M&S Validation and Verification.

Within testing and customer constraints, attempt to accommodate any requested model or simulation validation and verification efforts.

APPENDIX A. LAND NAVIGATION COURSE SURVEY DATA.

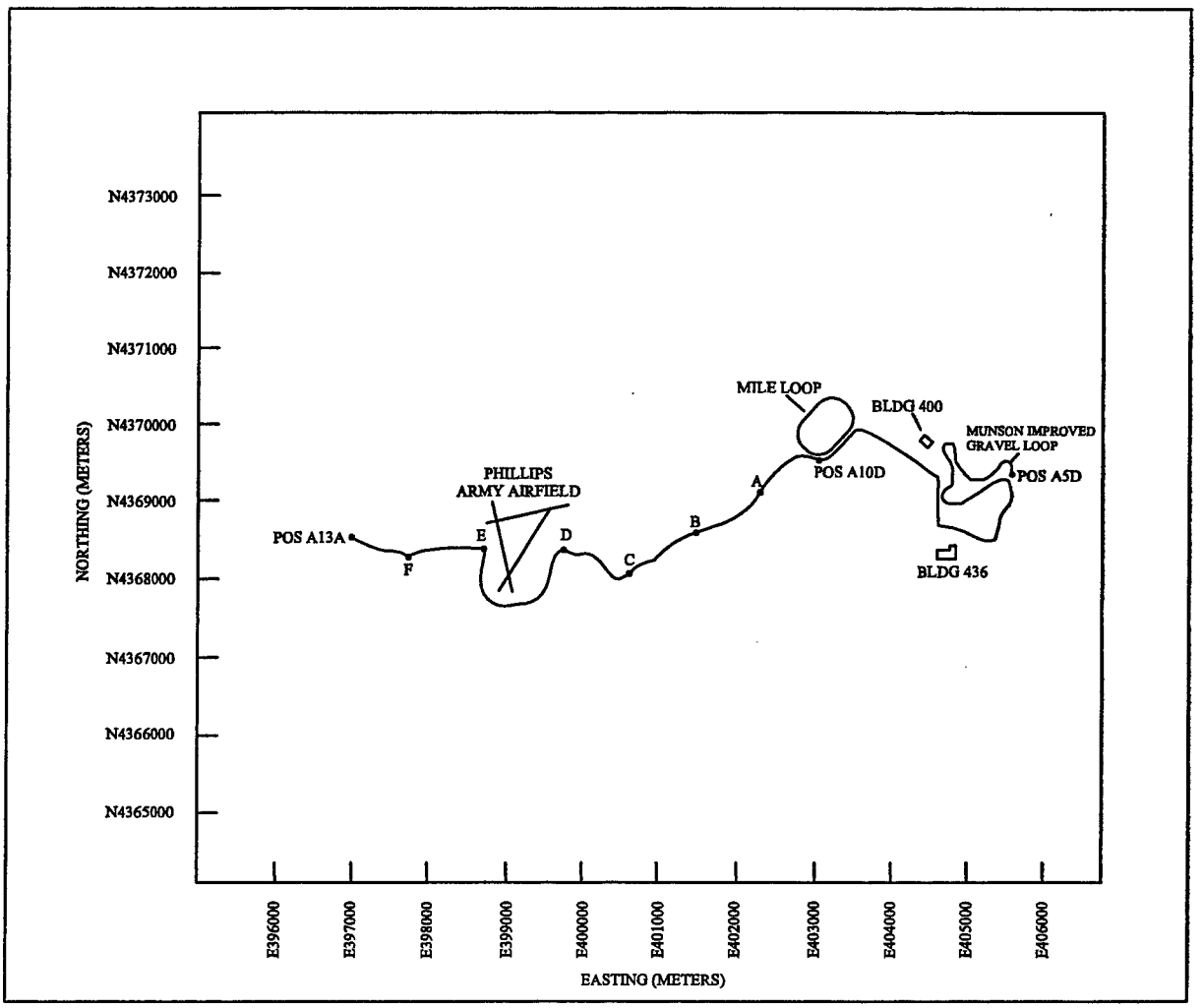


Figure A-1. General Navigation Course at APG.

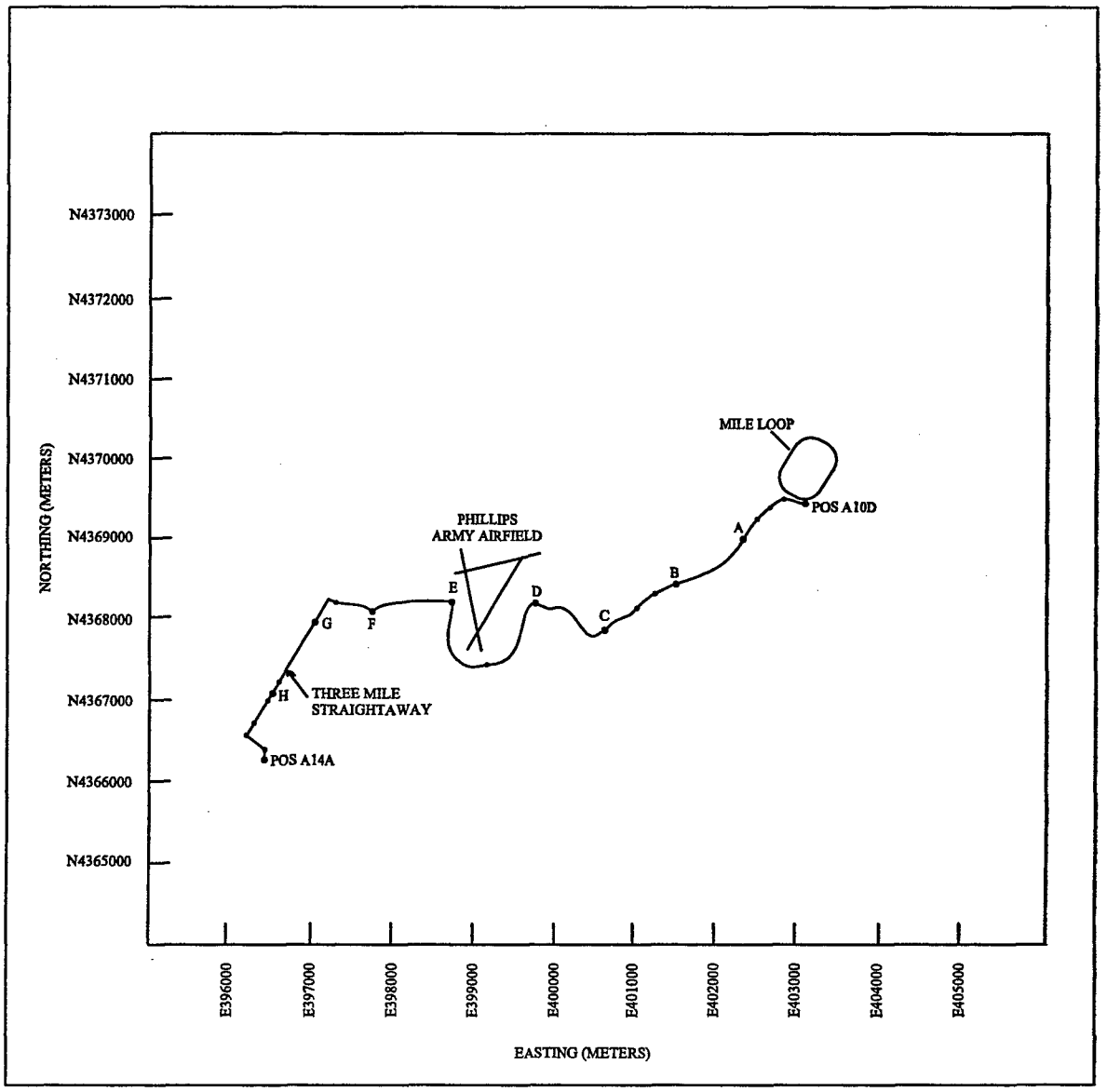


Figure A-2. 10-Kilometer Course at APG.

The following trig list contains UTM grid azimuth, northing, and easting. Alt is the mean low tide height. The geodetic information contained in this list were obtained essentially from surveys conducted circa 1988 and are based on NAD 1927 control.

This list is intended to be used solely for planning purposes and general reference. This list will be updated as ongoing WGS84-based surveys are completed.

Do not attempt to conduct test requiring accuracy measurements of high accuracy using targets on trees and poles not set in concrete. Prior to testing, insure that the trig lists are current and have been verified for accuracy.

Table A-1. Trig List For USACSTA Navigation Courses.

SCP	End of Orienting Line	Azimuth	Northing	Easting	ALT
A1A	Target On Tree	163.46195	4368463.9	405447.4	3.0
A1B	Left Edge Of Storage Tank	233.2133	4368463.9	405447.4	3.0
A1C	Vent	265.06245	4368463.9	405447.4	3.0
A2A	P.K Nail In Pole	205.36265	4368342.6	405420.6	5.0
A2B	Left Edge Of Bldg 449	288.1432	4368342.6	405420.6	5.0
A3A	Center Line Lights-Microwave Tower	224.3739	4369223.1	405439.9	7.0
A3B	Left Edge Chimney-Bldg 439	259.31155	4369223.1	405439.9	7.0
A3C	Left Edge Chimney-Bldg 402	292.13375	4369223.1	405439.9	7.0
A3D	Center Line Lights-Microwave Tower	224.5501	4369223.1	405439.9	7.0
A3E	P.K. Nail In Pole	168.04175	4369223.1	405439.9	7.0
A3F	Left Edge Chimney-Bldg 439	258.5815	4369223.1	405439.9	7.0
A5A	Center Line Lights-Microwave Tower	225.16585	4369309.0	405534.7	4.0
A5B	Left Edge Chimney-Bldg 439	225.26310	4369309.0	405534.7	4.0
A5C	"A" Tower Light	278.36285	4369309.0	405534.7	4.0
A5D	Center Line Lights-Microwave Tower	224.09445	4369308.1	405538.4	4.0
A5E	Left Edge Chimney-Bldg 439	253.40450	4369308.1	405538.4	4.0
A5F	Left Edge Chimney-Cold Room	270.19425	4369308.1	405538.4	4.0

Table A-1. Trig List For USACSTA Navigation Courses. (cont'd)

SCP	End of Orienting Line	Azimuth	Northing	Easting	ALT
A6A	Center Line Lights-Microwave Tower	200.42065	4369143.6	404978.3	2.0
A6B	Left Edge Chimney-Bldg 439	256.13300	4369143.6	404978.3	2.0
A6C	Left Top Edge-Tan Bldg	98.40060	4369143.6	404978.3	2.0
A7A	Center Line Lights-Microwave Tower	196.12070	4369328.6	404977.8	3.0
A7B	Left Edge Chimney-Cold Room	269.45115	4369328.6	404977.8	3.0
A7C	Center Line Antenna-Checkered Water Tank	323.48245	4369328.6	404977.8	3.0
A8A	Center Line Lights-Microwave Tower	177.39425	4369128.6	404733.3	6.0
A8B	East Light- B-1 Velocity Tower	293.4238	4369128.6	404733.3	6.0
A8C	Left Edge Chimney-Bldg 339	344.09345	4369128.6	404733.3	6.0
A10A	P.K. Nail In Pole 1	196.41545	4369451.8	403021.2	12.0
A10B	P.K. Nail In Pole 2	297.3102	4369451.8	403021.2	12.0
A10C	Center Line Antenna-Checkered Water Tank	348.3738	4369451.8	403021.2	12.0
A10D	P.K. Nail In Pole 1	220.4713	4369451.0	403016.3	12.0
A10E	P.K. Nail In Pole 2	298.2854	4369451.0	403016.3	12.0
A10F	Center Line Antenna-Checkered Water Tank	347.50395	4369451.0	403016.3	12.0
A12A	Left Edge Chimney-Bldg 1089	54.46385	4367972.0	398586.7	12.0
A12B	Light on Top Right Side of Tower	80.0347	4367972.0	398586.7	12.0
A13A	Target On Pole	217.0728	4368569.9	397029.5	12.0
A13B	Target On Brick Bldg	23.4716	4368569.9	397029.5	12.0

Table A-1. Trig List For USACSTA Navigation Courses. (cont'd)

SCP	End of Orienting Line	Azimuth	Northing	Easting	ALT
A14A	Target On Pole	78.13155	4366309.8	396403.8	11.0
A14B	Target On Wood Tower	309.24335	4366309.8	396403.8	11.0
A15A	Target On Pole	292.3812	4369907.6	398170.0	13.0
A15B	Target On Cherry Tree	51.2516	4369907.6	398170.0	13.0
A			4369053.9	402282.1	12.0
B			4368519.6	401458.7	10.1
C			4367992.7	400609.9	9.0
D			4368381.5	399772.3	7.8
E			4368429.0	398692.6	14.8
F			4368328.5	397741.4	9.5
G			4367944.3	397050.2	12.6
H			4367089.7	396540.2	10.2
F1A		338.10405	4366361.4	405158.3	4.0
F1B		304.45525	4366361.4	405158.3	4.0
F1C		259.07450	4366361.4	405158.3	4.0
F1D		120.46569	4366361.4	405158.3	4.0
F1E		311.00326	4366361.4	405158.3	4.0
F2A		44.00595	4366684.9	404791.0	2.0
F2B		96.29270	4366684.9	404791.0	2.0
F2C		130.44180	4366684.9	404791.0	2.0
F2D		180.15034	4366684.9	404791.0	2.0
F2E		281.36294	4366684.9	404791.0	2.0

Table A-1. Trig List For USACSTA Navigation Courses. (cont'd)

SCP	End of Orienting Line	Azimuth	Northing	Easting	ALT
F3A		276.27250	4369553.9	403862.3	10.0
F3B		102.02205	4369553.9	403862.3	10.0
F3C		173.49565	4369553.9	403862.3	10.0
F4A		314.57135	4369191.1	403157.6	10.0
F4B		240.05295	4369191.1	403157.6	10.0
F4C		271.331854	4369191.1	403157.6	10.0
F5A		234.50520	4367318.2	401193.6	11.0
F5B		305.38285	4367318.2	401193.6	11.0
F5C		29.42585	4367318.2	401193.6	11.0

Table A-2. Resection Trig List For USACSTA Navigation Courses.

