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SELF-CONTAINED VEHICLE LAND NAVIGATION SYSTEMS (V-NAV) TEST II REPORT
(V-NAV II)

E. H. Rugenstein

Modern Army Selected Systems Test,
Evaluation, and Review
Fort Hood, Texas

6 January 1975

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DEPARTMENT OF THE ARMY
HEADQUARTERS MODERN ARMY SELECTED SYSTEMS TEST EVALUATION AND REVIEW
(MASSTER)
FORT HOOD, TEXAS 76544

6 January 1975

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SUBJECT: Self-Contained Vehicle Land Navigation Systems (V-NAV)
Test II Report, Test Number FM 237, Short Title (V-NAV II)

1. The Self-Contained Vehicle Land Navigation Systems (V-NAV) Test II Report, Test Number FM 237, is submitted in accordance with instructions contained in letter, Office of the Adjutant General, AGDA (M) (19 Aug 71) FOR DC EXO, 2 September 1971, subject: Charter of the Commanding General, Modern Army Selected Systems Test, Evaluation, and Review (MASSTER).

2. The findings, conclusions, and recommendations contained in this document are those of the Commanding General and not necessarily those of the Department of the Army.

FOR THE COMMANDER:

Earl W. Fletcher
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Colonel, Armor
Dep Cdr/CofS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report discusses the purpose, objectives, test methodology results and conclusions and recommendations for Self-Contained Vehicle Land Navigation Systems. Self-Contained Vehicle Land Navigation Systems provide a continuous display of the vehicles' position defined in 8-digit UTM coordinates. A compass readout is also provided noting the vehicles heading. Self-Contained systems do not require any external signals or related equipment to operate, but are totally contained on the vehicle itself. The systems acquire heading input from either a magnetic compass, gyro or a combination of the two. Distance input is		

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derived from the vehicle's transmission. This specific report is concerned with the AGA, ANS-150K (Swedish System) and the Land Warfare Laboratory/Westinghouse (US) systems. Data are also included from test FM 194, conducted on the LNS-500 series Land Navigation Systems developed by Aviation Electric, Limited, Canada, for comparative purposes. The test included four subtests designed to investigate the effects of electromagnetic and magnetic environment on the operation of the systems, accuracy testing, and tactical applications and use as a navigational aid to be used in conjunction with the topographic map and standard lensatic compass. An evaluation was also made of the potential of an onboard, magnetic compass for vehicles. The unit used for this evaluation was the VCS-500, Onboard Compass manufactured by Aviation Electric, Limited.

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SELF-CONTAINED VEHICLE LAND NAVIGATION SYSTEMS (V-NAV) TEST II REPORT

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SELF-CONTAINED VEHICLE LAND NAVIGATION SYSTEMS (V-NAV) TEST II REPORT
(Test Number FM 237)

EXECUTIVE SUMMARY

1. Purpose. To evaluate the military potential of existing self-contained land navigation systems (four candidate systems) and to provide data to aid in a determination of compliancy with requirements documents.

2. Objectives.

a. Objective 1 - To compare the operational and performance characteristics of the test systems.

b. Objective 2 - To provide data on the operator and maintenance personnel training requirements to properly operate and maintain the systems.

c. Objective 3 - To provide data on the logistical support and human factors implications associated with the systems.

d. Objective 4 - To document any observed instance of incompatibility of the systems in the electromagnetic environment.

3. Background.

a. A document titled *DA approved Materiel Need (MN for the Positioning and Navigation System (PANS))* (short title: PANS-MN), CDCMS-E, Headquarters, Department of the Army, 29 Nov 72, was developed to define the total Army requirements for navigation systems for air and ground forces, both active and passive. The document states the projected requirements, a description of desired systems' accuracies, and concepts of employment. The Project Manager, Navigation Control (PM, NAVCON) is responsible for management of all existing and planned tasks being conducted to meet the ground, marine, and airborne requirements of the Army for position locating and navigation.

b. The state-of-the-art for passive land navigation systems has developed to the extent required to support military operations. The PM, NAVCON is investigating various systems from US and foreign manufacturers to determine their potential use by the US Army. HQ, MASSTER is aiding in this investigation by performing evaluations on the systems specified by the PM, NAVCON and approved for testing by the Test Schedule and Review Committee (TSARC).

c. The Outline Test Plan (OTP) for the subject test listed four candidate systems to be tested. The listed systems included the Acetylene Gas Accumulator (AGA) (Swedish) ANS-150K, Sperry-Gyro (United Kingdom), AMBAC (France) System, and the Land Warfare Laboratory (USALWL)/Westinghouse (USA) Magnetic System. In addition, the Aviation Electric, Limited (AEL), LNS-517 (Canadian) System was to be tested to determine if modifications had been accomplished as suggested in Test Report FM 194, Self-Contained Land Navigation Systems. Of the above systems, only the manufacturers of the AGA (ANS-150K), and the LWL/Westinghouse (LWL/WHS) system provided devices for testing at MASSTER. The evaluation and testing of these available systems were conducted in the same manner as testing of the LNS-500 series during FM 194. This provides a data base for comparison of all Self-Contained Land Navigation Systems, tested at MASSTER to comply with test objective 1.

4. History.

a. Aviation Electric, Limited, Canada.

(1) The US Army tested the MAN/GAN, the mechanical version of a magnetic and a gyro land navigation system, at Fort Carson, Colorado, in the late 1960s. This system was developed by AEL, and the deficiencies noted led to the development of the LNS-500 solid state series. The LNS-500 series is composed of the LNS-516 (gyro system), the LNS-517 (gyro/magnetic system), and the LNS-518 (magnetic system). These systems are less expensive and are of reduced weight and size when compared to the original MAN/GANs.

(2) The Canadian Armed Forces purchased six of the LNS-517 systems for engineer tests and troop evaluation tests. Two of these systems were loaned to the United States on a Standardization Loan Agreement for the calendar year 1973. When the systems arrived at Fort Hood for testing (FM 194) during the period July to September 1973, it was noted that the technical representative from AEL had also brought a north-seeking gyro which provided the capability to operate the LNS-517 as an LNS-516 (gyro system). The LNS-516 is designed to operate in a tank, and during the first 2 weeks of the test period it was planned that an M60A1 tank would be on the site for magnetic environment tests. The AEL technical representative agreed to mount the LNS-516 in this tank for limited evaluation during the time the tank was available.

b. Acetylene Gas Accumulator (AGA) Company.

(1) The AGA, ANS-100 was developed and accepted as a standard navigation system in the Swedish Army. The ANS-100 contained only a directional gyro and had no onboard north-seeking capability. Alignment of the system was accomplished by optical sighting. The PANS-MN document required a Self-Contained Land Navigation System with a self-alignment capability; therefore, the ANS-100, as used by the Swedish Army, was not satisfactory for US Army use.

(2) The AGA Corporation joined with Singer-Kearfott (a US firm based in New Jersey) in an effort to incorporate a single north-seeking/directional gyro in the ANS-100. Their efforts produced the ANS-150K, which was the system tested at Fort Hood during this test. The ANS-150K is unique in that it is a full gyro system, utilizing only one gyro to perform both northing alignment of the system and heading reference during travel. Previous systems of this type used two gyros to perform these functions.

c. USALWL/Westinghouse. USALWL developed a magnetic vehicle navigation system (no gyros utilized) to determine if there is a less expensive, minimum maintenance, small, compact vehicle system that could meet the requirements of the ANS-MN. The system was developed (for concept testing only) by USALWL (in conjunction with Westinghouse of Baltimore, Maryland) using the engineering concept of the AN/PSN-7 man-pack land navigation system. An engineering model of the system, in a breadboard configuration, was made available for this test.

5. Equipment Description.

a. ANS-150K. The ANS-150K is designed to operate in all types of military tactical vehicles, wheeled or tracked. The readout device (navigator) contains a computer for calculation of the 8-digit coordinates displayed on the readout device. Input to the computer is provided in the form of distance traveled (measured from the vehicle transmission) and heading of vehicle (determined from Singer-Kearfott gyro). When the vehicle is stopped, the gyro functions as a north-seeking gyro and performs the initial alignment of the system. When the vehicle begins to move, the gyro goes into a directional gyro mode of operation and provides a continual direction of travel input. This information is also displayed on the readout device (navigator) on a card type dial giving the operator an immediate reference to the direction the vehicle is facing. Controls and adjustments required for use by the operator are located on the readout device for easy access.

b. LWL/WHS Magnetic Vehicle Land Navigation System. The LWL/WHS system is completely self-contained in one package which may be fastened or strapped to any part of the vehicle on which it is used. The readout device is handheld or may be attached to the operators' web gear. Since the readout device is linked to the basic component of the system by one cable, it may be used by any person in the vehicle (i.e., track commander, driver, observer, or unit commander). It may also be used inside or outside the vehicle when the commander is riding with the hatch open. The distance input to the system is taken from the vehicle transmission and the direction of travel obtained from an externally mounted flux-valve compass. A heading reference indicator is also provided to give the vehicle driver or commander a continual display of the vehicle's direction of travel. The only permanent mounting of components necessary for the system to operate are the distance input and the flux-valve compass; therefore, the system is easily removed and mounted in another vehicle.

c. VCS-500, Onboard Magnetic Heading Reference Unit, AEL. The VCS-500 was used as a comparative device to the standard lensatic compass. This device is an onboard heading reference system composed of a flux-valve sensor and compass card type readout. The compass may be installed on the M113A1 or M151A2 (or similar type vehicles) without major modifications to the vehicle. The readout provides an onboard, continuous display of the vehicle's direction of travel either in reference to magnetic heading or (when properly adjusted for the area of operations) grid heading reference.