SCP	Point	Northing	Easting
1	1	4368420.6	405475.2
	2	4369426.1	405436.2
	3	4368452.5	405397.1
2	1	4368332.6	405388.0
	2	4368383.8	405379.1
	3	4368399.5	405400.1
3/4	1	4369168.3	405427.5
	2	4369190.6	405408.8
	3	4369212.1	405384.8
5	1	4369263.2	405506.6
	2	4369288.7	405463.9
	3	4369330.0	405464.9
10	1	4369486.8	402997.2
	2	4369495.1	403057.5
	3	4369443.2	403058.0
14	1	4366325.5	396383.5
	2	4366347.1	396405.1
	3	4366325.6	396433.9
15	1	4369935.5	398156.0
	2	4369946.4	398178.2
	3	4369925.8	398192.3

APPENDIX B. AZIMUTH DETERMINATION BY THREE-POINT RESECTION.

Three-point resection is a method of survey used to obtain control for an unknown point based on three known line-of-sight points. This discussion is concerned only with azimuth determination but could easily be extended to position determination.

Before continuing, several factors must be considered. In Figure B-1, the points at the vertices of angles A, B, and C should be selected so that angles α, β, B, and C are at least are at least 22.5° and preferably more than 30°. In addition, the problem is indeterminate if T lies on or near the great circle passing through the points at A, B, and C. This situation will be evidenced by the condition that the sum of the angles α, β, and A is between 160° and 200°.

For this discussion, all angles and azimuths will be in degrees. Furthermore, azimuths are referenced from grid north.

The three-point resection method of azimuth determination requires a prior knowledge of lengths b and c, angle A, and the grid azimuth from A to C, denoted AZ_{AC}. These can be obtained by field survey or derived from the northings (N_A, N_B, N_C) and eastings (E_A, E_B, E_C) of the points at A, B, and C as follows:

$$a = \sqrt{(N_B - N_C)^2 - (E_B - E_C)^2}$$

$$b = \sqrt{(N_A - N_C)^2 - (E_A - E_C)^2}$$

$$c = \sqrt{(N_A - N_B)^2 - (E_A - E_B)^2}$$

$$A = \cos^{-1}\left(\frac{b^2 + c^2 - a^2}{2bc}\right)$$

$$AZ_{AC} = 180 + \tan^{-1}\frac{E_A - E_C}{N_A - N_C} \text{ if } (N_A - N_C) < 0$$

$$AZ_{AC} = 270 \text{ if } (N_A - N_C) = 0 \text{ and } (E_A - E_C) < 0$$

$$AZ_{AC} = 90 \text{ if } (N_A - N_C) = 0 \text{ and } (E_A - E_C) > 0$$

$$AZ = 360 + \tan^{-1}\frac{E_A - E_C}{N_A - N_C} \text{ if } (N_A - N_C) > 0$$

where: N_A, N_B, and N_C are the northings of the points A, B, and C, respectively.

and: E_A, E_B, and E_C are the eastings of the points A, B, and C. respectively.

Having dispensed with preliminary considerations, the problem at hand can be approached. Given b, c, A, AZ_{AC}, and the observed angles α, β, and γ (Figure B-1) determine the azimuth from the theodolite (transit) position, T, to position P.

If T is either outside the triangle ABC and opposite A or within the triangle ABC, let:

$$S = 180 - \frac{A + \alpha + \beta}{2}$$

If T is outside the triangle ABC and on the same side of side a as A, let:

$$S = 180 - \frac{A - \alpha - \beta}{2}$$

for which case, the solution by this method is impossible when $\alpha + \beta = A$. Now let:

$$\phi = \tan^{-1}\left(\frac{c \sin \beta}{b \sin \alpha}\right)$$

and let:

$$\theta = \tan^{-1} [\cot(\phi + 45) \tan(S)]$$

then let:

$X = S + \text{abs}(\theta)$ if $\tan(\theta)$ is negative

$X = S - \text{abs}(\theta)$ if $\tan(\theta)$ is positive

The desired azimuth from T to P, denoted Az_{tp}, is:

$Az_{tp} = AZ_{AC} - X + \gamma + 360$ if $(AZ_{AC} - X + \gamma)$ is negative

$Az_{tp} = AZ_{AC} - X + \gamma$

$Az_{tp} = AZ_{AC} - X + \gamma - 360$ if $(AZ_{AC} - X + \gamma)$ is positive but ≥ 360

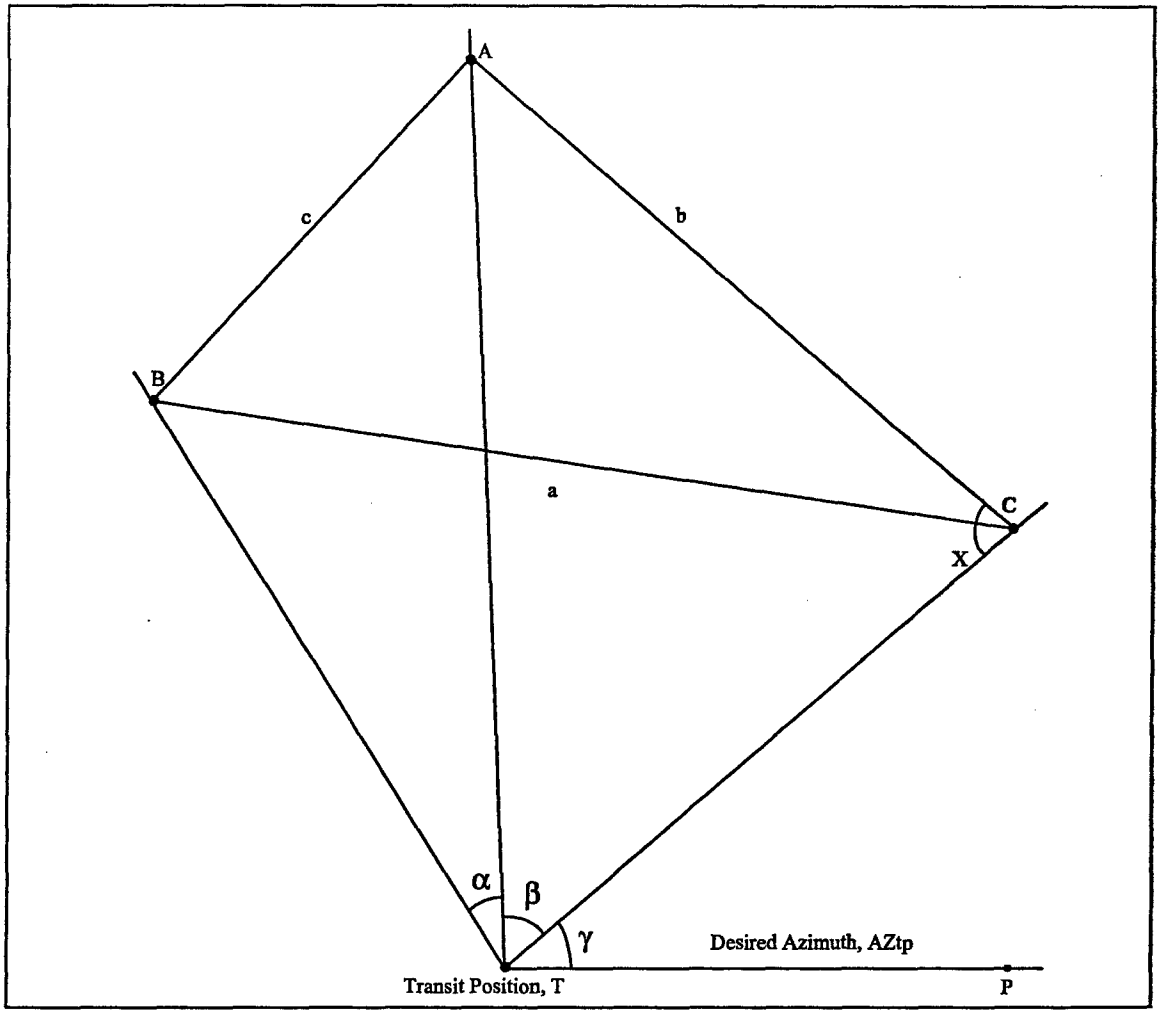


Figure B-1. Azimuth Determination by Three-Point Resection.

APPENDIX C. ABBREVIATIONS.

A_a - achieved availability
ADACS - Automated Data Collection System
AMC - U.S. Army Materiel Command
APG - U.S. Army Aberdeen Proving Ground
ATC - U.S. Army Aberdeen Test Center
BDU - battle dress uniform
BIT - built-in test
CDU - Control and Display Unit
CDUS - CDU Simulator
cm - centimeter
CRTA - U.S. Army Cold Regions Test Activity
DRUH - Dynamic Reference Unit Hybrid
EMP - electromagnetic pulse
GPS - Global Positioning System
HFE - human factors engineering
HHAR - health hazard assessment report
ID - identification or identification number
kg - kilogram
LRU - line replaceable unit
MAPSH - Modular Azimuth Positioning System Hybrid
MOS - military occupational specialty
MR - maintenance ratio
MMBF - mean-miles-between-failures
MRBF - mean-rounds-between-failures
MTBF - mean-time-between-failures
MTTR - mean-time-to-repair
NBC - nuclear, chemical, biological
NET - new equipment training
PLGR - Precision Lightweight GPS Receiver
RAM - reliability, availability, maintainability
SAC - Supportability Analysis Chart
SAR - safety assessment report
SCP - survey control point
SOMTE - soldier-operator-maintainer test and evaluation
SOP - Standing Operating Procedure
SSP - system support package
TECOM - U.S. Army Test and Evaluation Command
TIR - Test Incident Report
TMDE - test measurement and diagnostic equipment
TOP - Test Operations Procedure
UTM - Universal Transverse Mercator
V - volt
VMS - Vehicle Motion Sensor
YPG - U.S. Army Yuma Proving Ground

APPENDIX D. REFERENCES.

1. TOP-1-1-060, System Safety Engineering, 7 April 1986.

2. Army Regulation 200-2, Environmental Effects of Army Actions, 23 December 1988.

3. Army Regulation 200-3, Natural Resources - Land, Forest and Wildlife Management, 28 February 1995.

4. TOP 2-2-601, Electrical Systems (Vehicular and Weapon Subsystems), 20 June 1977.

5. MIL-STD-1275, Characteristics of 28-volt DC Electrical Systems in Military Vehicles, 23 April 1981.

6. MIL-STD-810E, Environmental Test Methods and Engineering Guidelines, 14 July 1989.

7. TOP 6-2-542, Electromagnetic Interference Tests for Electronic Equipment, 1 February 1974.

8. TOP 1-2-511, Electromagnetic Compatibility Requirements, System Testing, 29 December 1989.

9. MIL-STD-882C, System Safety Program Requirements, 19 January 1993.

10. TOP 1-1-059, Soldier-Computer Interface, 30 November 1985.

11. TOP 1-2-609, Instructional Material Adequacy Guide and Evaluation Standard (IMAGES), January 1981.

12. TOP 1-2-610, Human Factors Engineering, Parts I and II, 15 May 1990.

13. MIL-STD-1472D, Human Engineering Design Criteria for Military Systems, Equipment, and Facilities, 30 June 1993.

14. MIL-STD-1474C, Noise Limits for Army Materiel, 8 March 1991.

15. TECOM Pamphlet 602-1, Questionnaire and Interview Design (Subjective Testing Techniques), Vol I, 25 July 1975.

16. TOP 3-2-503, Safety Evaluation of Fire Control Systems - Electrical and Electronic Equipment, 14 September 1993.

17. TOP 10-2-508, Safety and Health Hazard Evaluation - General Equipment, 6 May 1980.

18. Army Regulation 702-3, Army Materiel Systems Reliability, Availability, Maintainability, 31 May 1984.

19. AMC Regulation 70-13, Test and Evaluation - Incidents Disclosed During Materiel Testing, 16 August 1982, with TECOM Supplement 1, 12 April 1983.

20. AMC Regulation 700-15, Integrated Logistic Support (ILS), 20 June 1980 with TECOM Supplement 1, 30 September 1991.

21. MIL-HDBK-759, Human Factors Engineering Design for Army Materiel, 12 March 1975.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to one of the following addresses: Commander, U.S. Army Test and Evaluation Command, ATTN: AMSTE-TM-T, Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: Commander, U.S. Army Aberdeen Test Center, ATTN: STEAC-TE -I, Aberdeen Proving Ground, MD 21005-5059. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.

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13. ABSTRACT *(Maximum 200 words)*

This Test Operation Procedure (TOP) describes procedures for conducting technical performance tests of land navigation and positioning systems. It is modeled around the Modular Azimuth Positioning System Hybrid (MAPS Hybrid) but is applicable to all land-based navigation systems including those using the Global Position System (GPS). This TOP incorporates procedures that require automated data collection instrumentation and a reference system that will provide medium-to-high position/attitude accuracy.