6. Test Description. The test was conducted in three phases on two test sites and consisted of a total of four subtests. System vehicle configurations tested included the AGA and the LWL/WHS mounted in the M113A1 armored personnel carrier and the M151A2 (1/4-ton truck (jeep)).

a. Phase I, conducted at Fort Hood, Texas, consisted of equipment inventory, installation, compensation and calibration, and training of operators.

b. Phase II, also conducted at Fort Hood, Texas, consisted of controlled accuracy tests and electromagnetic/magnetic environment tests to determine the systems' capabilities under ideal conditions and in a battlefield environment. This phase of testing consisted of a 3-kilometer, straight and level calibration course; a 1 kilometer, straight line course traversing a magnetic north-south direction of travel with three parallel courses 5, 10, and 15 meters from the primary course and two closed loop accuracy courses (one rough and one level) approximately 20 kilometers in length; and two open-end courses (one rough and one level) approximately 25 kilometers in length.

c. Phase III, conducted in Sam Houston National Forest near Huntsville, Texas, consisted of simulated tactical operations requiring the operator to traverse unknown terrain using the systems as navigation aids in conjunction with a 1:24,000 topographic map. Using slightly different aggressor activities and bypass route requirements, comparative runs were conducted first with the land navigation system and then with the map and compass or AEL onboard compass, VCS-500.

7. Test Results (Findings).

a. Phase I. (Pretest activities and subtest I consisted of system inventory and preparation for testing and operator training.)

(1) The 40 hours of classroom training and practical exercises provided the operators with the basic knowledge required to operate the systems once the systems were compensated and calibrated. An additional 60 hours of field use was then required to integrate the navigation system as an aid to navigation with the topographic map.

(2) The systems received for testing were not production models. The LWL/WHS system was an engineering test model containing many "hard wired, breadboard modules." Failure of these modules resulted in many hours of downtime (i.e., resoldering broken wires or replacement of wires). The AGA, ANS-150K had an extra electronic box that will not be required on the production model which contained the interface circuitry for the Singer-Kearfott gyro. This circuitry was added to the Swedish ANS-100 to produce the ANS-150K. The circuitry in this box will be repackaged in the base of the gyro in a production model.

(3) No major modifications were required to be performed on the test vehicles to mount the navigation systems tested.

b. Phase II. (Subtests II and III consisted of calibration, electromagnetic and magnetic, electronic warfare, and accuracy testing.)

(1) Calibration.

(a) Calibration controls on both the systems tested were not adequate for operator use. Dials, although configured with reference marks or numbers, had no correlation to specific amounts of adjustment for given situations or correction of errors. All calibration (and compensation of the LWL/WHS system) was accomplished by the technical representatives.

(b) Once the systems were compensated and/or calibrated, a check was performed each morning and evening prior to and after testing to insure the settings were still valid. The LWL system required continual recompensation of the compass throughout the test. The ANS-150K maintained its calibration settings from day to day with only minor variations caused by a change in tire pressure or change of tires on the wheeled vehicle. Once the gyro was aligned on the center axis of the test vehicle during initial installation, no further adjustments were required.

(2) Electromagnetic Environment. The radio frequency interference (RFI) and electronic warfare (EW) environment created by radios and radio jamming devices had no effect on the operation of the ANS-150K. No specific electronic signature was detected by EW sensing equipment. Radios (when transmitting) on the test vehicle trapped the flux-valve compass on the LWL/WHS system and caused a false heading input to the computer. The compass was not affected when the system was operated in the vicinity (5 to 15 meters) of another transmitting radio.

(3) Magnetic Environment. The introduction of a magnetic environment did not affect the operational characteristics of the ANS-150K. The LWL/WHS system was affected on some runs when conducted in a change of magnetic environment (operating hub-to-hub or within 5 to 15 meters of an M60A2) yet was not affected on others. Problems with the compass compensation during this phase of testing resulted in inconclusive data for this portion of the test.

(4) Accuracy.

(a) The AGA, ANS-150K mounted in the M113A1 had a maximum miss distance of 50 meters over the closed loop level accuracy course, 60 meters for the closed loop rough course, 60 meters for the open end level course, and 120 meters for the open end rough course. The error at the end of these courses (approximately 19 to 27 kilometers long) ranged from 0.13 percent to 0.5 percent error for distance traveled.

(b) When mounted in the M151A2, the maximum miss distances for the AGA, ANS-150K were 105 meters on the closed loop level accuracy course, 65 meters for the closed loop level course, 80 meters for the open end level course, and 120 meters for the open end rough course. The errors noted at the end of the various courses ranged from 0 percent to 0.4 percent error for distance traveled.

(c) The maximum miss distance for the AGA system for all vehicle configurations traversing the various accuracy courses was 35 to 50 meters for the closed loop level course, 45 to 75 meters for the closed loop rough course, 60 meters for the open end level course, and 120 meters for the open end rough course.

(d) Based on all accuracy data collected on the AGA, ANS-150K for all vehicle configurations, courses, and terrain, the maximum miss distance expected is 40 meters after 28 kilometers of travel which reflects an approximate percent error for distance traveled of 0.18 percent (fig 1). (See appendix A for methodology.)

(e) The LWL/WHS did not achieve the design accuracies due to continued problems with the breadboard modules, resulting in the inability to maintain compensation of the flux-valve compass. Results achieved during runs when these problems were experienced showed maximum miss distances from 500 to 700 meters, representing a 3 to 5 percent error for distance traveled.

(f) During some accuracy test runs, stable compensation of the LWL/WHS compass was achieved. This occurred on the closed loop rough course with the system mounted in the M113A1. The maximum miss distance during these runs was 250 meters after 19 kilometers of travel, reflecting a 1.5 percent error for distance traveled. The average maximum miss distance (occurring at the course finish point) was 175 meters, reflecting a 0.9 percent error for distance traveled. Throughout the test period, isolated runs reflected acceptable accuracies with miss distances ranging from 10 to 190 meters. Errors at the end of these courses ranged from 0.3 percent to 0.75 percent error for distance traveled.

(g) Throughout the testing, the LWL/WHS system displayed a high degree of repeatability. Even though the system was reflecting miss distances in excess of 500 meters, repeated runs over the same course

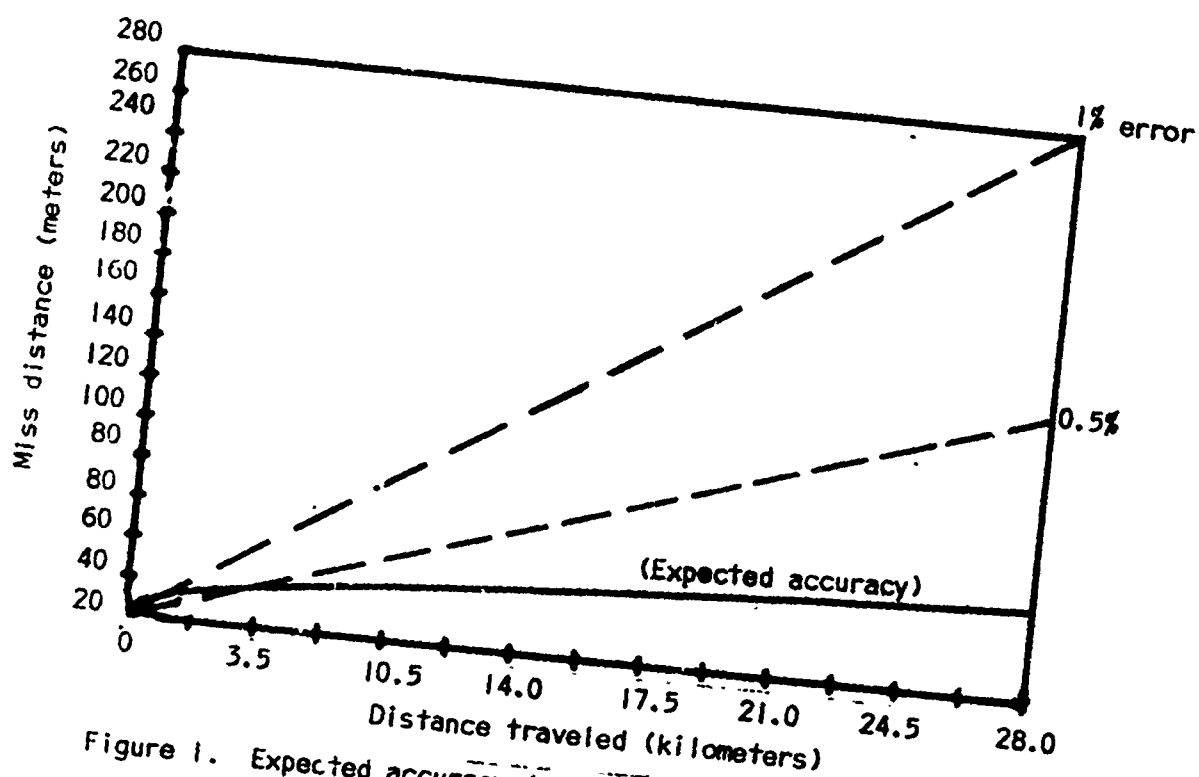


Figure 1. Expected accuracy (miss distance and percent error for distance traveled) for the AGA vehicle land navigation system.

reflected coordinate readouts taken at the same data point were within +50 to 100 meters of each other.

(h) Considering *all* runs conducted by the LWL/WHS system, the expected accuracy of the system ranges from 50 meters after 2 kilometers of travel to 500 meters after 28 kilometers of travel. The engineer test model's expected percent error after 28 kilometers is 1.75 percent error for distance traveled (fig 2).

c. Phase II: (Subtest IV consisted of simulated tactical operations.)

(1) Operators' comments and observations by test control personnel reflected that the navigation systems did not serve as an aid to navigation until each operator developed confidence in the system. By continued practical application, the operators were assured the system could provide relatively accurate position fixing (8-digit UTM coordinates) and navigation information (direction of travel).

(2) Similar observations indicated that, once the operators had gained confidence in the systems and learned to use them in conjunction with a topographic map, they were able to negotiate the courses and complete their missions better than with the aid of a map and compass only.

(3) Although navigation system operators did at times become disoriented when traversing cross-country, they could plot their locations on the map from the system readout. Additionally, they could obtain a relatively accurate position, determine the course required to get back to their checkpoint, and use the system to insure that they were traveling in the proper direction. These functions could be performed even with limited visibility, in dense undergrowth, restricted line-of-sight, or in the absence of prominent geographic features that could be used for navigational purposes.

(4) In comparison, operators with map and compass only (in similar circumstances as in (3) above) found themselves traveling in circles, retracing their previous course, or traveling many kilometers off course before being able to definitely locate themselves and return to the prescribed course.

(5) Operators using the AGA, ANS-150K as a navigation aid produced the best results during this phase of testing. They were consistently closer on reported position locations, aggressor locations, and more effective in performing their mission than those operators using other navigation aids. Operators using the VCS-500, onboard compass, were second best in these areas, and the map and lensatic compass and LWL/WHS system produced the least results. The results obtained from the LWL/WHS system produced greater errors due to the problems with compensation and calibration.

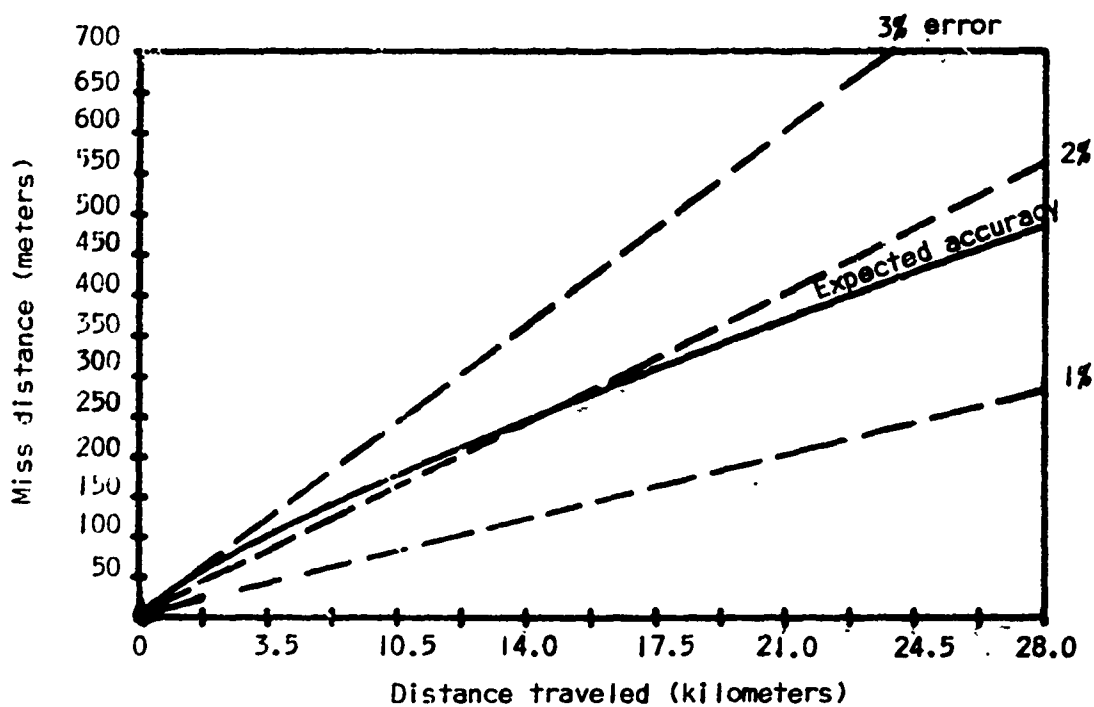


Figure 2. Expected accuracy (miss distance and percent error for distance traveled) for the LWL WHS vehicle land navigation system.

(6) During this phase of testing, the ANS-150K operator was never more than 500 meters in error during the day or 1,000 meters in error at night. Operators using the map and lensatic compass reported 6 percent of their locations or aggressor locations with an error of 1,000 meters or more during the day and 10 percent at night. Additionally, the VCS-500, onboard compass, never was in error more than 1,000 meters during day or night operations.

(7) All the operators stated that they were able to devote more time to the performance of their mission with the aid of a navigation system and have the confidence that they could obtain a position fix in less time, with better accuracy, than when conducting comparative runs with the map and lensatic or onboard compass only. When using the map and lensatic or onboard compass only, they had to devote their full attention to navigation in order to assure themselves that they could provide an accurate position fix or aggressor location when required. This distracted from the performance of their mission.

8. Human Factors. The primary human factors faults found with the ANS-150K and LWL/WHS system were as follows:

(1) ANS-150K.

(a) The inner card dial for 0.1° readout on the compass readout display confused the operators.

(b) The lack of the letters N, E, S, and W at the appropriate degrees on the compass card dial made it more difficult for the operator to rapidly orient himself with his map or relate direction to the terrain.

(c) The initial (start) coordinates are set on the system by the operator with a two-speed, manually operated toggle switch. The slow speed position was still too fast to enable the operator to set the coordinates without overshooting the desired setting.

(d) The operators had difficulty observing the readout device in the M151A2. The face of the readout device was horizontal rather than mounted at an angle facing toward the operator.

(2) LWL/WHS system:

(a) Calibration controls for distance adjustment would be more convenient if placed on the handset.

(b) A bracket could be devised for the handset so that it could be affixed to the vehicle when not in use.

(3) General operator comments included the suggestion that a course to steer indicator on the compass readout dial of any navigation system considered by the Army would enhance cross-country navigation. (This was provided on the LWL/WHS system.)

9. Logistics.

a. The AGA, ANS-150K and LWL/WHS systems developed no maintenance problems that could not be repaired in the field with common electronic repair tools.

b. The common problems associated with the ANS-150K were electrical cable connectors working loose and waterproof seals leaking and allowing moisture into the electronics of the system.

c. The LWL/WHS system experienced continual problems with the hard wired breadboard modules. This resulted in problems with maintaining calibration and compensation adjustments.

d. Both systems are designed to be based on printed circuit cards that could be (and were) tested and replaced in the field with repair of the card conducted at higher level maintenance facilities.

e. Percentage of downtime (hands-on maintenance time) for the systems tested was as follows:

(1) ANS-150K - 3.1 percent.

(2) LWL/WHS - 12 percent.

10. Conclusions.

a. Self-contained passive vehicle navigation systems, as represented by the LNS-500 series (MASSTER Test Report FM 194, dated 15 Jan 74), and the ANS-150K are effective navigation aids in that they significantly reduce the time required for navigation and greatly improve the user's navigation and position fixing capabilities when compared to the use of the lensatic compass in conjunction with a topographic map alone.

b. The ANS-150K is a viable candidate to aid in fulfilling Army requirements for self-contained vehicle navigation systems as specified in the PANS-MN.

c. Although the engineer test model of the LWL/WHS navigation system provided for this test did not meet the accuracy requirements stated in the PANS-MN, it did demonstrate potential as a candidate to aid in fulfilling Army requirements for a navigation system to be mounted in the M113A1 and M151A2 or similar type vehicle.

d. There is no noticeable effect on the accuracy of the ANS-150K navigation system when subjected to RFI or EW electromagnetic or magnetic environment.

e. The LWL/WHS system accuracy is affected by close proximity electromagnetic environment. Testing conducted as to the affect on accuracy in a magnetic environment was not conclusive.

f. Forty hours of classroom and field training are adequate for basic training on the navigation systems; however, approximately 60 additional hours of field use are required to develop operator confidence and skills which will enable him to take full advantage of the system's navigation and position fixing capabilities.

g. Based on the subjective evaluations by the test officer and test control personnel, it appears that self-contained navigation systems could be repaired (component and printed circuit card replacement) in the field by signal maintenance units.

h. The LWL/WHS navigation system could not be evaluated as to reliability in that a production system was not available for test purposes; however, such a system, when in final configuration, could be maintained within battalion and higher signal equipment repair channels with a minimum of additional training of TOE signal equipment repair personnel.

i. The VCS-500, onboard compass provides a convenience to the vehicle commander in that he does not have to stop periodically and dismount from his vehicle to obtain a heading reference as is required with the lensatic compass. The use of the onboard compass also aids the vehicle commander to reduce time and improve his efficiency when navigating cross country, determining his location, and providing a position fix on aggressor locations. However, to produce these results, the operator is required to devote his full time referring to his map, which distracts from the accomplishment of his primary mission. In comparison (with the aid of a navigation system), he only needs to make occasional reference to his map in conjunction with the navigation system readout to determine his current position.

II. Recommendations.

a. That self-contained vehicle land navigation systems be included in the Army inventory to fulfill the Army's requirements for such systems as defined in the PANS-MN document.

b. That two types of self-contained vehicle land navigation systems be considered for adoption:

(1) A system designed for use in heavily armored or highly magnetized vehicles (i.e., tanks, self-propelled artillery, and reconnaissance scout vehicles), that utilize a single gyro for northing and heading reference.

(2) A magnetic system for soft or lightly armored or nonmagnetic vehicles that utilize only a flux-valve compass (or equivalent) for heading reference input.

c. That the gyro and magnetic systems be composed of interchangeable components.

d. That an onboard compass (equal to those tested; i.e., Sperry-Rand Remote Magnetic Heading Reference System, and Aviation Electric Limited, VCS-500) be considered as a candidate for use on soft or lightly armored vehicles, and that the PANS-MN should be reviewed and updated to include a requirement for an onboard compass.