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Test Operations Procedure (TOP) 3-2-046 **31 July 1997**
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LAND NAVIGATION AND POSITIONING SYSTEMS

			Page
PARAGRAPH	1.	SCOPE	2
	2.	FACILITIES AND INSTRUMENTATION	2
	2.1	Facilities	2
	2.2	Instrumentation	3
	3.	REQUIRED TEST CONDITIONS	3
	4.	TEST PROCEDURES	4
	4.1	Receipt Inspection and Inventory	4
	4.2	Electrical System	5
	4.3	Environmental	8
	4.4	Electromagnetic Interference/Compatibility	11
	4.5	Performance Accuracy	11
	4.6	Software	21
	4.7	Human Factors	22
	4.8	Safety and Health	24
	4.9	Reliability	24
	4.10	Integrated Logistic Supportability	25
	5.	DATA REQUIRED	26
	5.1	Receipt Inspection and Inventory	26
	5.2	Electrical System	26
	5.3	Environmental	26
	5.4	Electromagnetic Interference/Compatibility	27
	5.5	Performance Assessment	27
	5.6	Software	29
	5.7	Human Factors	29
	5.8	Safety and Health	30
	5.9	Reliability	30
	5.10	Integrated Logistic Supportability	30
	6.	MODELING AND SIMULATION CONSIDERATION	31
APPENDIX	A.	LAND NAVIGATION COURSE SURVEY DATA	A-1
	B.	AZIMUTH DETERMINATION BY THREE POINT RESECTION	B-1
	C.	ABBREVIATIONS	C-1
	D.	REFERENCES	D-1

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1. SCOPE.

This TOP describes procedures for conducting technical performance tests of inertial land navigation and positioning systems. It is modeled around the Modular Azimuth Positioning System Hybrid (MAPSH) but is applicable to all inertial land-based navigation systems including those aided by the Global Positioning System (GPS). The MAPSH comprises the Dynamic Reference Unit Hybrid (DRUH), a Precision Lightweight GPS Receiver (PLGR) and vehicle mount, a remote GPS antenna and mount, a Vehicle Motion Sensor (VMS), a Control and Display Unit (CDU) or CDU Simulator (CDUS), and interconnecting cabling.

This TOP does not completely cover position accuracy testing of GPS only systems or systems operated in a GPS only mode. Although much of the TOP can be used to test GPS systems, it essentially applies to inertial systems. GPS systems are not inertial systems and require a host of other considerations.

This TOP restricts position and attitude accuracy testing to static tests. There are currently no dynamic position/attitude requirements for land-based navigation systems.

This TOP incorporates procedures that require automated data collection instrumentation and a reference system that will provide medium-to-high position/attitude accuracy.

A listing of acronyms used within the TOP is presented as Appendix C.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Variable power supply	To conduct the power control tests of paragraph 4.2.2.
Environmental chambers	To perform the environmental tests of paragraph 4.3.
A shielded, enclosed anechoic chamber	To conduct the electromagnetic interference and compatibility tests of paragraph 4.4.
Navigation courses consisting of roads and trails with Survey Control Points (SCPs)	Position coordinates ±0.1 m. Azimuth reference ±0.1 mil.
Automated data collection system	To electronically record data from instrumentation with little or no action required from the operator.

2.2 Instrumentation.

Devices for Measuring	Measurement Accuracy
Physical dimensions	± 2 mm
Weight	± 0.2 kg
Center of gravity	± 25 mm
Temperature	± 1° C
Voltage, DC, 0 to 50 V	±1% full scale reading
Current, DC, 0 to 15 Amps	±1% full scale reading
Pitch (elevation) and cant	10% of required accuracy (typically ±0.1 mil)
Azimuth	10% of required accuracy (typically ±0.3 mil)
Universal Transverse Mercator (UTM) position coordinates	10% of required accuracy (typically ±1 m)

3. REQUIRED TEST CONDITIONS.

a. Perform a safety assessment to identify all safety hazards that may be present during testing. NOTE: If weapon system siting information is generated by the navigation system, then the system accuracy has a safety aspect. Use TOP 1-1-060[1*] for guidance. Ensure that Standing Operating Procedures (SOPs) are current and will provide adequate guidance to assure safety for personnel and equipment. Ensure that SOPs are posted at each test site where test operations will be conducted. Conduct a safety briefing at the beginning of each day's testing with all test personnel present who will be involved.

b. Ensure that environmental documentation has been prepared and approved by the installation environmental quality coordinator prior to initiation of test. Use Army Regulations 200-2[2] and 200-3[3] for guidance.

c. Ensure that energy conservation has been considered in the planning and execution of this test.

d. Establish and maintain a maintenance schedule for all test vehicles and appropriate equipment. Ensure that a corrosion control plan has been incorporated along with the maintenance schedule.

e. Establish a reliability, availability, maintainability (RAM) data base to record all test incidents and to provide for the organized and timely collection, analysis, use, systematic storage, and disposition of data. Provide RAM data and Test Incident Reports (TIRs) to the materiel developer, combat developer, testers, evaluators, logisticians, and others as directed in a timely and responsive manner.

* Superscript numbers correspond to those in Appendix D, References.

f. Ensure the availability of appropriate facilities and coordinate test support requirements, including technical documentation, training materials, personnel, vehicles, radios for mission communications, test equipment, maintenance facilities, spare parts, instrumentation, and test courses.

g. Verify the accuracy of instrumentation and test equipment used to control, monitor, or measure test parameters prior to testing. Ensure that test equipment meets and maintains calibration certification requirements.

4. TEST PROCEDURES.

4.1 Receipt Inspection and Inventory.

4.1.1 Method.

a. Inventory the test items and the system support package (SSP) against the packing list, SSP element list, or other applicable documentation.

b. Inspect the test items and the SSP for damage. Conduct nondestructive testing for suspected cracks and discontinuities.

c. Inspect the test items and the SSP for missing or inappropriate markings that caution the handlers.

d. Ensure that line replaceable units (LRUs) are properly code-marked for identification and reference throughout testing.

e. Assure conformance of LRUs to physical specifications stipulated in the requirements documents. Take measurements of physical dimensions, center of gravity, and weight.

f. Take characteristic photographs of the test items.

g. Conduct a pretest operational checkout to ensure that the system works properly.

4.1.2 Data Required.

a. Record the results of the inventory against the packing list, SSP element list, or other applicable documentation. Record and report all discrepancies. Record the nomenclature, serial numbers, manufacturer, and software version of each LRU.

b. Record the results of the receipt inspection. Document any damage and anomalies.

c. Record any missing or inappropriate markings on the test items or SSP that caution the handlers.

d. Compile a list that correlates LRUs with code-marks used for identification and reference.

e. Record the following physical measurements for each LRU.

(1) Weight (kg).

(2) Dimensions (cm x cm x cm).

(3) Center of gravity (cm).

f. Take characteristic, presentation-quality photographs of the test item.

g. Record the results of the pretest operational checkouts.

4.2 Electrical System.

Conduct this procedure using TOP 2-2-601[4] to ensure that the battery system which will be adapted to provide electrical power to the test item during testing does not impose a safety hazard to test personnel or equipment. Two common configurations are:

a. Connecting the test item directly into the host vehicle electrical system.

b. Establishing an independent battery system for the test item. This system will normally be charged through the host vehicle electrical system.

4.2.1 Battery System.

4.2.1.1 Method.

a. Ensure that the battery system complies with appropriate schematics.

b. Inspect the battery system for any defects. Ensure that connections and workmanship are adequate.

c. Ascertain whether batteries and cabling are accessible for testing, maintaining, and simplicity of installation.

d. Ensure that the battery system has overload protection.

e. Ensure that the system has isolation circuitry to prevent the test item batteries from discharging through the vehicle electrical system.

f. Determine the amount of protection from contact with live electrical circuits that is provided to personnel.

4.2.1.2 Data Required.

a. Obtain a detailed description of the test item power system. Include schematics and photographs for each vehicle type.

b. Record any defects in workmanship, connections, overload protection, and isolation circuitry.

c. Note the effectiveness of personnel protection from contact with live electrical circuits.

d. Note any malfunctions and anomalies discovered in the test item battery system and the vehicle electrical systems.

4.2.2 Power Control. Perform the following procedures applicable to the test item. Bench mount the test item to allow observation of all connections. If sparking or excessive heat occurs, discontinue the test immediately. Use calibrated instrumentation to monitor voltage and current.

4.2.2.1 Method.

a. Turn-on. Perform this procedure if the test item is required to turn on within a range of voltages.

(1) Connect the test item to a variable power supply adjusted to deliver less than the minimum turn-on voltage stated in the test item specifications.

(2) Connect instrumentation to monitor the input voltage and current.

(3) Slowly increment the voltage to determine the voltage at which the test item activates.

(4) Turn the test item off.

CAUTION: Perform the following steps if the test item is required to turn on below a specified voltage. Application of over-voltage to unprotected equipment could result in damage to the test item.

(5) Adjust the variable power supply to deliver slightly more voltage (no more than 5%) than the maximum turn-on voltage stated in the test item specifications.

(6) Slowly decrease the voltage by increments to determine the voltage at which the test item activates.

b. Operation. Perform this procedure to ensure that the test item operates within its required range of voltage and current.

CAUTION: Some equipment that has electromagnetic pulse (emp) protection (like the druh) have transorbs between the power lines and chassis ground. These devices are high power zener diodes which clip the spikes around 60 volts. Use caution to protect test equipment from high current levels.

(1) Connect the test item to a variable power supply adjusted to deliver the minimum turn-on voltage stated in the specifications.

(2) Connect instrumentation to monitor voltage and current.

(3) Turn the test item on.

(4) Operate the test item to verify that all functions are performing in accordance with the requirements document.

(5) Adjust the variable voltage power supply to the maximum operating voltage stated in the requirements document.

(6) Operate the test item to verify that all functions are performing in accordance with the requirements document.

c. Turn-off. Perform this procedure if the test item is required to turn off outside a range of voltages.

(1) Connect the test item to a variable power supply adjusted to deliver more than the minimum turn-on voltage stated in the test item specifications.

(2) Connect instrumentation to monitor voltage and current.

(3) Turn the test item on.

(4) Slowly decrease the voltage by increments to determine the voltage at which the test item deactivates.

CAUTION: Perform the following steps if the test item is required to turn off above a specified voltage. Application of over-voltage to unprotected equipment could result in damage to the test item.

(5) Adjust the variable power supply to deliver less than the maximum operating voltage stated in the test item specifications.

(6) Turn on the test item.

CAUTION: When performing the following step, if the test item fails to turn off when the input voltage is increased beyond 5% of the maximum operating voltage (or as otherwise specified in the requirements document), discontinue this procedure. Application of over-voltage to unprotected equipment could result in damage to the test item.

(7) Slowly increment the voltage to determine the input voltage at which the test item deactivates.

d. Transient. Perform this test if the test item is required to operate in the presence of transient power surges.

(1) Connect the test item to a variable power supply adjusted to the nominal operating voltage stated in the test item specifications.

(2) Connect the test item to a signal generator capable of producing voltage spikes that simulate the power surges during which the test item is required to operate.

(3) Connect instrumentation to monitor the test item input voltage and current.

(4) Turn on the test item.

(5) While maintaining constant input voltage from the power supply, inject voltage anomalies from the signal generator to test the worst-case limits specified by MIL-STD-1275[5].

(6) Operate the test item to verify that all functions are performing in accordance with the requirements document.

(7) Perform steps (1) through (6) above over the full operating voltage range.

4.2.2.2 Data Required. Record any failures, erratic behavior, or other anomalous conditions observed during testing. Record the following data applicable to the test item.

a. Turn-on. Record the minimum and maximum voltage (±0.1 V) within which the test item will turn on. Record the observed current (±0.1 A) at these values.

b. Turn-off. Record the minimum and maximum voltage (±0.1 V) outside which the test item will turn off. Record the observed current (±0.1 A) at these values.

c. Operation. Record the minimum and maximum voltage (±0.1 V) within which the test item will operate. Record the observed current (±0.1 A) at these values.

d. Transient. Record the behavior of the test item when subjected to the worst-case limits of MIL-STD-1275.

4.3 Environmental.

4.3.1 Method.

4.3.1.1 General.

a. Land navigation and positioning system requirements documents typically specify the environmental tests included in this section. Conduct only those tests deemed necessary. For additional environmental tests, consult MIL-STD-810E[6].

b. Carefully consider the order in which the environmental tests are conducted if a particular test item undergoes a series of these tests. The test item can be favorably or unfavorably conditioned for a given test by a previous test.

c. Before and after each environmental test, inspect the test item for damage and physical integrity.

d. Before and after each environmental test, mount the test item in a vehicle and conduct a performance accuracy check in accordance with paragraph4.5. For a given test item, the post-test performance check can serve as the pretest performance check for the next environmental test.

e. Environmental chamber tests generally require operational checks before, during, and after exposure to the environmental conditions. When appropriate, vary the input voltage along its operational range during operational checks. The before and after exposure operational checks should consist of a complete checkout of all functions. Limited access to the test item often restricts operational checks during exposure to environments. This may require remote or unattended operation of the test item. During exposure, operational checks should consist of ensuring that the test item will at least:

(1) Turn on and off.

(2) Accept commands.

(3) Display built-in test (BIT) information.

(4) Display navigation and position data.

Land navigation systems often incorporate odometer aiding. Since chamber testing is static, conduct operational checks in the free inertial mode (or if available, in a GPS only mode using a remote GPS antenna or GPS simulator). Operational checks of odometer aiding devices such as the VMS can be performed separately by monitoring the VMS output signals (e.g., using an oscilloscope) while rotating the VMS input shaft with a calibrated electric motor.

4.3.1.2 Low Pressure (Altitude). Perform this test to determine if the test item can withstand, and operate in, a low-pressure environment. Bench mount the test item and subject it to altitude testing in accordance with MIL-STD-810E, method 500.3, procedures I and II.