SELF-CONTAINED VEHICLE LAND NAVIGATION SYSTEMS (V-NAV) TEST II REPORT
(Test Number FM 237)

CHAPTER I

GENERAL

1-1. Purpose. To evaluate the military potential of existing self-contained land navigation systems (four candidate systems) and to provide data to aid in determination of compliancy with the requirements documents.

1-2. Objectives.

a. Objective 1 - To compare the operational and performance characteristics of the test systems.

b. Objective 2 - To provide data on operator and maintenance personnel training requirements to properly operate and maintain the systems.

c. Objective 3 - To provide data on the logistical support and human factors implications associated with the systems.

d. Objective 4 - To document any observed instance of incompatibility of the systems in the electromagnetic environment.

1-3. Background.

a. Authority. The Self-Contained Land Navigation Systems Test was authorized by letter, DAFD, subject: Department of the Army Five Year Test Program (FY 1974-1978), 25 July 1973.

b. History.

(1) The Positioning and Navigation System - Materiel Need (PANS-MN) document was developed to define the total Army requirements for navigation systems for air and ground forces, both active and passive type systems. The document states the projected requirements, description of desired systems and accuracies, and concepts of employment. The Project Manager, Navigation Control (PM, NAVCON) is responsible for management of all existing and planned tasks being conducted to meet the ground, marine, and airborne requirements of the Army for position locating and navigation.

(2) The state-of-the-art of self-contained, passive vehicle land navigation systems has been developed to the extent required to feasibly support military operations. Several foreign armies have already incorporated these systems into their inventory. To determine their potential for

US Army use, MASSTER is evaluating systems selected by FM, NAVCON and authorized for testing by the Test Schedule and Review Committee (TSARC).

(3) Aviation Electric, Limited (AEL) of Canada developed mechanical navigation systems (called the MAN/GAN systems) which were tested by the US Army at Fort Carson, Colorado, in the late sixties. The MAN was a magnetic system and the GAN a full gyro system. The deficiencies noted in these tests led to the development of the solid state LNS-500 series, which contains the LNS-516 (full gyro system), LNS-517 (flux-valve compass slaved to a directional gyro), and LNS-518 (full magnetic system). These systems are improved, less expensive, and of reduced weight and size as compared to the original MAN/GAN's. The LNS-500 series was one of the family of systems that was selected by FM, NAVCON and tested by MASSTER during test FM 194, from July to September 1973. Testing by the Canadian Army included a 1 year evaluation followed by an additional 6 months of laboratory testing. The Canadian Armed Forces has purchased six of the LNS-517s for field trials (user evaluation) currently being conducted at Petawawa, Canada by the Canadian 8th Hussars (Armored Recon).

(4) US Army Land Warfare Laboratory (USALWL), in conjunction with Westinghouse, developed a compact, inexpensive magnetic vehicle navigation system for use on lightly armored vehicles (wheeled or tracked) and the wheeled vehicles used in the tactical unit (e.g., 1/4-ton truck). This system is based on the same engineering principles of the AN/PSN-7 Man-Pack Land Navigation System previously tested at MASSTER (Test 118). Two devices were received for this test, each being engineer test models containing approximately 50 percent breadboard modules (hard wired rather than printed circuits). The system was submitted by USALWL for concept testing.

(5) Acetylene Gas Accumulator (AGA) Corporation of Sweden provided an ANS-150K, full-gyro, land navigation system for testing. This system was a modified version of the ANS-100 Navigation System, manufactured by AGA, and currently used in the Swedish Army. The ANS-100 does not have a self-alignment feature (onboard north-seeking capability) and therefore requires optical alignment of the vehicle in order to place the proper heading reference in the system prior to operation. The ANS-150K contains a Singer-Kearfott gyro which is capable of providing a northing reference to give the system its initial alignment; it acts as a heading reference (directional gyro) once the system is placed in "navigate." The unique feature of this system is that one gyro performs the functions of two gyros on similar type systems. The system received for testing was a modified ANS-100 and not of production quality.

(6) Although PM, NAVCON envisioned that Sperry-Gyro of the United Kingdom and AMBAC of France would also have systems represented in this test, they did not respond to the invitation to bid. This test was conducted because of the lack of response to MASTER Test FM 194 which was conducted from July to September 1973 (only AEL participated with the LNS-516, -517, and -518). Therefore, to comply with objective 1, both test reports must be considered to properly compare the various systems tested.

(7) Also evaluated during this test was the VCS-500, onboard magnetic compass, manufactured by AEL. This compass was developed for use on wheeled or tracked vehicles (lightly armored). By adding components such as a distance input, computer, and readout device, the compass can become the heading reference unit for a magnetic navigation system. The compass was obtained by an unsolicited proposal from AEL. It was used during this test as a comparative device with the standard lensatic compass for use when navigating in wheeled or tracked vehicles.

c. General description.

(1) AGA, ANS-150K. The basic system is comprised of an AGA navigator (readout device)/computer (ANS-100) separate pulse (distance) generator, a north seeking gyro/directional and a power supply unit (fig 1-1). The navigation system presents the vehicle's position to the nearest 10 meters in the form of map references (8-digit UTM coordinates) on two 4-digit counters - one for north-south travel and one for east-west travel. Each counter is initially set or adjusted to the desired figure (start coordinates) by means of springloaded toggle switches. These are operated by a two-hand operation to avoid unintentional changing. The navigator also presents the heading on a servodriven indicator with separate coarse and fine scales that can be graduated with any desired system: 360°, 6,400 mils, etc. A mode selector and controls for latitude correction are grouped on the navigator panel, together with trimming controls for gyro drift and distance correction. The controls are accessible through a covered opening. The system also contains the circuitry required for computing the position, using the information received from the pulse generator (distance) and the gyro (heading). The calculations are made electronically without any mechanical components. Integrated circuits are used to a large extent. The illumination of the position counters, the heading indicator, etc., can be controlled by a separate knob.

(2) LWL/WHS. The LWL/WHS Navigation System is fully magnetic (no gyros for northing; alignment or heading reference), utilizing a horizontally compensated flux-valve compass (fig 1-2).

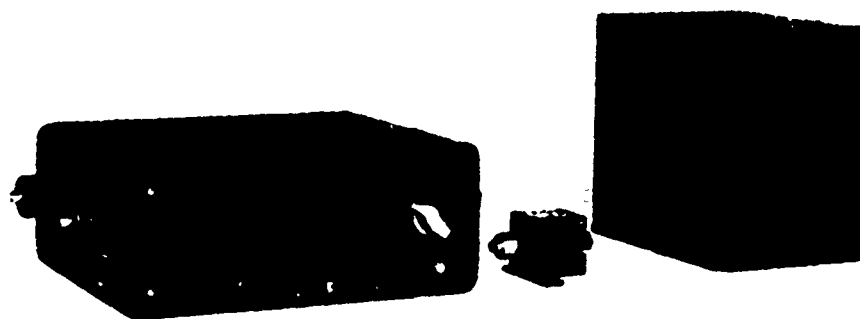


Figure 1-1. ACA, ANS-150K Self-Contained Vehicle Land Navigation System.

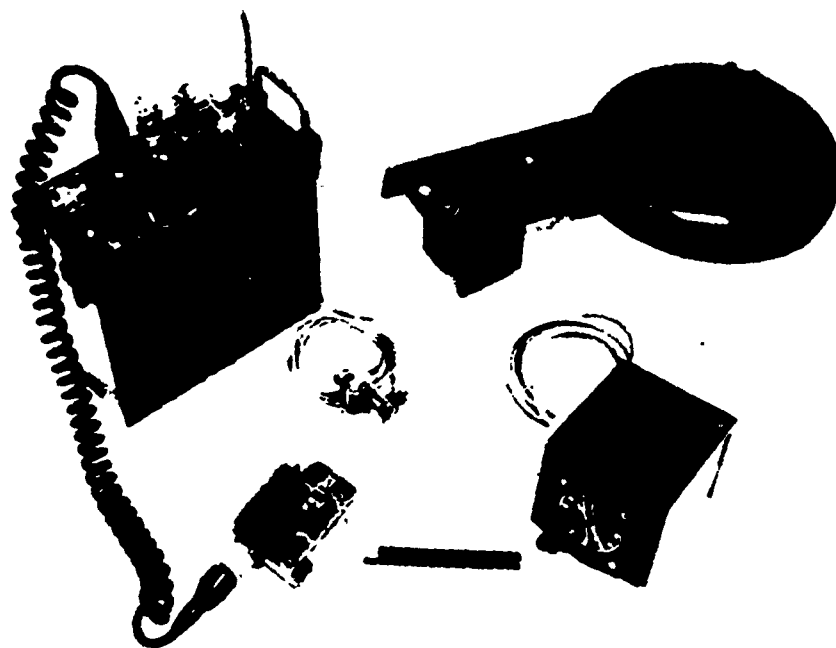


Figure 1-2. LWL/WH5 Self-Contained Vehicle Magnetic Land Navigation System.

(a) The system is comprised of five components:

1. The flux-valve compass. (A pendulously-mounted, flux-valve detector, responsive to the local direction of the earth's magnetic field whose reading is expressed as an electrical signal which can be processed and used by the associated navigation processor (computer).) A compensating coil is incorporated into the unit which renders the flux-valve insensitive to the horizontal magnetic field of the carrier vehicle.
2. Distance pulse generator. (This generator senses the distance the vehicle travels by electronically measuring the revolutions per minute of the vehicle's transmission.)
3. Heading repeater (display) unit. (This unit provides a compass type readout of the vehicle's direction of travel.)
4. Processor. (A computer which converts distance traveled and heading to 8-digit UTM coordinates.)
5. Handset (readout device). (This device gives a digital readout of 8-digit UTM coordinates.)