4.3.1.3 High Temperature. Perform this test to determine if the test item can be stored and operated under hot climatic conditions without experiencing physical damage or deterioration in performance. Bench mount the test item and subject it to high temperature testing in accordance with MIL-STD-810E, method 501.3, procedures I and II.

4.3.1.4 Low Temperature. Perform this test to determine if the test item can be stored and operated under low temperature conditions without experiencing physical damage or deterioration in performance. Bench mount the test item and subject it to low temperature testing in accordance with MIL-STD-810E, method 502.3, procedures I and II.

4.3.1.5 Temperature Shock. Perform this test to determine if the test item can withstand sudden changes in the temperature of the surrounding atmosphere without experiencing physical damage or deterioration in performance. Bench mount the test item and subject it to temperature shock testing in accordance with MIL-STD-810E, method 503.3.

4.3.1.6 Solar Radiation (Sunshine). Perform this test to determine if the test item can withstand exposure to solar radiation without sustaining damage or deteriorated performance. Bench mount the test item and subject it to solar radiation testing in accordance with MIL-STD-810E, method 505.3, procedures I and II.

4.3.1.7 Rain. Perform this test to determine the following:

a. The effectiveness of the test item's protective cover and case in preventing the penetration of rain or high-pressure water washdown.

b. The capability of the test item to satisfy its performance requirements during and after exposure to rain.

c. The physical deterioration of the test item caused by rain.

Bench mount the test item and subject it to rain testing in accordance with MIL-STD-810E, method 506.3, procedures I and III.

4.3.1.8 Humidity. Perform this test to determine the resistance of the test item to the effects of warm, humid atmosphere. Bench mount the test item and subject it to humidity testing in accordance with MIL-STD-810E, method 507.3, procedure I or III.

4.3.1.9 Fungus. Perform this test to determine the extent to which the test item will support fungal growth or how fungal growth may affect performance or use of the test item. Bench mount the test item and subject it to fungus testing in accordance with MIL-STD-810E, method 508.4.

4.3.1.10 Salt Fog. Perform this test to determine the resistance of the test item to the effects of aqueous salt atmosphere. Bench mount the test item and subject it to salt fog testing in accordance with MIL-STD-810E, method 509.3.

4.3.1.11 Sand and Dust. Perform this test:

a. To determine the ability of the test item to resist the effects of dust particles which may penetrate into cracks, crevices, bearings, and joints.

b. To determine if the test item can be stored and operated under blowing sand conditions without experiencing degradation of its performance, effectiveness, reliability, and maintainability due to the abrasion (erosion) or clogging effect of large sharp-edged particles.

Bench mount the test item and subject it to sand and dust testing in accordance with MIL-STD-810E, method 510.3, procedures I and II.

4.3.1.12 Leakage (Immersion). Perform this test to determine if the test item can withstand immersion in water without leakage. Subject the test item to leakage testing in accordance with MIL-STD-810E, method 512.3.

4.3.1.13 Vibration. Perform this test to determine the resistance of the test item to vibrational stresses expected in its shipment and application environments. Subject the test item, along with mounting or support brackets, to vibration testing in accordance with MIL-STD-810E, method 514.4.

4.3.1.14 Shock. Perform this test to determine if the test item can withstand the relatively infrequent, nonrepetitive shocks or transient vibrations encountered in handling, transportation, and service environments. Subject the test item, along with mounting or support brackets, to shock testing in accordance with MIL-STD-810E, method 516.4.

4.3.1.15 Icing and Freezing Rain. Perform this test to determine the effect of icing produced by freezing rain, mist, or sea spray on the operational capability of the test item. Bench mount the test item and subject it to icing and freezing rain testing in accordance with MIL-STD-810E, method 521.1.

4.3.2 Data Required.

a. Take photographs of the test setup. Make notes and record observations at regular intervals. Take photographs of any damage noted on the test item.

b. Obtain the results of the pretest and post-test performance accuracy check in accordance with paragraph 4.5.2. For a given test item, the results of the post-test performance check can serve as the pretest performance check for the next environmental test.

c. Measure and record the data listed in MIL-STD-810E, section II-4, for each of the respective methods designated in paragraph 4.3.

d. Note any malfunctions and incidents (for both the test item and the test apparatus).

4.4 Electromagnetic Interference/Compatibility.

4.4.1 Method. Conduct electromagnetic interference and compatibility testing in accordance with TOPs 6-2-542[7] and 1-2-511[8], respectively.

4.4.2 Data Required. As stated in TOPs 6-2-542 and 1-2-511.

4.5 Performance Accuracy.

Perform this test to assess the accuracy and operability of the test item in wheeled and tracked vehicles when operated under various alignment conditions, operational modes, vehicle dynamics, and deployment conditions.

4.5.1 Method.

4.5.1.1 General. The stated accuracy of the test item will dictate the sophistication of the measurement devices and procedures used during performance accuracy testing. Since this TOP is modeled around the Modular Azimuth Positioning System Hybrid (MAPSH), the following items apply.

a. Use an electronic automated data collection system to measure, record, and control data for immediate reduction, presentation, or transferral to a data base. An automated data collection system is imperative to reduce human error and to decrease test time. In addition, an automated data collection system is usually necessary to minimize or eliminate effects of test measurements on the test item performance. In the case of MAPSH, the CDUS functions not only as a control and display unit, but as an automated data collection system. In fact, the CDUS has specific design requirements to function as an automated data collection system that will interface with the U.S. Army Aberdeen Test Center (ATC) data collection requirements for navigation testing.

b. Use digital inclinometers capable of providing the automated data collection system with pitch and cant measurements to within ±0.1 mil accuracy. Use a gunner's quadrant only if adequate digital inclinometers are not available.

c. Use an onboard device capable of providing the automated data collection system with reliable real-time azimuth orientation measurements to within ±0.3 mil accuracy during field testing. Use a one-second theodolite to measure the azimuth orientation of the test item if the onboard real-time device is not available.

d. Use a reliable position location measurement system (e.g., a differential GPS system) capable of providing the automated data collection system with real-time position coordinates accurate to within ±1.0 meter. Use high-order surveyed SCPs in conjunction with the position location measurement system to determine position coordinates.

4.5.1.2 Navigation Courses. A navigation course consists of roads and trails along which are survey control points (preferably on a level concrete pad) from which accurate position and azimuth orientation can be obtained for the test item. Use the following road courses (or those proposed as noted) for navigation testing.

a. General Navigation Courses (ATC). One course has up to 12 SCPs and is about 15 kilometers end-to-end. This course can be extended indefinitely by completing as many continuous iterations as needed. The general navigation course can be customized to include the Munson and Perryman test courses. Additionally, the firing ranges along the main front and Mulberry Point Road can be accessed for firing scenarios. For wheeled vehicles, an additional course measuring 25 kilometers, can be customized to extend from an SCP at U.S. Army Aberdeen Proving Ground (APG) to an SCP at the Churchville Site. This course offers the most diverse terrains and road surface types available for navigation testing.

b. 10-Kilometer Course (ATC). The 10-kilometer course is a subset of the general navigation course which has SCPs at 1-kilometer intervals. Although this course is not 10 kilometers from end-to-end, it does extend generally in a single direction for 10 kilometers of road travel. This course consists of a 3/7 ratio of paved/unpaved roads.

c. 3-Mile Straightaway (ATC). This 5-kilometer course has SCPs at 0, 250, 500, 1000, 2500, and 5000 meters. The road is straight over a level, paved road surface.

d. 14-Acres (ATC). The 14-acre test course has an 800-meter test track bounded by Jersey walls. This course consists of level, gravel road surfaces. It is highly suitable for safety testing of unmanned ground vehicles.

e. General Navigation Course (ATC - Churchville). The Churchville course offers up to 200 meters of elevation change over 1.5 kilometers for tracked vehicles and 3 kilometers for wheeled vehicles. The Churchville courses are over smooth, dirt roads and hilly terrain.

f. Interstate-95 Course (proposed) (ATC). This course is planned to extend from the Fort McHenry Tunnel in Baltimore to the Aberdeen Proving Ground exit. This proposed 50-kilometer course will be available for test vehicles able to travel public highways at speeds from 64 to 88 km/hr.

g. High Latitude Course (U.S. Army Cold Regions Test Activity (CRTA)).

h. General Navigation Course (U.S. Army Yuma Proving Ground (YPG)). This course begins at Firing Point Road on the KOFA firing range and extends about 20 kilometers in an easterly direction. The course then turns to the north for 2kilometers and then turns easterly for another 17 kilometers. Approximately 80% of the course is over hard-packed gravel road. The remaining 20% is over paved roads. This course begins in UTM grid zone 11 and crosses into zone 12 after about 30 km of travel. SCPs (without concrete pads) are located at 5-kilometer intervals. Both wheeled and tracked vehicles may use this course.

i. Gravity Anomaly Course (YPG). The Topographic Engineering Center has identified a gravity anomaly between SCP 95-1 on "Old" Highway 95 and SCP TRH-1 on the Truck Rolling Hill Course. Road surfaces are hard-packed, gravel, sand, and concrete.

4.5.1.3 Mission Profile Table. Prepare a mission profile table. A mission profile table is a concise summary of the scope of performance accuracy testing. A typical mission profile table for a MAPSH test consists of rows with the following information.

a. Mission scenario (see para 4.5.1.4).

b. Test location (e.g., APG, CRTA, or YPG).

c. Navigation modes (GPS/odometer/inertial, odometer/inertial, GPS/inertial, inertial-only, or GPS-only).

d. Number of missions. Indicate the number of missions that will be run for each type of host test vehicle.

4.5.1.4 Mission Scenarios.

a. Design mission scenarios. Mission scenarios are detailed procedures designed to assess specific requirements of the test item in dynamic field environments or in static controlled environments. Test scenarios shall:

(1) Have an introduction stating the purpose and the scope.

(2) Be tailored to the test item and the test requirements.

(3) Be integrated into the mission profile table of paragraph 4.5.1.3 above.

(4) Contain detailed instructions for conducting the test scenario. Include required data and summary tables for navigation and firing sequences.

(5) Contain appropriate warning and cautions to safely execute the procedure.

b. General navigation scenarios. A general navigation scenario embodies as many operational conditions as possible that the test item would be expected to encounter in actual service. Some considerations are: mission duration, distance traveled, road surfaces, weather conditions, vehicle dynamics, and combat environments (excluding live firing). Avoid conditions that would not likely be encountered under realistic operational situations.

c. Firing scenarios. A firing scenario is a general navigation scenario that incorporates live or simulated firing sequences. Design the procedure to assess pointing accuracy if the test item is used to point the weapon for firing. When the primary purpose for live firing is exposure to gun fire shock, replace actual firing sequences with simulated firing sequences if an acceptable simulator is available.

d. Straight-line scenarios. Straight-line scenarios provide base line performance data. The course shall consist of reasonably straight, paved roads (or improved secondary roads) not oriented in a strictly north-south or east-westdirection. Tailor the scenarios for distances traveled specific to the test requirements.

e. Criteria-based scenarios. Criteria-based scenarios assess a limited number of criteria or conditions while minimizing the influence of other factors. Important criteria-based scenarios include:

(1) Zone-change scenario. Use a zone-change scenario to assess performance accuracy when the test item crosses UTM grid zone boundaries. A test course spanning a UTM grid zone has been established at YPG.

(2) High-latitude scenario. Design this scenario to assess the test item's performance accuracy at or near the highest latitude specified in the requirements documents. The accuracy (particularly azimuth accuracy) of navigation and positioning systems generally degrades at high latitudes. For testing outside 65° S to 65° N latitudes, the expected accuracy, A_e, for a given latitude LAT_e, is given by:

$$A_e = \frac{\cos(LAT_s)}{\cos(LAT_e)} A_s$$

where:

A_s is the required accuracy at the highest specified latitude, LAT_s.

(3) High-altitude scenario. Design this scenario to assess the test item through the full specified altitude range.

(4) Gravity-anomaly scenario. Perform this scenario to assess the accuracy and performance of the test item when operated at or near a gravity anomaly. The alignment of the orthogonal axes of the test item's inertial frame-of-reference with respect to the earth's coordinate axis is greatly influenced by the gravitation potential gradient at the location of the test item. A test course exhibiting a relatively large variation in the gravitation potential gradient has been established at YPG.

(5) Azimuth-drift scenario. Assess azimuth drift in a static environment. Mount the test item rigidly (preferably on a granite test table), prohibiting all movement. After initializing the system, monitor the displayed azimuth every 10 minutes or less, for four or more hours. This test is not applicable to systems that incorporate ring laser gyros (e.g., the MAPSH).

(6) Angular rate-of-change scenario. Assess angular rate-of-change in a static environment.

(a) Mount the test item on a rate table in a normal case orientation and rotate in accordance with the rates specified in the requirements documents. Monitor the displayed azimuth and angular rate at discrete time intervals.

(b) Perform the previous step with the test item mounted 90° offset in the pitch axis from the normal case orientation and again with the test item mounted 90° in the roll axis from the normal orientation.

4.5.1.5 Single Theodolite Azimuth Measurement Procedure. Numerous procedures are available for measuring the azimuth (heading) of the test item with respect to UTM grid north. This procedure employs one theodolite and is recommended for quick, accurate, and precise measurements. When reference is made to a theodolite reading or procedure, proper theodolite operating procedures (e.g., leveling) are implied.

a. The requirements for this procedure are:

(1) First order SCPs with position coordinates (northing, easting, altitude) at the vehicle stopping points and reference distant aiming points from the theodolite position.

(2) A 1-second theodolite.