(b) The distance pulse generator senses the vehicle's distance traveled from the rpm of the vehicle transmission while the direction of travel is determined by the flux-valve compass. These two data elements are transmitted electronically to the processor where the northing and easting coordinates are determined. The coordinates are then transmitted to the handset and displayed as 8-digit UTM coordinates. Also included on the handset are those controls necessary to set start coordinates, turn the system on, and calibrate the distance input. The handset may be handheld, fastened to the operator's web gear, or affixed to the vehicle. It is connected to the processor by a 6-foot spiral cable. A heading repeater (display) unit may be mounted as optional equipment in the driver's compartment of a vehicle to provide him with a continuous display of the vehicle's direction of travel. This device also provides a means to set a desired "course to steer" to aid the driver in keeping the vehicle traveling a desired direction when proceeding cross country. The only portions of the system that must be firmly affixed to the vehicle are the flux-valve compass and distance pulse generator. All other components may be strapped down to the vehicle by temporary restraints.

(3) VCS-500. In addition to the AGA and LWL/WHS systems tested, an Aviation Electric, Limited, onboard magnetic compass, VCS-500, was also evaluated (fig 1-3) as a comparative device with the lensatic compass. This device is completely self-contained, solid state, designed to provide a continuous vehicle heading reference in all classes of

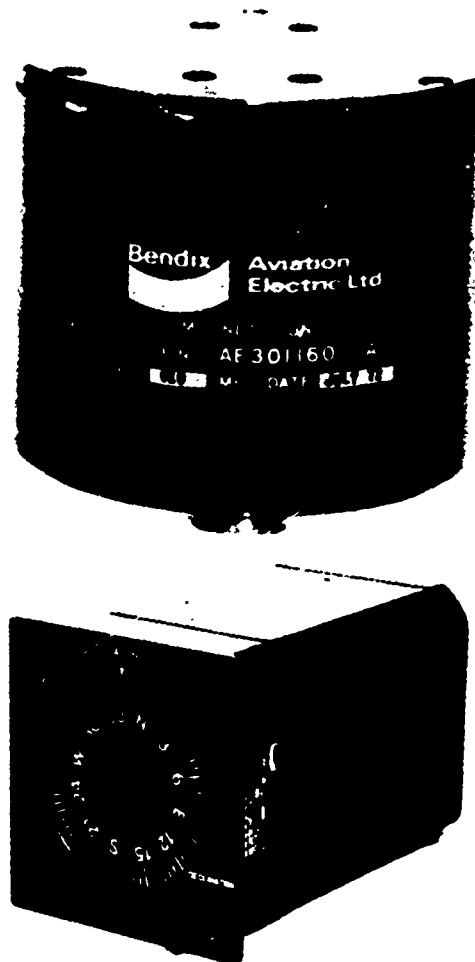


Figure 1-3. VCS-500, Aviation Electric, Limited, onboard compass.

military vehicles. The system is composed of two components: a heading reference indicator (compass display), mounted near the vehicle commander or driver, and a flux-valve compass. The compass display provides a declination control which enables the main dial to be set to read heading either in terms of magnetic north or grid north. The system can be applied to practically all types of military vehicles with the provision that those equipped with large turreted weapons may require the guns to be placed in the same position (vertically and horizontally) as when the system was compensated to insure accurate heading readings. The VCS-500 was obtained by an unsolicited proposal from AEL.

d. Technical characteristics.

(1) AGA, ANS-150K

Overall system accuracy	- 0.5 percent of distance traveled + 10 meters or better
Gyro drift rate	- 0.25°/hour
Computer accuracy	- 0.2 percent
Resolution: Position	- 5 meters
Heading	- 1 mil
Temperature range with full performance	- -40° to +50° C
Vibration	- Designed to withstand any vibration that may arise in vehicle operation
Power supply	- 11-35 volts direct current
Power consumption	- 55 watts direct current (85 watts first 60 seconds)

Size and weight.

Navigator	- 10x8x4 in	10.1 lb
Pulse generator	- 3x1.5x1.5 in	0.7 lb
Gyro compass	- 10 1.25x9x10 in	10.0 lb
Power supply unit	- 8x10x4.5 in	15.5 lb

(2) LWL/WHS Magnetic Vehicle Land Navigator.

Calibration	- Self-contained, semiautomatic
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Size and weight.

Processor	- 12x10x6 in	15.0 lb
Readout	- 3x4x1.3 in	2.0 lb
Compass housing	- 3x5x4x1.3 in	2.5 lb
Heading indicator	- 4x5x7 in	14.5 lb

Power requirements.

Consumption

Type

Battery life

Accuracy

Readout

- 3 watts nominal
- Gel/cel rechargeable batteries
- 8 hours continuous (16-hour recharge time)
- 2.5 percent of distance traveled
- Right and up, 8-digit UTM coordinates, 10 meters resolution

(3) VCS-500, FEL.

Dial diameter

Dial calibration

Calibration interval

Accuracy

North reference

Declination control

Power ON control

Lighting

Lighting control

Size

Weight

Power (direct current)

- 3 inches
- degrees or mils
- every 5° or every 80 mils
- +2° or +36 mils
- Magnetic north or grid north selectable by operator
- 0-30° (0-533 mils) east or west
- External (vehicle switch)
- Red lighting standard, white optional
- External (vehicle light switch)
- 4.25x4.25x7 in deep
- 5 lb
- 12 watts @24 volts direct current nominal

c. Concept of employment. The vehicle land navigators are designed as an aid to conventional navigation methods. These systems will provide a vehicle commander or driver with continuous realtime positioning information to facilitate accurate navigation and to provide more accurate positioning information than is currently available using only a map and compass. They are designed to provide this capability during all weather conditions, in all types of terrain, in conditions of near-zero visibility, and in unfamiliar or unmapped terrain. The information obtained from this device could greatly increase the unit commander's capabilities in the areas of command and control, reconnaissance, medical evacuation, determining friendly unit locations, target acquisition, intelligence reporting, and more accurate and improved fire support. The device is applicable to all combat units, as well as combat support units whose mission requires navigation and position fixing using a topographic map.

1-4. Concept of Test.

a. Test design. Testing was conducted over various types of terrain to determine the military potential of the vehicle land navigators. The systems were tested in vehicles recommended by the manufacturer which included the M113A1 armored personnel carrier and M151A2,

1/4-ton truck (jeep). Though not tested during this test, the ANS-150K is designed to operate in armored vehicles (i.e., M60A1 or M60A2 tank).

(1) The test was conducted in three phases:

(a) Phase I - Inventory, Installation, and Training (pretest activities and subtest I).

(b) Phase II - Performance Characteristics.

1. Subtest II - Calibration, Electromagnetic, and Magnetic Environment.

2. Subtest III - System Accuracy.

(c) Phase III - Tactical Operations, Subtest IV - Tactical Applications.

(2) Phases I and II were conducted at Fort Hood, Texas, while phase III was conducted in Sam Houston National Forest near Huntsville, Texas. Two operators were trained for each system tested (AGA, LWL, and the VCS-500) and alternately operated the system throughout the test. This provided additional data concerning the man and machine interface of the various systems. Comparative data were obtained by the operators conducting selected portions of the test using only maps and lensatic handheld compasses. A total of 7 weeks was required for the test: 1 week of training, 3 weeks for phase II, and 3 weeks for phase III. The total number of iterations conducted during each subtest is depicted in figure 1-4.

b. Environmental conditions. During the field testing at Fort Hood, there were no environmental conditions that hampered the speed or conduct of testing. Although occasional showers were experienced at Sam Houston National Forest, the conditions did not affect the testing or its schedule. All planned testing was completed.

(i) Fort Hood.

(a) The weather was sunny and clear with temperatures ranging from 68° to 96° and humidity readings of 26 to 99 percent. Only a slight trace of rain was experienced during this phase of testing.

(b) The terrain varied from flat to slopes of 25° with light to heavy vegetation. Figure 1-5 shows the various courses used for subtests II and III and the terrain that was traversed.

	ANS-150K	LWL/WHS	M/VCS-500	Map/Compass
Subtest II				
Calibration and calibration verification	127	162	-	-
Electromagnetic	18	28	-	-
Magnetic	12	26	-	-
SUBTOTAL	157	216		
Subtest III				
Closed level	23	8	-	11
Closed rough	16	10	-	2
Open level	16	6	-	-
Open rough	16	11	-	12
SUBTOTAL	71	35		15
Subtest IV				
Day	14	21	14	28
Night	10	18	10	20
SUBTOTAL	24	39	24	48
TOTAL	252	290	24	63

Figure 1-4. Total number of runs conducted during test period.

(2) Sam Houston National Forest.

(a) Light showers were experienced over scattered areas of the test courses; however, the weather was mostly sunny and clear. Temperatures ranged from 67° to 94°, and the humidity ranged from 35 to 97 percent.

(b) The terrain was gently rolling, with a few slopes in excess of 30°. Vegetation consisted of double canopy with dense undergrowth approximately 4 to 8 feet tall. Road conditions varied from hard surface to improved dirt roads, logging trails, and abandoned trails.

CHAPTER 2

DETAILS OF TEST

Section 1. SUBTEST 1 - INSPECTION AND INVENTORY

2-1. Purpose. To determine if the vehicle land navigation systems received for test purposes were complete, operational, and free of defects and damage.

2-2. Methodology. Upon arrival of the systems at MASSTER, a complete inventory was conducted by a representative of Deputy Chief of Staff, Logistics in the presence of the manufacturer's representative and the test officer's representative. Upon completion of the inventory, the systems were mounted in the test vehicles by the manufacturer's representative and made operational.

a. Compensation (magnetic systems only). This adjustment corrects the effects of the magnetic signature of the vehicle to prevent interference with the operation of the northing reference magnetic sensor. This requires a special compensation instrument. This instrument is not considered a component of each individual system, but would be found at the level of maintenance designated to install the system. Once the system is compensated, no further consideration need be given to compensation unless the system is removed and installed on another vehicle or the northing reference magnetic sensor is replaced. The current method of compensation requires a compass rose (or device to determine the true heading of the vehicle at time of compensation adjustments) and some algebraic computations for the settings on some systems. Compensation of the various systems ranged from 15 to 60 minutes.

b. Calibration. This adjustment consists of two settings; one for distance and one for heading. These two input adjustments are required on all UTM coordinate readout type navigation systems.

(1) The heading adjustment is required to align the northing sensor with the vehicle's actual direction of travel. This adjustment refines the heading input to an accurate heading reference within the limits of the system.

(2) The distance input is adjusted for the specific vehicle transmission on which the system is mounted. This takes into account the variables that could cause the same system to measure slightly different from one vehicle to another (e.g., variance in wear on transmissions, tire or track wear, or any other variance that could cause a variation in rpm of the transmission at a fixed speed).

(3) Once the systems are compensated and calibrated, the only operational adjustment required is to "update" or "realign" the gyro periodically to compensate for gyro drift. The operator may also correct the system when errors are developed in the UTM readout by resetting the 8-digit coordinates at known geographical features he can identify on his map. Realignment of the Singer-Kearfott gyro, a component of the ANS-150K, requires approximately 15 minutes. If the true heading of the vehicle is known, this can be manually set and the alignment time reduced to 90 seconds.

2-3. Results (Findings).

a. All material items which comprised the ANS-150K, LWL/WHS, and VCS-500 were received without damage. The basic systems were mounted in the test vehicles (M113A1), compensated, calibrated, underwent a pre-operational and operational check, and were declared ready for testing by the manufacturer's representatives (technical representatives).

b. The ANS-150K and LWL/WHS system were not production models. The ANS-150K was a modified version of the Swedish ANS-100. This modification was comprised of the replacement of the ANS-100 directional gyro being replaced by a Singer-Kearfott north-seeking/directional gyro. The interface for this new gyro required additional electronic circuitry which was contained in an additional package (ACE Box) not planned to be part of the final production model. The LWL/WHS system was an engineer test model developed from the man-pack AN/PSN-5 (predecessor of the AN/PSN-7) and adapted for vehicle use. This system contained several "hard wired" breadboard modules. These modules would be printed circuits in the production model.

2-4. Analysis of Results (Findings).

a. All systems received were fully operational and ready to begin subtest II.

b. The ANS-150K and LWL/WHS systems would require further engineering and modification prior to introduction in the field on a production level.

Section II. SUBTEST II - CALIBRATION, ELECTROMAGNETIC, AND MAGNETIC ENVIRONMENT

2-5. Purpose. To calibrate the equipment for testing and determine the effect of the electromagnetic and magnetic environment on the systems.

2-6. Methodology. The subtest was conducted in four phases over two courses.

a. Phase A - calibration. A 3,000 meter, surveyed, straight-line course was traversed by each of the systems to be tested. During the first 3,000-meter run, the system was calibrated for distance and heading. Once the calibration was set, the vehicle returned to the start point to verify the calibration setting. These procedures were performed a minimum of three times by each system (i.e., navigation system/vehicle configuration) to be tested. A compass rose was also provided for flux-valve compass alignment and verification of alignment.

b. Phase B - verification of calibration. Each system again traversed the calibration course without making additional calibration adjustments to verify the previously determined calibration setting. The coordinate readout was reset at each end of the 3,000-meter course to the actual UTM coordinates. Each system traversed the course a minimum of three times. The readout was recorded by the data collector at the end of each 3,000-meter leg prior to resetting the system to the surveyed coordinates.

c. Phase C - electromagnetic environment. A 1,000-meter, straight and level primary course was established on a magnetic north/south alignment with three parallel courses at 5, 10, and 15 meters from the primary course. One run on this course consisted of two 1,000-meter legs. The operator reset the coordinate readout to the surveyed coordinate at the end of each 1,000-meter iteration. Prior to resetting the coordinate readout, the data collector recorded the system readout. During each iteration the vehicle proceeded 1,000 meters to the checkpoint, the coordinate readout was recorded, readout was reset to the actual surveyed coordinates as directed by test control headquarters, and the vehicle returned to the start point where the readout was again recorded by the data collector.

(1) The first runs were used to determine baseline data that reflected the inherent inaccuracies of the systems. Each system conducted a minimum of three runs for baseline data.

(2) Upon completion of the baseline data runs, the vehicle then made a series of runs with their onboard radios transmitting continuously to determine the effect of the electromagnetic environment on the system's accuracy and operational characteristics.

(3) The next series of runs was conducted with an M60A2 tank operating hub-to-hub with the test vehicle as it proceeded along the 1,000-meter course with its radio continuously transmitting.

(4) Subsequent runs were conducted as described in (3) above with the tank operating 5, 10, and 15 meters from the test vehicle or until no further affect was rated.

(5) All runs were conducted with the systems mounted in the M113A1, armored personnel carrier and then the M151A2, 1/4-ton truck (jeep).

(6) The Electronic Warfare Division, Combat Support Directorate, MASSTER, with assistance of an Air Force electronic warfare (EW) team, conducted SIGINT tests on the AGA, ANS-150K. Based on their results, an ASA team then conducted further testing to determine the possible use and effect of electronic countermeasures on self-contained land navigation systems. The results of these tests are included in a separate classified report prepared by the Air Force and has received the same distribution as this test report. A copy is on file with the Special Programs Division, Combat Service Support and Special Programs Directorate, MASSTER.

d. Phase D - magnetic environment. This phase was conducted on the same course as phase C using the same test procedures as described above.

(1) An external magnetic effect was tested by operating the M60A2 tank adjacent to the test vehicle at varying distances similar to the procedures described in c(3) and (4) above.

(2) Internal magnetic load effects were tested by placing linked ammunition, smoke grenades, and weapons inside the M113A1 and M151A2 with LWL/WHS and ANS-150K. Procedures for testing were as described in c(3) and (4) above.

(3) The M151A2 system configuration was tested for magnetic effects, as above, by loading a trailer with a 1,427-pound metallic cargo composed of linked ammunition and smoke grenades and towed behind the test vehicle. Additional runs with the ANS-150K were also conducted on a closed loop level course approximately 25 kilometers in length.

The LWL/WHS system was tested by placing a 1,000-pound load of grenades and ammunition in the back of the M151A2 test vehicle.

2-7. Results (Findings).

a. During phases A and B, calibration and verification of calibration, the system operators experienced difficulties in accomplishing the required functions on both the ANS-150K and the LWL/WHS systems.

(1) AGA, ANS-150K. Although the adjustments for heading and distance were located on the readout device, actual use of these for calibration purposes was difficult for the operator. The markings on the dials were not representative of any particular adjustment nor were they linear (i.e., one mark on the dial may represent a 1-meter adjustment at 1 kilometer of travel but may be only 1.5 meters at 2 kilometers of travel). Therefore, adjustment became a hit-or-miss proposition which required several runs on a trial-and-error basis to complete any calibration adjustment.

(2) LWL/WHS. The engineering test model provided for this test did not have provisions for operator adjustment. To properly calibrate the system, special test equipment had to be attached. Adjustments were then made by adjustment of voltage levels. All calibration was accomplished by the Westinghouse technical representative. After the calibration was set, many problems were experienced in maintaining the setting. The calibration settings would change from one day to the next or from morning to afternoon.

b. The LWL/WHS system was inoperative during most of this phase of testing. Many problems were encountered with the hard wired, breadboard modules because of the vibration of the test vehicle. Due to the extensive downtime, some phases of electromagnetic testing did not reach the density of iterations planned, and some of the data were inconclusive.

c. The verification of calibration, magnetic and electromagnetic test results of this subtest are portrayed graphically in appendix A.

2-8. Analysis of Results (Findings).

a. Verification of calibration.

(1) The AGA, ANS-150K was mounted in the M113A1 and M151A2. Figure B-1 depicts the plots of the readouts at the end of the 3,000-meter course in relation to the surveyed coordinates (center of circle). There were 107 data points recorded of which 95.1 percent were within 30 meters of the actual coordinates (representing a 1.0 percent error, or less, for distance traveled), and the remaining 4.9 percent were within 30 to 60 meters of the actual coordinates (representing a 1.0 percent to 2.0 percent error for distance traveled).

(2) The LWL/WHS system was also mounted in the M113A1 and M151A2. Figure B-2 depicts the plots of the readouts at the end of the 3,000-meter course in relation to the surveyed (actual) coordinates (center of circles). Although the system performance during this phase of testing was extremely inaccurate, it did reflect a repeatable pattern. Each readout for the same calibration setting (denoted by the date of the run) and for a specific direction of travel (east or west), generally fell within a 30-meter circle.

b. Electromagnetic environment.

(1) Figure B-3 depicts the baseline data of the AGA, ANS-150K on the 1,000-meter course for runs traveling north and south. All baseline plots were from 0 to 40 meters from the surveyed coordinates (represented by the center of the circle). When the test vehicle traversed the

course with its onboard radios operating, the miss distance of the system was 0 to 10 meters (fig B-4). During runs conducted with the M60A2 tank (traveling adjacent to (hub-to-hub) and parallel to the test vehicle with the system and radios transmitting continuously on the M60A2), the miss distances were from 0 to 40 meters (fig B-5). Figure B-6 reflects that the miss distances were 0 to 10 meters when the M60A2 tank had its radios continuously transmitting and was traveling 5 meters from the test vehicle.