(3) A porro prism that can be mounted on the test item or test fixture/mounting plate. A porro prism is a 90° prism mounted on a magnetic base with a magnetic switch and bubble levels. The purpose of a porro prism is to allow greater flexibility in measuring azimuth. To measure azimuth with a porro prism, it is necessary only to position the theodolite's sight axis perfectly normal to the transverse axis of the porro prism surface. Using a simple mirror would require positioning the theodolite normal to both the transverse and vertical axes of the mirror surface. A similar problem arises when measuring azimuth using scribe lines.

(4) A host vehicle configuration that permits the theodolite operator to position the theodolite over the theodolite position and sight to the porro prism installed on the test item. The vehicle or test item must be capable of being oriented in such a way to allow the theodolite operator to see his/her reverse image in the porro prism.

b. The following environmental considerations can adversely affect the quality of the azimuth measurement. Accordingly, the effects of the conditions must be minimized or eliminated.

(1) Vehicle movement due to wind buffeting, engine vibration, personnel movement, etc.

(2) Visual distortions due to hot, dry air (heat waves).

(3) Limited visibility due to inclement weather.

c. The following method shall be used.

(1) Stop the vehicle at an SCP with the vehicle alignment mark positioned as close to the vehicle stopping point (P_2, fig. 1) as possible.

(2) Install a porro prism on the test item, and level the bubble.

(3) Locate a theodolite directly over the SCP theodolite position, (T_1, fig. 1). The vehicle operator carefully jockeys the vehicle back and forth until the theodolite operator can see the reverse image of the theodolite in the porro prism. Ensure that the vehicle alignment mark remains near the vehicle stopping point. Relevel the porro prism bubble.

CAUTION: Ensure that test item azimuth outputs and the orienting line are both in the same north reference system (grid north or true north).

(4) Sight the theodolite along the orienting line (OL) (T_1 to P_1, fig.1), to a reference distant aiming point (P_1, fig. 1). Record the direct theodolite reading, D_1.

WARNING: Do not set the known ol azimuth on the theodolite. Setting the recording scale on a theodolite is a source of error and defeats the steps of this procedure which, if followed, insures accurate and precise measurements.

(5) Turn the theodolite telescope in a clockwise angle to the porro prism, and record the direct theodolite reading, D_2.

(6) Plunge the theodolite telescope and record the indirect theodolite reading, I_2, to the porro prism.

(7) Turn the theodolite telescope in a counterclockwise angle to the reference distant aiming point, P_1, and record the indirect theodolite reading, I_1.

(8) Calculate the test item azimuth (AZ_{tp}, fig. 1) from the known OL azimuth (AZ_{ol}) and the theodolite readings D_1, D_2, I_2, I_1, by:

Let AVE_ANGLE = $((D_2 - D_1 + C_1) + (I_2 - I_1 + C_2))/2$

where:

$C_1 = 360$ if $(D_2 - D_1) < 0$

$C_1 = 0$ if $(D_2 - D_1) \geq 0$

$C_2 = 360$ if $(I_2 - I_1) < 0$

$C_2 = 0$ (if $I_2 - I_1) \geq 0$

then:

$AZ_{tp} = AZ_{ol} + AVE_ANGLE - C_3$

where

$C_3 = 0$ if $(AZ_{ol} + AVE_ANGLE) < 360$

$C_3 = 360$ if $(AZ_{ol} + AVE_ANGLE) \geq 360$

NOTE: The preceding calculations assume that the measured angles and the reference OL azimuth are in degrees referenced from grid north. The range of possible values for D_1, D_2, I_1, and I_2 is from zero to less than 360 degrees.

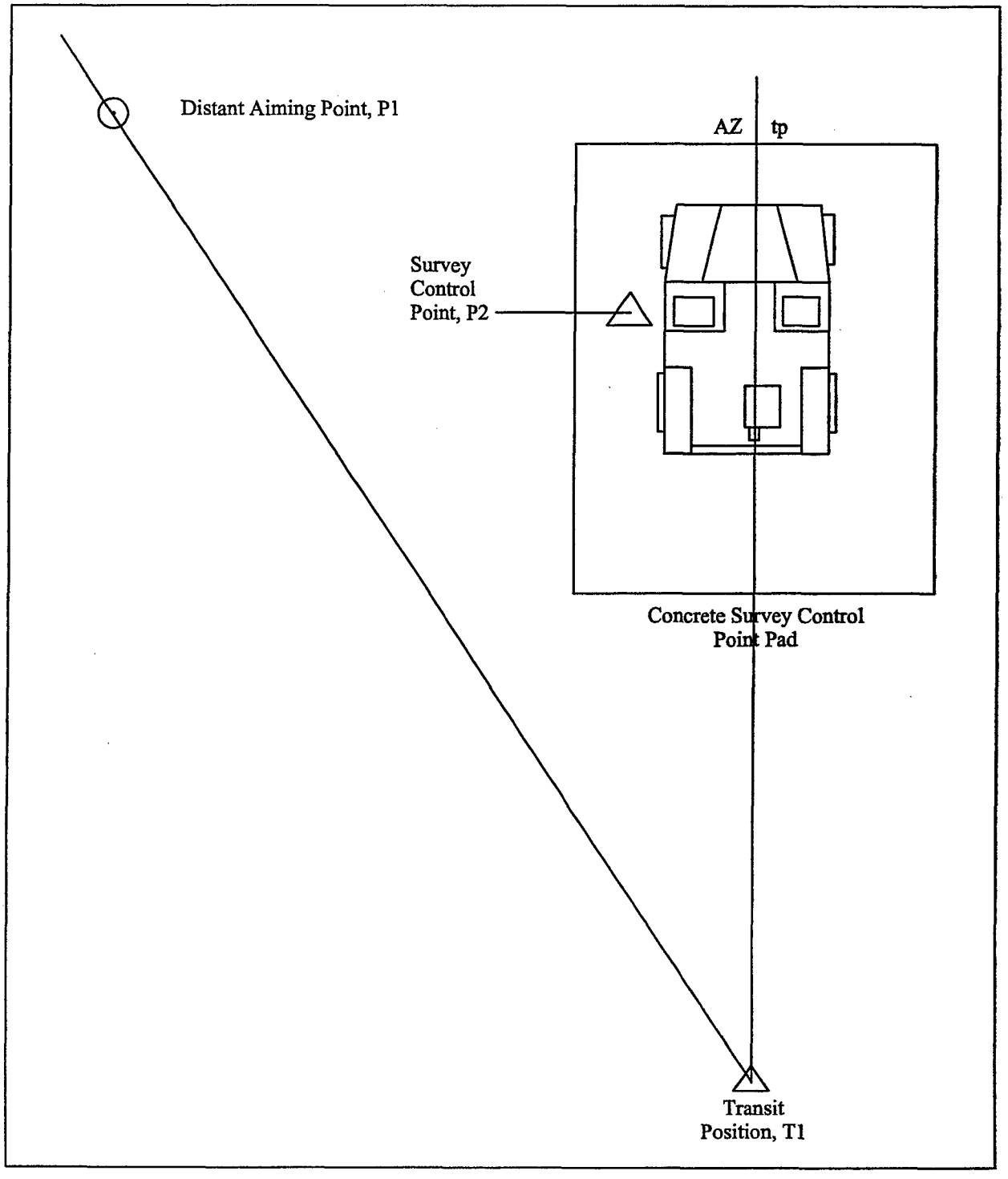


Figure 1. Single Theodolite Azimuth Measurement.

4.5.1.6 Azimuth Measurement Using Three-point Resection. This single theodolite survey procedure is recommended for quick, accurate, and precise azimuth measurements when it is not practical to position the theodolite over a known SCP. As before, when reference is made to a theodolite reading or procedure, proper theodolite operating procedures are implied.

a. The requirements for this procedure are:

(1) First order SCPs with position coordinates (northing, easting, altitude) at the vehicle stopping points and reference distant aiming points from the theodolite position.

(2) A one-second theodolite.

(3) A porro prism that can be mounted on the test item or test fixture/mounting plate.

(4) A host vehicle configuration that permits the theodolite operator to position the theodolite over the theodolite position and sight to the porro prism installed on the test item. The vehicle or test item must be capable of being oriented in such a way to allow the theodolite to see his/her reverse image in the porro prism.

b. The following environmental considerations can adversely affect the quality of the azimuth measurement. Accordingly, the effects of the conditions must be minimized or eliminated.

(1) Vehicle movement due to wind buffeting, engine vibration, personnel movement, etc.

(2) Visual distortions due to hot, dry air (heat waves).

(3) Limited visibility due to inclement weather.

c. The following method shall be used. Refer to the diagram in AppendixB.

(1) Locate the theodolite to sight along the desired azimuth, AZ_{tp}.

(2) Sight the theodolite to the resection point, B. Record the direct theodolite reading, D_1.

WARNING: Do not set the known ol azimuth on the theodolite. Setting the recording scale on a theodolite is a source of error and defeats the steps of this procedure which, if followed, insures accurate and precise measurements.

(3) Turn the theodolite telescope through clockwise angles to the second and third resection points (A and C), and record the corresponding direct theodolite readings, D_2 and D_3.

(4) Turn the theodolite through a clockwise angle to AZ_{tp} and record the direct theodolite reading, D_4.

(5) Plunge the theodolite telescope and record the indirect theodolite reading, I_4.

(6) Turn the theodolite telescope through counterclockwise angles back to the resection points: A, B, and C. Record the corresponding indirect theodolite readings: I_3, I_2, and I_1.

(7) Calculate angles, α, β , and γ (see fig. B-1), using the method of paragraph4.5.1.5c(8) in which:

α is the angle from B to A (using readings D_1, D_2, I_2, and I_1)

β is the angle from A to C (using readings D_2, D_3, I_3, and I_2)

γ is the angle from C to P (using readings D_3, D_4, I_4, and I_3)

(8) Using the method of Appendix B, calculate AZ_{tp} from the known resection data and the observed angles: α, β, and γ.

4.5.2 Data Required. If practical, implement an automated data collection system to electronically measure, record, and control data for immediate reduction or transferral to a data base. An automated data collection system is imperative for extensive tests to reduce human error and to decrease test time. In addition an automated data collection system is usually necessary to minimize the effects of test measurements on the test item.

4.5.2.1 General. Record the results of daily calibration checks. For example, the daily end-for-end micrometer test of gunner's quadrant or instrumented inclinometer.

4.5.2.2 Navigation Courses. Obtain a current trig list for all SCPs used throughout testing. Do not assume that the trig list contained in Appendix A is the most current. Maintain a time history of changes to the trig list throughout testing.

4.5.2.3 Mission Profile Table. Obtain the mission profile table from the test plan or as prepared prior to testing. Maintain a time history documenting the extent of completion of the testing described in the table.

4.5.2.4 Mission Scenarios. Record/obtain the following as is applicable:

a. Start-of-mission data consisting of:

(1) Date of mission.

(2) Test location (e.g., ATC or YPG).

(3) Name of mission scenario (e.g., general navigation scenario or gravity anomaly scenario).

(4) Test vehicle identification number (ID).

(5) Test item ID and serial number.

(6) Test equipment ID and serial number.

(7) Names of test personnel.

(8) Description of weather conditions.

(9) Description of road conditions.

b. Test data at each SCP consisting of:

(1) SCP ID.

(2) Time of day.

(3) Measured azimuth (and measured position coordinates when a high accuracy position location system is used in lieu of fixed SCPs).

(4) Test item displayed azimuth and position coordinates.

(5) Measured test item pitch and cant.

(6) Test item displayed pitch and roll.

(7) Number of rounds, type of rounds, and zone of propelling charge (for firing missions).

c. Test data throughout the mission consisting of:

(1) Temperature readings every hour at selected positions on or around the test item.

(2) Any unusual or anomalous alerts and messages displayed by the test item.

(3) Peak input voltage (VDC) to the test item.

(4) Distance traveled (km).

(5) Hours of operation.

d. Any failure data consisting of:

(1) Incident narrative description.

(2) Time of failure.

(3) How the failure was detected.

(4) Mode of operation and environment at time of failure.

(5) Nomenclature/description of failed item.

(6) Major item model number, serial number, and manufacturer.

(7) System life (hours, distance traveled, rounds) at time of incident or failure.

(8) Major part data, including: national stock number, drawing number, manufacturer's part number, serial number, and part test life.

(9) Action taken to correct failure.

(10) Incident classification.

(11) Weather and course conditions at time of failure.

4.5.2.5 Single Theodolite Azimuth Measurement Procedure. Record/obtain the following:

a. SCP numbers with position coordinates.

b. Reference distance aiming points from the theodolite position.

c. Direct and indirect theodolite readings.

d. Calculated and test item-generated azimuth.

4.5.2.6 Azimuth Measurement Using Three-Point Resection. Record/obtain the following:

a. SCP numbers with position coordinates.

b. Three resection aiming points.

c. Direct and indirect theodolite readings.

d. Calculated and test item-generated azimuth.

4.6 Software.

Perform the following procedure to determine if the test item's software meets system requirements.

4.6.1 Method.

4.6.1.1 General. Generate a system level software requirements matrix from the software requirements documents. Analyze the requirements matrix to determine if requirements are addressed elsewhere (e.g., as a performance requirement) or if a specific software test is needed. This rigorous approach will ensure that all software requirements are adequately addressed.

4.6.1.2 Software Requirements Matrix. Perform the following test using the software requirements matrix.

a. Verify that the test item properly handles operator-entered data. Monitor the test item's response to valid and invalid data items as well as data at boundary conditions.

b. Verify the interoperability of the test item with other systems. Verify that the test item's interfaces are in accordance with interface specifications. Monitor data busses as needed.

c. Verify software performance through system level performance testing. That is, exercise the system to insure that the test item's software properly handles every item in the software requirements matrix. Whenever possible, monitor the software response in real-time.

4.6.1.3 Software Maintainability. Analyze the test item software documentation for completeness and traceability.

4.6.1.4 Software Safety. Analyze each software requirement for system safety implications. Test software requirements having safety implications in accordance with MIL-STD-882C[9].

4.6.2 Data Required.

a. Software requirements matrix from the test plan or as prepared prior to testing.

b. Any unusual or anomalous responses to entered data (valid and invalid).

(1) Incident narrative description.

(2) Time of incident.

(3) How the incident was detected.

(4) Mode of operation and environment at time of incident.

(5) Nomenclature/description of item.

(6) System life (hours, distance traveled, rounds) at time of incident or failure.

(7) Action taken.

(8) Incident classification.

c. Degree of interoperability of the test item and its interfaces with other systems.

d. Completeness and traceability of software documentation.

e. Results of the software safety assessment in accordance with MIL-STD-882C.

4.7 Human Factors.

Conduct this test using TOPs1-1-059[10], 1-2-609[11], 1-2-610[12], MIL-STD-1472D[13], MIL-STD-1474C[14], and TECOM Pamphlet 602-1[15].

4.7.1 Method.

4.7.1.1 Demographic and Anthropometric. Collect demographic data for each military occupational specialty (MOS) qualified soldier-operator-maintainer test and evaluation (SOMTE) test participant using TOP1-2-610. Take anthropometric measurements of test personnel at the beginning of the test to ensure that they are in the 5th to 95th percentile specified in TOP1-2-610.

4.7.1.2 Workspace. Take workspace measurements at all crew stations inside the vehicle relative to the test item operation and maintenance.

4.7.1.3 Lighting. Take interior illumination measurements within the vehicle to determine light levels provided for test item operation or maintenance. Take brightness and contrast measurements on all displays, warning lights, and indicator lamps on the test item components.

4.7.1.4 Control and Display. Assess human factors engineering (HFE) characteristics of controls and displays through observations and measurements, using the checklist contained in MIL-STD-1472D. Take force measurements of all controls that test personnel determine require too much or too little force to operate. Also, measure any knob, crank, handwheel, lever, toggle switch, pushbutton, etc., that HFE personnel deem inadequate or detrimental to the man/machine interface. Take all measurements at least five times, and average them to obtain a mean value for each item.

4.7.1.5 Noise. Measure steady-state noise levels at crew stations or other operations/maintenance areas in order to determine hearing protection requirements in accordance with MIL-STD-1474C. Activate all vehicle components that are required to be operating in conjunction with test item operations or maintenance. Record sound pressure levels with the vehicle stationary and operating, as appropriate.

4.7.1.6 Manual Readability. Determine the reading grade level of the test item operator and maintenance manuals, using the guidelines in TOP1-2-609.

4.7.1.7 Crew Performance. Determine the ability of personnel to perform critical operational and maintenance tasks while outfitted in battle dress uniform (BDU), arctic gear, and NBC protective ensembles by comparing performance times required to complete tasks. Use SOMTE personnel with appropriate experience for operational and maintenance testing of the test item.

4.7.1.8 Questionnaires and Interviews. Administer HFE questionnaires to all test participants assigned to operate or maintain the test item, using TECOM PAM602-1 as a guide. Subjectively, determine the adequacy of new equipment training (NET) using the NET questionnaire at the beginning of the test.

Document comments and informal interviews, with respect to HFE observations, throughout all testing. Use these interviews, comments, and observations to augment the data from this HFE subtest.

4.7.2 Data Required. Record/obtain the following as required in applicable guidance documents:

a. Demographic and anthropometric data of all test participants.

b. Dimensions and weights of all test item components measured during initial inspection.

c. Workspace measurements at the crew areas and at selected areas relevant to the test item operability/maintainability.

d. Brightness and contrast measurements of lighted dials and gages; illumination measurements from work stations.

e. Observations on the legibility of all labels and displays.

f. Results of control and display assessment.

g. Results of operational and maintenance tasks by MOS-qualified SOMTE personnel wearing arctic and NBC protective clothing.

h. Results of steady-state noise tests.

i. Results of readability tests conducted on the operation and maintenance manuals.

j. Results of crew performance tests.

k. Summaries of questionnaires and checklists.

l. Observations and comments by HFE test personnel.

4.8 Safety and Health.

4.8.1 Method.

a. Before testing begins, review the developer's safety assessment report (SAR) and Health Hazards Assessment Report (HHAR). Identify all potential hazards to determine what testing must be conducted or what restrictions must be applied to safely operate the test item or host vehicle.

b. Throughout testing, document observations relative to any existing or potential safety hazard.

c. Periodically, throughout the test, assess the test item using TOPs3-2-503[16] and 10-2-508[17] as guides. Review the results of all other subtests for safety and health related issues.

4.8.2 Data Required. Record/obtain the following:

a. Observations and comments about any existing or potential safety hazard.

b. Any performance limitations of the test item or the host vehicle that are imposed due to the test item safety considerations.

c. The results of the review of all other test results for safety and health related issues.

d. Review of technical manual instructions for adequacy of safety instructions, cautions, etc.

4.9 Reliability.

Perform this test to collect:

a. Data to determine the capability of the test item to accomplish its specified mission in a supportable manner and to determine the nature of failures that occur during operations.

b. Data to verify that reliability failure modes identified during previous technical testing have been corrected and no further degradation of reliability has occurred.

c. All reliability data generated on the test item, and based on these data, to compute various indices with respect to hours of operation.

d. Data for other subtests such as performance, safety, HFE, and integrated logistics supportability.

NOTE: Use Army Regulation 702-3[18] and AMC Regulation 70-13[19] as general guidelines for reporting reliability data.

4.9.1 Method.

a. Prior to testing, establish a TECOM Automated Data Collection System (ADACS) reliability data base. Design forms and data entry software to collect reliability data.

b. Observe and record all test item operations and maintenance. Record test item hours of operation and mileage operated over each test course throughout all phases of testing. Document and maintain a complete history and description of all failures, unscheduled maintenance actions, and repairs.

c. During the course of testing, closely monitor and record changes made to the test item software and hardware. Cross reference all data recorded throughout testing with the configuration existing at the time data were observed.

4.9.2 Data Required. Record/obtain the following data:

a. Observations of the capability of the test item to accomplish its specified mission in a supportable manner and data to determine the nature of failures that occur during operations.

b. Results of verification that reliability failure modes identified during previous technical testing have been corrected and no further degradation of reliability has occurred.

c. All reliability data generated on the test item.

d. Data from other subtests such as performance, safety, HFE, and integrated logistics supportability.

e. Observations and records of all test item operations and maintenance. Record test item hours of operation and mileage operated over each test course throughout all phases of testing. Document and maintain a complete history and description of any failures, unscheduled maintenance actions, and repairs.

f. Record of changes made to the test item software and hardware, cross referencing all data recorded throughout testing with the configuration existing at the time data were observed.

4.10 Integrated Logistic Supportability.

Perform this test to collect maintenance data and, based on these data, compute various maintainability indices to support logistic supportability issues. Use TECOM Supplement 1 to AMC Regulation 700-15[20] as a guide for collecting and reporting maintenance data.

4.10.1 Method.

a. Observe and record all scheduled and unscheduled maintenance operations. Record what maintenance tasks were performed and total man-hours and clock hours expended. Perform all maintenance using applicable maintenance manuals. Perform all scheduled maintenance at the specified intervals. Obtain representative times to perform daily checks and services to the test item.

b. Maintain a log of all BIT and related alerts messages displayed throughout all testing.

c. Identify all parts repaired or replaced by nomenclature, manufacturer's part number, and functional group.

d. During each maintenance task, observe and comment on the adequacy of tools, test measurement and diagnostic equipment (TMDE), equipment publications, and repair parts.

4.10.2 Data Required. Use TECOM Supplement 1 to AMC Regulation 700-15 as a guide for reporting maintenance data. Record/obtain the following data.

a. Observations and records of all scheduled and unscheduled maintenance operations.

b. Records of what maintenance tasks were performed and total man-hours and clock hours expended.

c. Representative times for performing operator's daily checks and services.

d. Log of all BIT and related alerts messages displayed throughout all testing.

e. List of all parts repaired or replaced by nomenclature, manufacturer's part number, and functional group.

f. Comments and observations on the adequacy of tools, test measurement and diagnostic equipment, equipment publications, and repair parts used during each maintenance task.

5. PRESENTATION OF DATA.

5.1 Receipt Inspection and Inventory.

a. Compare the measurements of weight, dimensions, and center of gravity with the criteria of the requirements documents.

b. Report any damage, missing items, and other discrepancies discovered during the receipt inspection using TIRs in accordance with AMC Regulation 70-13 and the TECOM Supplement thereto. Include thorough narratives and photographs as appropriate.

c. Provide sorted lists of all incidents, malfunctions, or discrepancies reported by TIRs as needed from the ADACS data base.

5.2 Electrical System.

a. Compare voltage, amperage, and power measurements with the criteria of the requirements documents.

b. Report any malfunctions, erratic behavior, or other anomalous conditions observed during the electrical systems checkouts using Test Incident Reports (TIRs) in accordance with AMC Regulation 70-13 and the TECOM Supplement thereto. Include thorough narratives and photographs as appropriate.

c. Provide sorted lists of all incidents, malfunctions, or discrepancies reported by TIRs as needed from the ADACS data base.

5.3 Environmental.

a. Present test chamber parameter data as graphs plotted for selected parameters, accompanied with tabular data. Indicate test item specifications or test criteria on the presentation to facilitate analysis and assessment.

b. Present evidence of any damage or physical deterioration of the test item as a chronological series of photographs and correlating narrative descriptions.

c. Report any malfunctions, damage, and other incidents, occurring as a result of environmental testing, using Test Incident Reports (TIRs) in accordance with AMC Regulation 70-13 and the TECOM Supplement thereto. Include thorough narratives and photographs as appropriate.

d. Provide sorted lists of all incidents, malfunctions, or discrepancies reported by TIRs as needed from the ADACS data base.

5.4 Electromagnetic Interference/Compatibility.

As stated in TOPs 6-2-542 and 1-2-511.

5.5 Performance Assessment.

Summarize data obtained from each performance parameter in tabular or graphical form, and compute the appropriate statistics defined in the following paragraph.

5.5.1 Error Definitions. Use the following error definitions unless otherwise specified in the requirements documents.

a. Radial error (RE), also referred to as linear error. RE is the linear difference in horizontal position between the measured and reference values for a single position measurement. Compute RE by:

$$RE = \sqrt{(m_n - M_n)^2 + (m_e - M_e)^2}$$

where m_n and m_e are the measured northing and easting, respectively and M_n and M_e are the reference northing and easting, respectively.

b. Root mean square (RMS) error. RMS error is the square root of the mean of the squared errors, relative to the reference value(s), for all measurements in the sample. Compute RMS by:

$$RMS = \sqrt{\frac{\sum_{i=1}^{N} (X_i)^2}{N}}$$

where: N is the total number of measurements in the sample.

X_i is the error in the i^{th} measurement with respect to the reference value.

$X_i = m_i - M_i$ for linear or angular errors.

$$X_i = 100 \frac{m_i - M_i}{S_i - S_o}$$ for percentage of distance traveled errors.

$$X_i = \frac{(m_i - M_i) + (m_0 - M_0)}{T_i - T_o} \text{ for drift errors.}$$

m_i is the i^{th} measurement in the sample

m_o is the initial measurement).

M_i is the reference value associated with the i^{th} measurement.

$S_i - S_o$ is the odometer distance traveled since the last position update.

$T_i - T_o$ is the travel time since the last alignment.

c. Probable error (PE). PE is the equally likely deviation (50% probability) of a set of linear measurements about the true (reference) value. Compute PE by:

$$PE = 0.6745 \times RMS_x$$

where RMS_x is the RMS of the sample set represented by x.

d. Circular error probable (CEP). CEP is the radius of a circle centered about true so that any measured position has a 50% probability of lying inside the circle. Compute CEP by:

$$CEP = 1.1774 \frac{RMS_n + RMS_e}{2}$$

where:

RMS_n and RMS_e are the RMS errors in northing and easting, respectively.

e. 2DRMS. 2DRMS is a frequently used measure of accuracy computed by:

$$2DRMS = 2\sqrt{\sigma^2_n + \sigma^2_e}$$

where:

σ_n and σ_e are the northing and easting standard deviations, respectively.

A circle of radius 2DRMS will contain the true horizontal position with a certain probability. However, this probability varies with the error ellipse from 95.4% to 98.2%. In the sense of the DOD usage of this term, 95% of the horizontal errors are less than 2DRMS. Assuming an unbiased, uncorrelated normal distribution with equal standard deviation (σ) in all directions:

$$2DRMS = \sigma\, 2\ln(20) = 2.448\sigma$$

5.5.2 Adjustment of Data.

a. Do not adjust data recorded from the test item.

b. Correct measured cant and elevation for any gunner's quadrant errors noted during quadrant calibration. Should a significant change in inherent error arise in the gunner's quadrant during periodic calibration checks, review the data taken since the previous calibration to determine when and under what circumstances the change occurred and what additional corrections, if any, should be applied to the actual cant and elevation readings recorded during this period.

c. Correct measured tube azimuth for the inherent error formed when a theodolite sights on a taped surface which is canted. This error is called the theodolite (transit) angle T error. Apply the following theodolite angle T error calculation algebraically to the theodolite reading.

$$T = \tan^{-1}\left(\frac{\sin E}{\left(\frac{L\cos^2 E}{R-r}\right) - \sin E\sqrt{\cos^2 E - \sin^2 K}}\right)$$

where:

T = theodolite angle error, the sign of which is the same as the sign of the howitzer cant.