(2) Figures B-7 and B-8 depict the baseline data runs for the LWL/WHS system when traveling north and south, respectively, on the 1,000-meter course. With the exception of two runs in each direction, miss distances for the baseline data were from 0 to 45 meters. Figure B-9 represents the results of testing with the onboard radios of the test vehicle continuously transmitting during the 1,000-meter run. The angle of heading deflection from north/south represented by this chart is equal to the angle formed by the vehicle antenna and the compass in relation to the center line axis of the vehicle. Results reflect that the transmitting radio "trapped" the compass and produced a false northing reference. When figure B-10 (M60A2 tank, with radios transmitting continuously, traveling hub-to-hub with the test vehicle) was compared to figure B-9, it could not be determined if these effects were from the transmitting radios or the magnetic effects of the M60A2 tank. Figures B-11 through B-13 depict the results of the M60A2 tank traveling 5, 10, and 15 meters from the test vehicle with radios continuously transmitting. In all three cases, the miss distances were now 0 to 45 meters from the surveyed coordinates and comparable to those of the baseline data.

c. Magnetic environment.

(1) All runs conducted with the AGA, ANS-150K system showed a consistent variation in miss distances of 0 to 20 meters. Additional runs were conducted with the M151A2 towing a trailer loaded with 1,427 pounds of metallic cargo to include smoke grenades and caliber 0.50 ball ammunition, linked. These runs were conducted on a 22 kilometer, closed loop level course. Figure B-14 shows that the system operated within 1.25 percent error for distance traveled for the first 6 to 8 kilometers, 0.5 to 1.0 percent error up to 10 kilometers of travel for two runs, and 17 kilometers for the third run; and less than 0.5 percent error for distance traveled at 10 to 22 kilometers of travel on two runs and 17 to 22 kilometers on the third. The finish readout for all three runs was approximately 0.25 percent error for distance traveled.

(2) Figure B-15 shows the various runs for the LWL/WHS system during this phase of testing. A and A' reflect the baseline data as compared to the other symbols depicting the various test situations and magnetic environment introduced. These data do not compare with the

results of the electromagnetic environment where the M60A2 tank was also used at the same distances and reflected no effect at 5 to 15 meters. During this segment of testing, there were continual problems with the compass compensation and calibration of the system.

Section III. SUBTEST III - SYSTEM ACCURACY

2-9. Purpose. To determine the accuracy and repeatability of each vehicle land navigation system operating under controlled conditions.

2-10. Methodology. The subtest was conducted in two phases.

a. Phase A - closed loop accuracy course. This phase consisted of one closed loop course over level terrain and one over rough terrain, with several intermediate changes of direction. The systems were not updated to correct the error during any of the runs of this subtest. The closed loop courses were 21.4 kilometers (level) and 19.4 kilometers (rough) in length and had seven and six surveyed data points, respectively, which were marked by red stakes. The data collector radioed test headquarters at each red stake encountered throughout the course and transmitted the 8-digit coordinates displayed on the land navigation system readout device. This information was recorded on the data form provided. All land navigation systems tested ran the same course starting at 15-minute intervals.

b. Phase B - open end accuracy course. This phase consisted of one open end course over level terrain and one over rough terrain, with several changes of direction. All runs were conducted the same as in phase A of this subtest. The length of the open end courses was 27 kilometers (level) and 23.2 kilometers (rough). There were nine data points on the level course and six data points on the rough course.

c. Position fixing of data points with map and compass. Additionally, operators traversed the accuracy courses using a standard 1:50,000 topographic map and lensatic compass to make their determination of their 8-digit UTM coordinates of the data points being reported by the navigation systems tested. These data points were the same surveyed points marked by red stakes described in 2-10a and 2-10b above.

2-11. Results (Findings). The results of all phases of this subtest are depicted graphically in appendix C of this report. Figure 2-1 reflects the total number of runs and data points sampled for each system/vehicle configuration while traversing the accuracy courses. (For comparative purposes, appendix D (fig D-1 through D-9) depicts the accuracy results of the Aviation Electric, Limited, LNS-500 series, navigation systems.)

Course	Runs	M113	M151	Data points	Total possible	Total collected
AGA, ANS-150K navigation system						
Open level	16	71	72	9	144	143
Open rough	16	48	48	6	96	96
Closed level	23	76	69	7	161	155
Closed rough	16	46	46	6	96	93
I.WL/WHS navigation system						
Open level	6	30	18	9	54	48
Open rough	11	42	24	6	66	64
Closed level	8	21	35	7	56	56
Closed rough	10	47	11	6	60	58

Figure 2-1. Number of runs and data points sampled by the system/accuracy courses.

2-12. Analysis of Results (Findings).

a. Phase A - closed loop accuracy courses. Figures C-1 through C-8 depict all runs conducted by system/vehicle configuration, distance traveled, percent of error for distance traveled, and actual miss distance (in meters) of the system readout, as compared to the actual surveyed coordinates.

(1) AGA, ANS-150K, mounted in M113A1, APC.

(a) Closed loop level course (fig C-1). During all runs conducted, there were only three data points that exceeded 0.5 percent error for distance traveled. The maximum miss distance experienced at any one data point was 50 meters. In all cases, the test system finished the course with a miss distance of approximately 30 meters or less, representing less than 0.15 percent for distance traveled (21.4 km).

(b) Closed loop rough course (fig C-2). The increased error due to the system measuring *only* horizontal distance is depicted in this figure. Two data points exceed the 1 percent error for distance traveled within the first 3 kilometers. At 6 kilometers, all runs were under 0.5 percent error for distance traveled with the exception of one data point. It could not be determined from the data collected if this was an actual readout of the system or a possible operator error; the data point has been included in all data presentations. For analysis purposes, excluding this one point, the maximum miss distance for any data

point was less than 60 meters with all runs ending at less than 0.25 percent error for distance traveled (19.4 km).

(2) LWL/WHS, mounted in M113A1, APC.

(a) Closed loop level course (fig C-3). Although the system could not be compensated or calibrated to maintain the design accuracy, it did display a pattern of repeatability. The midpoint between the minimum and maximum percent error for distance traveled at any given distance during the runs reflected a ± 1 percent or less variation in the system's readouts. Overall, only four data points exceeded 3 percent error for any distance traveled, and the finish readouts at the end of the 21.4-kilometer course were 1.5 to 2.5 percent error for distance traveled.

(b) Closed loop rough course (fig C-4). During this segment of the test, the technical representatives were able to improve the calibration and compensation of the system as reflected by the miss distances and percent error portrayed on the graph. Although this was the rough course where error would be expected to increase as compared to the level course above, this was not the case. Only six data points exceeded 2 percent error for distance traveled during eight runs conducted (a total of 47 data points), representing a miss distance of 40 to 175 meters. The maximum miss distance experienced during this course by the system was 275 meters. The error at the finish of the 19.4-kilometer course was less than 0.2 percent to approximately 1.5 percent error for distance traveled. Miss distances at the end ranged from 75 to 275 meters.

(3) AGA, ANS-150K, mounted in M151A2, 1/4-ton truck.

(a) Closed loop level course (fig C-5). Of a total of approximately 79 data points sampled during this segment of testing, only five exceeded 1 percent error for distance traveled representing a maximum miss distance of approximately 75 meters. During the entire course, the maximum miss distance for any run was approximately 105 meters, representing a 0.75 percent error for distance traveled. The closures for all runs conducted resulted in only two runs exceeding 0.25 percent error (0.315 percent error) while the remaining nine runs varied from 0 percent to 0.2 percent error for distance traveled. Miss distances at the finish point for these nine runs varied from 0 to 40 meters. Total distance traveled was 21.4 kilometers.

(b) Closed loop rough course (fig C-6). Only two data points of 47 sampled exceeded 1 percent error during the runs conducted representing a miss distance of 20 meters and 35 meters. At approximately 10 kilometers of distance traveled, all runs were equal to or less than

0.5 percent error for distance traveled. The maximum miss distance experienced during these runs was approximately 65 meters with closer miss distances after 19.4 kilometers of travel varying from 10 to 50 meters. These miss distances represented a spread of 0.075 percent to 0.275 percent error for distance traveled.

(4) LWL/WHS, mounted in M151A2, 1/4-ton truck.

(a) Closed loop level course (fig C-7). During the runs conducted on this course, the system continued to experience problems in compensation and calibration. As with the M113A1, a pattern of repeatability was established even though the system displayed large miss distances and percent errors for distance traveled. Comparing the system readouts of the five runs conducted, the readout of four runs averaged ± 0.5 percent for distance traveled at all the data points encountered during the runs.

(b) Closed loop rough course (fig C-8). Again, the system displayed a high percent error for distance traveled and a large miss distance, yet the average difference of the systems' percent error for distance traveled between the two runs conducted remained ± 0.5 percent, again displaying a pattern of repeatability. Due to the continued problems of compensation and calibration, additional data could not be obtained on this specific course.

b. Phase L - open end accuracy courses. Figures C-9 through C-16 depict all runs conducted by the system, vehicle configuration, distance traveled, percent error for distance traveled, and actual miss distance (in meters) of the system readout as compared to the actual surveyed coordinates.

(1) AGA, ANS-150K, mounted in M113A1, APC.

(a) Open end level course (fig C-9). Only three data points out of 71 exceeded 1 percent error for distance traveled during all the runs conducted. These three points represent a minimum of 12 meters miss distance and a maximum of 60 meters miss distance. After the system had traveled approximately 4.5 kilometers, all runs were less than 1 percent error for distance traveled with a maximum miss distance of 50 meters. At approximately 10 kilometers of travel, all runs were less than 0.5 percent error for distance traveled. The finish readouts at the end of the 21.9-kilometer course reflected a miss distance from 10 to 30 meters, a percent error for distance traveled of 0.06 percent to 0.13 percent.

(b) Open end rough course (fig C-10). At the end of 2 kilometers traveled, all runs were under 1 percent error for distance traveled and by 5 kilometers, the error was less than 0.5 percent. Only two runs exceeded 0.5 percent for distance traveled after this point, and it was

0.6 percent error with a miss distance of 120 meters. All other runs never exceeded 80-meters miss distance with the finish points resulting in less than 0.1 percent to 0.4 percent error for distance traveled with miss distances of 15 to 80 meters.