E = corrected cant of the howitzer.

L = distance between the scribe lines used along the centerline of the gun tube, defined as $L_S \cos Z$.

$$Z = \sin^{-1}\left(\frac{R - r}{L_S}\right)$$

L_S = length between scribe lines on gun tube.

R = radius of the gun tube at the scribe line nearest the breech end of the gun tube.

r = radius of the gun tube at the scribe line nearest the muzzle end of the gun tube.

5.6 Software.

Present any software discrepancies, failures, and defects using TIRs in accordance with AMC regulation 70-13 and the TECOM supplement thereto. Discuss in detailed narrative any incidents that impact on safety and human factors.

5.7 Human Factors.

a. Present in narrative form the degree to which the test item conforms to HFE standards and requirements. Support instances of non-conformance with regard to the effect on system and mission performance.

b. Discuss any degradation of the human/machine interface with regard to safety. Summarize the results of observations, checklists, interviews, and questionnaires in tabular form. Objectively assess the results of structured

c. Present all quantitative measurements (anthropometric, workspace, force, etc.) in tabular and graphical form for direct comparison to specific criteria of appropriate HFE guidance documents to show the degree of compliance. These documents include:

(1) MIL-STD-1472D.

(2) MIL-HDBK-759[21].

(3) MIL-STD-1474C.

(4) TOP 1-2-610.

5.8 Safety and Health.

Review the results of all subtests to determine which are significant to safety and health assessment of the test item. Present these results in narrative form, and discuss their impact on safety and health.

5.9 Reliability.

a. Calculate point estimates and lower 90% (or other specified) confidence limits for mean-time-between-failures (MTBF), mean-rounds-between-failures (MRBF), and mean-miles-between-failures (MMBF) in terms of those failures which would causea mission to be terminated or degraded performance below required levels specified in the requirements document. Assess mission and system reliability in accordance with the failure definition and scoring criteria and the failure decision flow charts provided by the developer.

b. Any failures will be identified and assessed to isolate recurrent failure modes. Failure modes and corrective actions will be analyzed for their effect on the mission reliability and performance.

5.10 Integrated Logistic Supportability.

Present all data generated during preventive and corrective maintenance operations in support of the system during testing on Supportability Analysis Charts (SACs). Compute the following maintainability indices based on data accumulated throughout testing.

a. Maintenance ratio (MR). Compute for each level of maintenance and overall maintenance:

$$MR = \frac{\text{Total scheduled and unscheduled active maintenance man - hours}}{\text{Total operating time}}$$

b. Mean-time-to-repair (MTTR). Compute for each level of maintenance and overall maintenance:

$$MTTR = \frac{\text{Total corrective maintenance time}}{\text{Total number of corrective maintenance tasks}}$$

c. Achieved availability (A_a). Compute achieved availability by:

$$A_a = \frac{\text{Total operating time}}{\text{Total operating time} + \text{Total active maintenance time}}$$

6. MODELING AND SIMULATION CONSIDERATION.

The US Department Of Defense (DOD) is relying more and more on Modeling and Simulation (M&S) of systems. The goal of this section is to feed real Navigation test data into the early stages of the system design and development process.

6.1 M&S Development.

Within testing and customer constraints, attempt to gather and disseminate data to organizations that can utilize these data for the future development of models and simulations.

6.2 M&S Validation and Verification.

Within testing and customer constraints, attempt to accommodate any requested model or simulation validation and verification efforts.

APPENDIX A. LAND NAVIGATION COURSE SURVEY DATA.

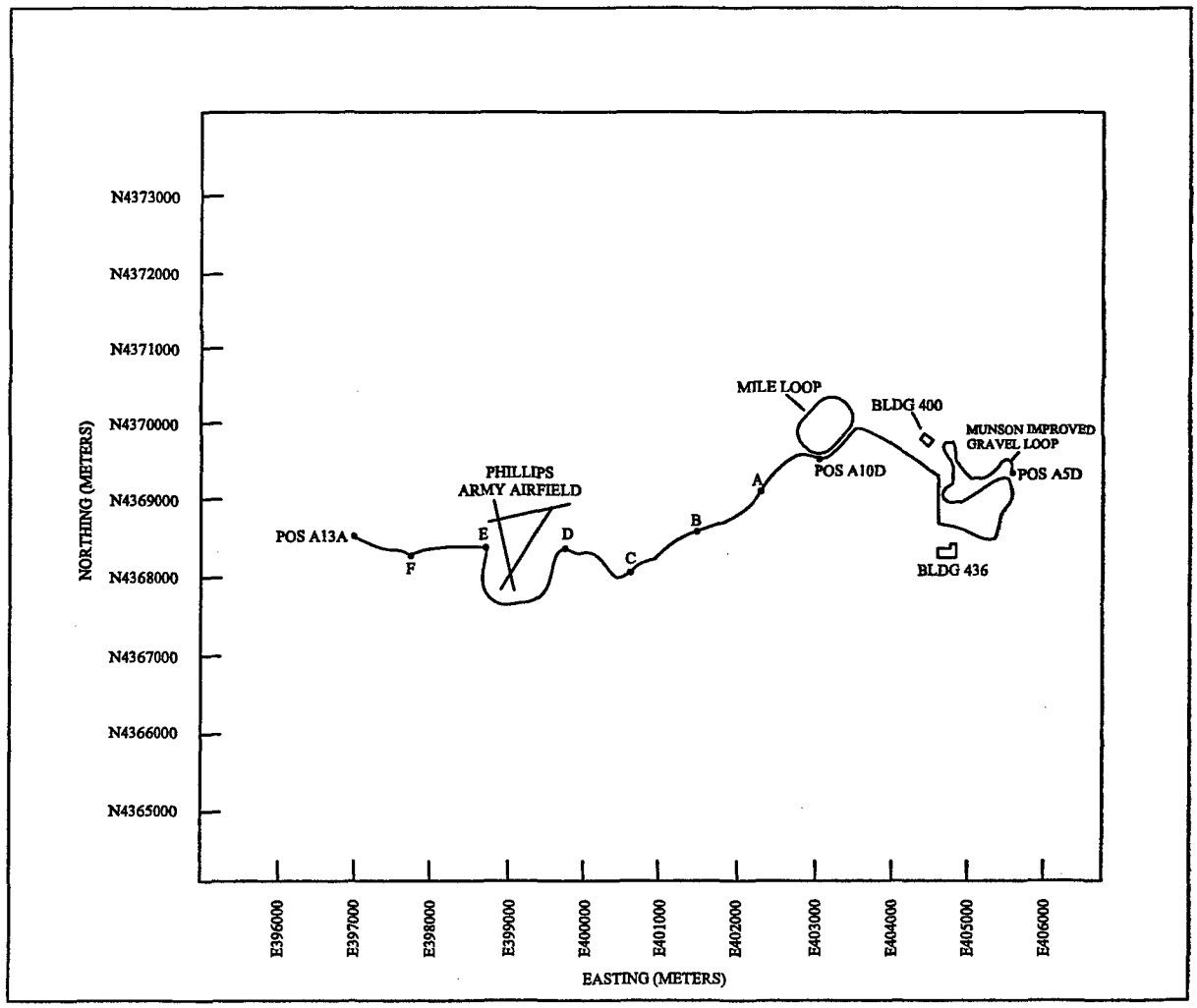


Figure A-1. General Navigation Course at APG.

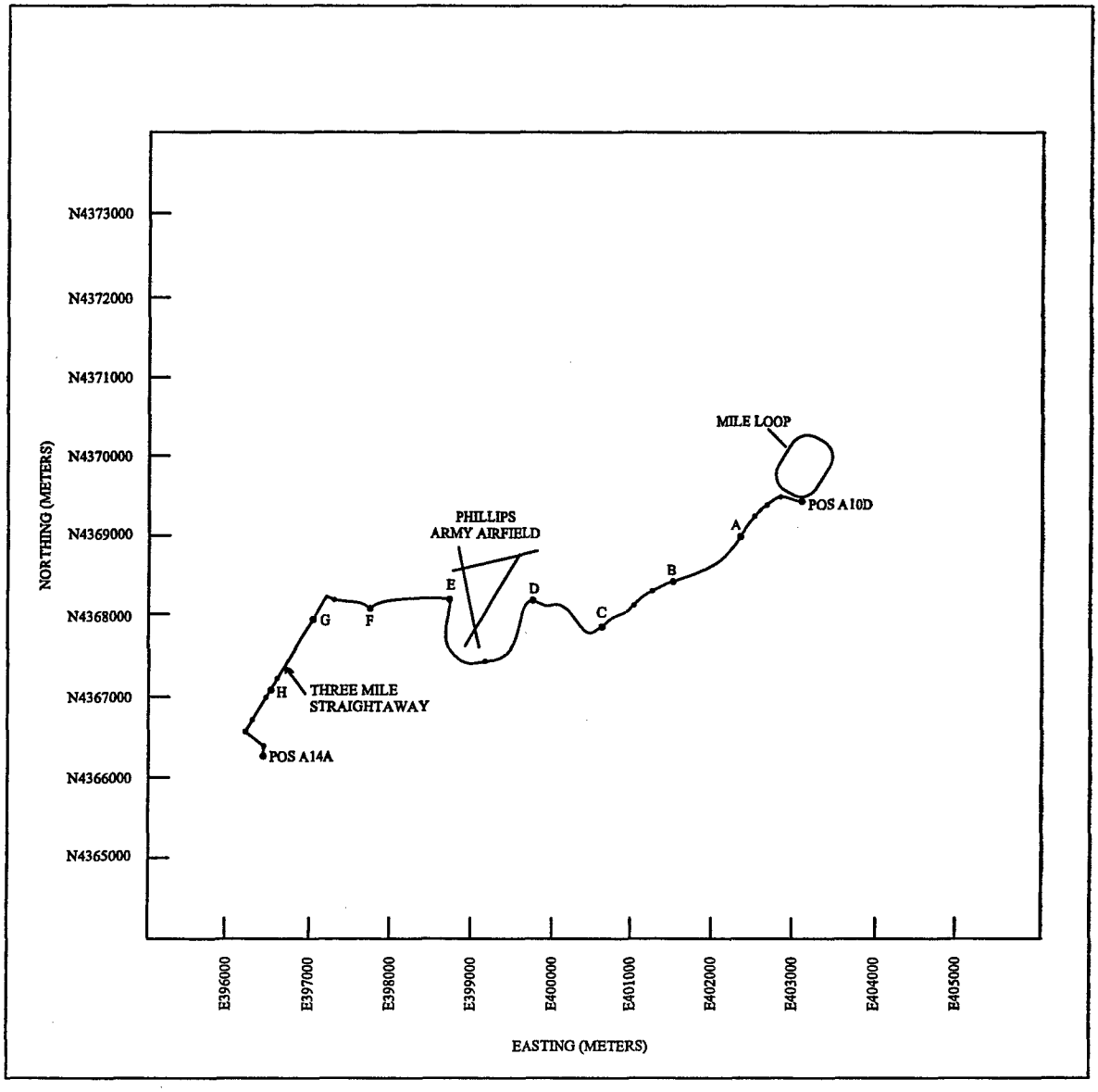


Figure A-2. 10-Kilometer Course at APG.

The following trig list contains UTM grid azimuth, northing, and easting. Alt is the mean low tide height. The geodetic information contained in this list were obtained essentially from surveys conducted circa 1988 and are based on NAD 1927 control.

This list is intended to be used solely for planning purposes and general reference. This list will be updated as ongoing WGS84-based surveys are completed.

Do not attempt to conduct test requiring accuracy measurements of high accuracy using targets on trees and poles not set in concrete. Prior to testing, insure that the trig lists are current and have been verified for accuracy.

Table A-1. Trig List For USACSTA Navigation Courses.

SCP	End of Orienting Line	Azimuth	Northing	Easting	ALT
A1A	Target On Tree	163.46195	4368463.9	405447.4	3.0
A1B	Left Edge Of Storage Tank	233.2133	4368463.9	405447.4	3.0
A1C	Vent	265.06245	4368463.9	405447.4	3.0
A2A	P.K Nail In Pole	205.36265	4368342.6	405420.6	5.0
A2B	Left Edge Of Bldg 449	288.1432	4368342.6	405420.6	5.0
A3A	Center Line Lights-Microwave Tower	224.3739	4369223.1	405439.9	7.0
A3B	Left Edge Chimney-Bldg 439	259.31155	4369223.1	405439.9	7.0
A3C	Left Edge Chimney-Bldg 402	292.13375	4369223.1	405439.9	7.0
A3D	Center Line Lights-Microwave Tower	224.5501	4369223.1	405439.9	7.0
A3E	P.K. Nail In Pole	168.04175	4369223.1	405439.9	7.0
A3F	Left Edge Chimney-Bldg 439	258.5815	4369223.1	405439.9	7.0
A5A	Center Line Lights-Microwave Tower	225.16585	4369309.0	405534.7	4.0
A5B	Left Edge Chimney-Bldg 439	225.26310	4369309.0	405534.7	4.0
A5C	"A" Tower Light	278.36285	4369309.0	405534.7	4.0
A5D	Center Line Lights-Microwave Tower	224.09445	4369308.1	405538.4	4.0
A5E	Left Edge Chimney-Bldg 439	253.40450	4369308.1	405538.4	4.0
A5F	Left Edge Chimney-Cold Room	270.19425	4369308.1	405538.4	4.0

Table A-1. Trig List For USACSTA Navigation Courses. (cont'd)

SCP	End of Orienting Line	Azimuth	Northing	Easting	ALT
A6A	Center Line Lights-Microwave Tower	200.42065	4369143.6	404978.3	2.0
A6B	Left Edge Chimney-Bldg 439	256.13300	4369143.6	404978.3	2.0
A6C	Left Top Edge-Tan Bldg	98.40060	4369143.6	404978.3	2.0
A7A	Center Line Lights-Microwave Tower	196.12070	4369328.6	404977.8	3.0
A7B	Left Edge Chimney-Cold Room	269.45115	4369328.6	404977.8	3.0
A7C	Center Line Antenna-Checkered Water Tank	323.48245	4369328.6	404977.8	3.0
A8A	Center Line Lights-Microwave Tower	177.39425	4369128.6	404733.3	6.0
A8B	East Light- B-1 Velocity Tower	293.4238	4369128.6	404733.3	6.0
A8C	Left Edge Chimney-Bldg 339	344.09345	4369128.6	404733.3	6.0
A10A	P.K. Nail In Pole 1	196.41545	4369451.8	403021.2	12.0
A10B	P.K. Nail In Pole 2	297.3102	4369451.8	403021.2	12.0
A10C	Center Line Antenna-Checkered Water Tank	348.3738	4369451.8	403021.2	12.0
A10D	P.K. Nail In Pole 1	220.4713	4369451.0	403016.3	12.0
A10E	P.K. Nail In Pole 2	298.2854	4369451.0	403016.3	12.0
A10F	Center Line Antenna-Checkered Water Tank	347.50395	4369451.0	403016.3	12.0
A12A	Left Edge Chimney-Bldg 1089	54.46385	4367972.0	398586.7	12.0
A12B	Light on Top Right Side of Tower	80.0347	4367972.0	398586.7	12.0
A13A	Target On Pole	217.0728	4368569.9	397029.5	12.0
A13B	Target On Brick Bldg	23.4716	4368569.9	397029.5	12.0

Table A-1. Trig List For USACSTA Navigation Courses. (cont'd)

SCP	End of Orienting Line	Azimuth	Northing	Easting	ALT
A14A	Target On Pole	78.13155	4366309.8	396403.8	11.0
A14B	Target On Wood Tower	309.24335	4366309.8	396403.8	11.0
A15A	Target On Pole	292.3812	4369907.6	398170.0	13.0
A15B	Target On Cherry Tree	51.2516	4369907.6	398170.0	13.0
A			4369053.9	402282.1	12.0
B			4368519.6	401458.7	10.1
C			4367992.7	400609.9	9.0
D			4368381.5	399772.3	7.8
E			4368429.0	398692.6	14.8
F			4368328.5	397741.4	9.5
G			4367944.3	397050.2	12.6
H			4367089.7	396540.2	10.2
F1A		338.10405	4366361.4	405158.3	4.0
F1B		304.45525	4366361.4	405158.3	4.0
F1C		259.07450	4366361.4	405158.3	4.0
F1D		120.46569	4366361.4	405158.3	4.0
F1E		311.00326	4366361.4	405158.3	4.0
F2A		44.00595	4366684.9	404791.0	2.0
F2B		96.29270	4366684.9	404791.0	2.0
F2C		130.44180	4366684.9	404791.0	2.0
F2D		180.15034	4366684.9	404791.0	2.0
F2E		281.36294	4366684.9	404791.0	2.0

Table A-1. Trig List For USACSTA Navigation Courses. (cont'd)

SCP	End of Orienting Line	Azimuth	Northing	Easting	ALT
F3A		276.27250	4369553.9	403862.3	10.0
F3B		102.02205	4369553.9	403862.3	10.0
F3C		173.49565	4369553.9	403862.3	10.0
F4A		314.57135	4369191.1	403157.6	10.0
F4B		240.05295	4369191.1	403157.6	10.0
F4C		271.331854	4369191.1	403157.6	10.0
F5A		234.50520	4367318.2	401193.6	11.0
F5B		305.38285	4367318.2	401193.6	11.0
F5C		29.42585	4367318.2	401193.6	11.0

Table A-2. Resection Trig List For USACSTA Navigation Courses.

SCP	Point	Northing	Easting
1	1	4368420.6	405475.2
	2	4369426.1	405436.2
	3	4368452.5	405397.1
2	1	4368332.6	405388.0
	2	4368383.8	405379.1
	3	4368399.5	405400.1
3/4	1	4369168.3	405427.5
	2	4369190.6	405408.8
	3	4369212.1	405384.8
5	1	4369263.2	405506.6
	2	4369288.7	405463.9
	3	4369330.0	405464.9
10	1	4369486.8	402997.2
	2	4369495.1	403057.5
	3	4369443.2	403058.0
14	1	4366325.5	396383.5
	2	4366347.1	396405.1
	3	4366325.6	396433.9
15	1	4369935.5	398156.0
	2	4369946.4	398178.2
	3	4369925.8	398192.3

APPENDIX B. AZIMUTH DETERMINATION BY THREE-POINT RESECTION.

Three-point resection is a method of survey used to obtain control for an unknown point based on three known line-of-sight points. This discussion is concerned only with azimuth determination but could easily be extended to position determination.

Before continuing, several factors must be considered. In Figure B-1, the points at the vertices of angles A, B, and C should be selected so that angles α, β, B, and C are at least are at least 22.5° and preferably more than 30°. In addition, the problem is indeterminate if T lies on or near the great circle passing through the points at A, B, and C. This situation will be evidenced by the condition that the sum of the angles α, β, and A is between 160° and 200°.

For this discussion, all angles and azimuths will be in degrees. Furthermore, azimuths are referenced from grid north.

The three-point resection method of azimuth determination requires a prior knowledge of lengths b and c, angle A, and the grid azimuth from A to C, denoted AZ_{AC}. These can be obtained by field survey or derived from the northings (N_A, N_B, N_C) and eastings (E_A, E_B, E_C) of the points at A, B, and C as follows:

$$a = \sqrt{(N_B - N_C)^2 - (E_B - E_C)^2}$$

$$b = \sqrt{(N_A - N_C)^2 - (E_A - E_C)^2}$$

$$c = \sqrt{(N_A - N_B)^2 - (E_A - E_B)^2}$$

$$A = \cos^{-1}\left(\frac{b^2 + c^2 - a^2}{2bc}\right)$$

$$AZ_{AC} = 180 + \tan^{-1}\frac{E_A - E_C}{N_A - N_C} \text{ if } (N_A - N_C) < 0$$

$$AZ_{AC} = 270 \text{ if } (N_A - N_C) = 0 \text{ and } (E_A - E_C) < 0$$

$$AZ_{AC} = 90 \text{ if } (N_A - N_C) = 0 \text{ and } (E_A - E_C) > 0$$

$$AZ = 360 + \tan^{-1}\frac{E_A - E_C}{N_A - N_C} \text{ if } (N_A - N_C) > 0$$

where: N_A, N_B, and N_C are the northings of the points A, B, and C, respectively.

and: E_A, E_B, and E_C are the eastings of the points A, B, and C. respectively.

Having dispensed with preliminary considerations, the problem at hand can be approached. Given b, c, A, AZ_{AC}, and the observed angles α, β, and γ (Figure B-1) determine the azimuth from the theodolite (transit) position, T, to position P.

If T is either outside the triangle ABC and opposite A or within the triangle ABC, let:

$$S = 180 - \frac{A+\alpha+\beta}{2}$$

If T is outside the triangle ABC and on the same side of side a as A, let:

$$S = 180 - \frac{A-\alpha-\beta}{2}$$

for which case, the solution by this method is impossible when $\alpha + \beta = A$. Now let:

$$\phi = \tan^{-1}\left(\frac{c \sin \beta}{b \sin \alpha}\right)$$

and let:

$$\theta = \tan^{-1} [\cot(\phi + 45) \tan(S)]$$

then let:

$X = S + \text{abs}(\theta)$ if $\tan(\theta)$ is negative

$X = S - \text{abs}(\theta)$ if $\tan(\theta)$ is positive

The desired azimuth from T to P, denoted Az_{tp}, is:

$Az_{tp} = AZ_{AC} - X + \gamma + 360$ if $(AZ_{AC} - X + \gamma)$ is negative

$Az_{tp} = AZ_{AC} - X + \gamma$

$Az_{tp} = AZ_{AC} - X + \gamma - 360$ if $(AZ_{AC} - X + \gamma)$ is positive but ≥ 360

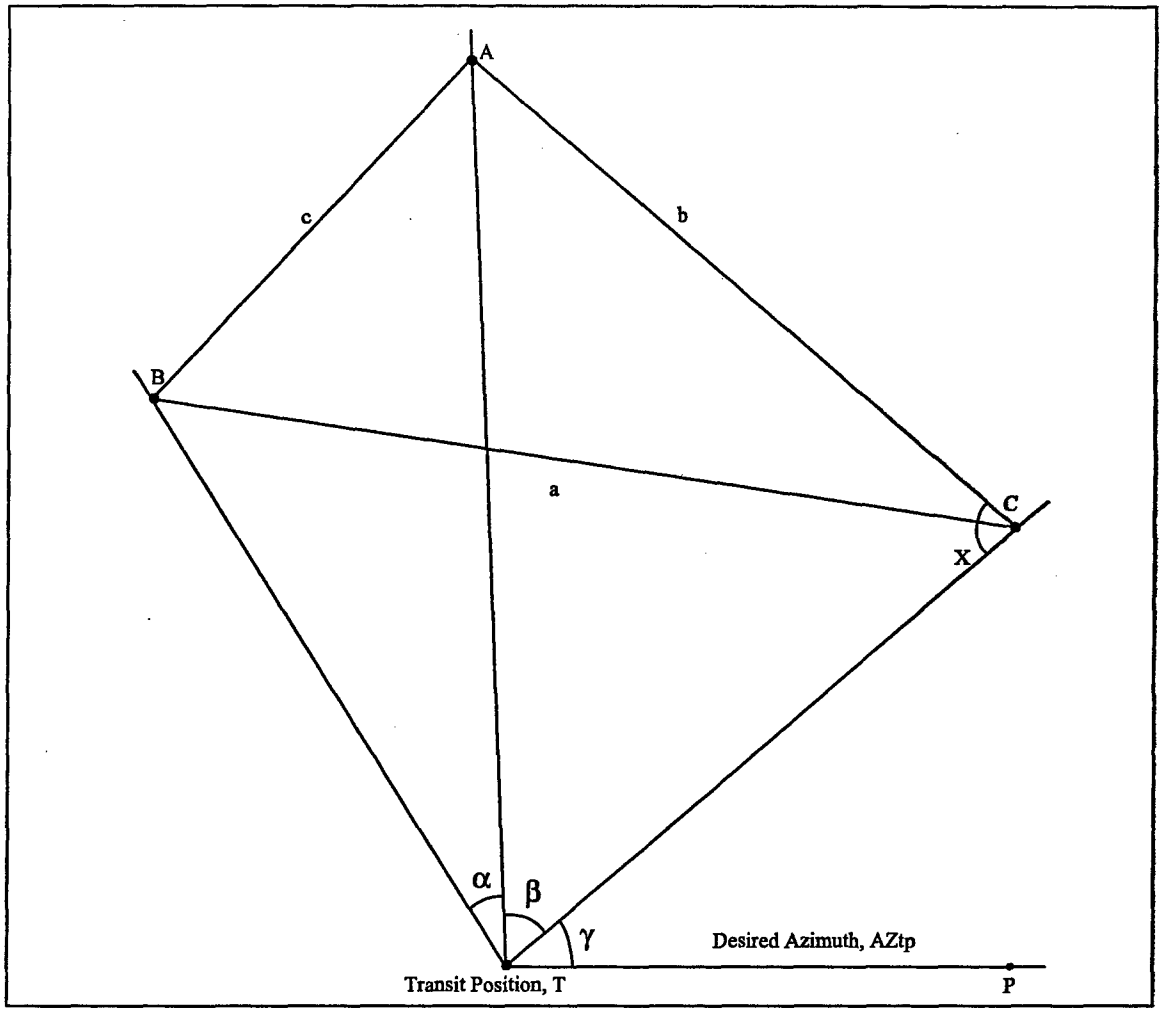


Figure B-1. Azimuth Determination by Three-Point Resection.

APPENDIX C. ABBREVIATIONS.

A_a - achieved availability
ADACS - Automated Data Collection System
AMC - U.S. Army Materiel Command
APG - U.S. Army Aberdeen Proving Ground
ATC - U.S. Army Aberdeen Test Center
BDU - battle dress uniform
BIT - built-in test
CDU - Control and Display Unit
CDUS - CDU Simulator
cm - centimeter
CRTA - U.S. Army Cold Regions Test Activity
DRUH - Dynamic Reference Unit Hybrid
EMP - electromagnetic pulse
GPS - Global Positioning System
HFE - human factors engineering
HHAR - health hazard assessment report
ID - identification or identification number
kg - kilogram
LRU - line replaceable unit
MAPSH - Modular Azimuth Positioning System Hybrid
MOS - military occupational specialty
MR - maintenance ratio
MMBF - mean-miles-between-failures
MRBF - mean-rounds-between-failures
MTBF - mean-time-between-failures
MTTR - mean-time-to-repair
NBC - nuclear, chemical, biological
NET - new equipment training
PLGR - Precision Lightweight GPS Receiver
RAM - reliability, availability, maintainability
SAC - Supportability Analysis Chart
SAR - safety assessment report
SCP - survey control point
SOMTE - soldier-operator-maintainer test and evaluation
SOP - Standing Operating Procedure
SSP - system support package
TECOM - U.S. Army Test and Evaluation Command
TIR - Test Incident Report
TMDE - test measurement and diagnostic equipment
TOP - Test Operations Procedure
UTM - Universal Transverse Mercator
V - volt
VMS - Vehicle Motion Sensor
YPG - U.S. Army Yuma Proving Ground

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