(2) LWL/WHS, mounted in M113A1, APC.

(a) Open end level course (fig C-11). Runs reflected on this chart again show a repeatable pattern of results with overall accuracies improved due to improved compensation and calibration of the system. The two runs that were not completed were due to mechanical failure of the M113A1. The one data point that was less than 2 percent error for distance traveled at approximately 23 kilometers of travel could not be explained. If the system was in error, it compensated (or canceled) this error prior to the next data point. It is also possible that the error was an operator error (i.e., misreading the coordinate readout). The majority of these runs were between 0.75 percent and 1.5 percent error for distance traveled after 12 kilometers of travel. With the exception of the runs not completed and the one data point at 23 kilometers discussed above, the miss distances ranged from 75 to 225 meters throughout the course.

(b) Open end rough course (fig C-12). These data reflect the effect of changing compensation and calibration after each run. The technical representatives were continually attempting to adjust the system between the various runs during this phase of testing. Four of the runs do reflect accuracies that the system can attain. These four runs maintained approximately 1 percent error or less for distance traveled and represented miss distances of 50 to 175 meters.

(3) AGA, ANS-150K, mounted in M151A2, 1/4-ton truck.

(a) Open end level course (fig C-13). Accuracies obtained when the system was mounted in the M151A2 showed a range of miss distances of 0 to 80 meters with all runs less than 0.4 percent error for distance traveled after approximately 12 kilometers of travel.

(b) Open end rough course (fig C-14). Results of this course are similar to those experienced on the level course with the exception of one run. Of the eight runs conducted, seven reflected miss distances ranging from 0 to 80 meters and a percent error for distance traveled of less than 0.4 percent. The one run that did not fall in these parameters still did not exceed 0.65 percent error for distance traveled, which depicted a maximum of 120 meters miss distance.

(4) LWL/WHS, mounted in M151A2, 1/4-ton truck.

(a) Open end level course (fig C-15). Due to system problems, only two runs were conducted over this course. Of the two, one reflects the problems experienced in compensation and calibration. The second run showed some improvement in the compensation and calibration and resulted in miss distances ranging from 100 to 225 meters. The system achieved a percent error for distance traveled of less than 1 percent error at approximately 10 kilometers of travel and maintained this accuracy to the finish point.

(b) Open end rough course (fig C-16). Problems continued with compensation and calibration during this portion of testing. It was decided to go ahead with the runs at one setting to determine the repeatability of the system in lieu of accuracy. The chart shows that the system is capable of maintaining good repeatability over the same course during repeated runs.

c. Selected runs for the LWL/WHS. Figure C-17 shows selected runs for the LWL/WHS system when mounted in the M113A1 with the compensation and calibration relatively stable and accurate. The system was capable (under ideal conditions) of producing results with percent error for distance traveled under 1 percent. These runs reflect miss distances of from 10 to 200 meters with good repeatability between runs.

d. AGA, ANS-150K gyro alignment. During one day of testing of the AGA, ANS-150K, the gyro was aligned only in the morning at the start of testing. No further realignment to compensate for gyro drift was performed during the day. Figure C-18 reflects the results of the first run of the morning (S) and the last run of the day (F) 7 1/2 hours later. There was only a 10-meter difference between the maximum miss distances of these two runs; both had an equal minimum miss distance of 10 meters; and a finish miss distance of 10 meters (0.08 percent error) and 30 meters (0.175 percent error), respectively.

e. Map and compass, M151A2, 1/4-ton truck.

(1) Open end level course (fig C-19). This course was comprised of all but one checkpoint located on road junction or other easily recognized features. The one data point that was not easily recognized is accented on the chart by the 900 to 1,000 meter miss distance (located at approximately 19 kilometers of travel distance).

(2) Open end rough course (fig C-20 and C-21). This course was characterized by rough terrain, and traversed tank trails that were not on the map, or had been changed since the maps were printed. As with the level course, larger miss distances were experienced where easily recognized geographic features were not present. Although the test personnel were traveling a designated (course marked with directional signs) course of travel, on familiar terrain, with all conditions being

the most conducive for map and compass navigation, miss distances on several points ranged from 500 meters to over 1 kilometer.

f. Overall system average percent error and miss distance.

(1) AGA, ANS-150K. Figures C-22 through C-29 reflect the average miss distances and percent error, overall, for the M113A1 and M151A2, respectively. These averages are reflected by course and by direction of travel over the course (i.e., clockwise, counterclockwise, north, or south). The results do not reflect any pattern for any specific type vehicle in which the system may be mounted or excessive differential in accuracies as to direction of travel. In all cases, the system provided less than 0.5 percent error for distance traveled at approximately 3 to 12 kilometers travel distance. All data, on the open rough course (with the exception of M113A1 average of 0.375 percent error for distance traveled) reflected the finish point accuracy to be equal to or less than 0.25 percent error for distance traveled.

(2) LWL/WHS. Figures C-30 through C-37 reflect the overall average miss distances and percent error for the M113A1 and M151A2. Due to the problems encountered throughout this portion of the accuracy tests, it is not possible to determine the effect, if any, from direction of travel. It is noted that in most test situations and vehicle configurations, the system functioned better in the M113A1 than it did when mounted in the M151A2. Figures C-32, C-33, C-36, and C-37 depict an overall average of 0.8 percent to 1.3 percent error for distance traveled when the system was mounted in the M113A1. Figure C-34 is the only instance where similar results were obtained when mounted in the M151A2.

(3) Accuracy requirements. The PANS-MN states the basic accuracy requirements for self-contained land navigation systems. Figures 2-2 and 2-3 show the probability in number of occurrences, and percentage of occurrences, of the systems' ability to provide accuracies ≤ 0.5 percent, ≤ 1 percent, ≤ 1.5 percent, or ≥ 1.5 percent error for distance traveled. These figures may be compared to the accuracy requirements in the PANS-MN (specific requirements are classified CONFIDENTIAL) to determine the degree with which they meet those requirements.

g. Data points. Figures C-38 through C-46 illustrate the location of several of the data points used in the various courses. Noted on the figures are the average miss distances for all the map and compass position fixing runs. As noted in paragraph e above, when the data point was associated with a geographic feature such as a road junction, easily identified on the ground, the individual could locate the point with accuracies comparable to the navigation systems (fig C-38, C-39, and C-40). When the road net or trails change through the years and vary from that shown on the map, the miss distances increase when using

the map and compass only for navigation purposes (fig C-41, C-43, and C-44). When the individual using only the map and compass for position fixing does not have easily identifiable features to locate himself, miss distances range up to 1,000 meters (fig C-44, C-45, and C-46). Although travel distances are noted in graphs, the distance traveled when navigating with only a map and compass has little bearing on miss distance when fixing a position.

Percent error for distance traveled categories					
Type vehicle	Number of occurrences				Total
	≤ 0.5	≤ 1	≤ 1.5	> 1.5	
M113A1	215	12	11	2	240
M151A2	191	22	12	5	230
TOTAL	406	34	23	7	470
Percentage	86.5%	7%	5%	1.5%	

Figure 2-2. Demonstrated accuracy of the AGA, ANS-150K by the number of occurrences which fell in each category of percent error for distance traveled by type vehicle.

Percent error for distance traveled categories					
Type vehicle	Number or occurrences				Total
	≤ 0.5	≤ 1.5	≤ 3.0	≥ 3	
M113A1	14	71	34	20	139
M151A2	1	13	29	43	86
TOTAL	15	84	63	63	225
Percentage	7%	37%	28%	28%	

Figure 2-3. Demonstrated accuracy of the LWL/WHS system by the number of occurrences which fell into each category of percent error for distance traveled by type vehicle.

Section IV. SUBTEST IV - TACTICAL APPLICATION

2-13. Purpose. To determine the various systems' capabilities to perform as navigation aids and position location instruments to a degree of accuracy that will improve the vehicle commander's capability to perform his mission when required to traverse unknown terrain.

2-14. Methodology.

a. The subtest was conducted in three phases, with each system mounted in the M151A2, 1/4-ton truck.

- (1) Phase A - Long-range reconnaissance patrol.
- (2) Phase B - Daytime reconnaissance patrols.
- (3) Phase C - Night reconnaissance patrols.

b. Phase A, long-range reconnaissance patrol was conducted from building 91010, West Fort Hood, via Copperas Cove, Burnet, Marble Falls, Round Mountain, Austin, Bryan, College Station, Navasota, Huntsville to the test site headquarters in Sam Houston National Forest. The test vehicles reported designated checkpoints of known locations along the route to determine their apparent accuracy during extended periods of operation and when traveling on concrete reinforced roads, near railroad tracks, and in built-up areas.

c. Phases B (daytime operations) and C (night operations) incorporated a total of 11 courses in Sam Houston National Forest approximately 75 to 100 kilometers long. Phase B contained six courses and phase C, five courses. In both phases, the operators of the test systems were given simulated tactical missions which included specific routes to follow and checkpoints to locate. The data collectors recorded the readout of the system at each checkpoint or place of a scenario event. Deviation from the prescribed course occurred only when the system operator was forced by the tactical situation. The tactical situation caused several deviations from the planned course requiring the operators to navigate unfamiliar terrain over unmarked and unmapped roads and trails. To the extent possible, the test personnel traversed the same or similar course alternately with map and navigation system and with map and compass alone. This was done to obtain comparative data relating to the effectiveness of the systems in aiding the operator to navigate over unfamiliar terrain and thus perform his mission in a more timely and effective manner.

d. During the day and night tactical missions, red smoke represented aggressor activity. At the first sign of red smoke, the test personnel

stopped their vehicle in place, contacted the test headquarters, and awaited further instructions. These instructions normally included reporting the location of their position, type and location of the activity sighted, and selection of an alternate route that would allow them to complete their mission.

e. During all phases of this subtest, the operators reset the land navigation systems' coordinate readouts to better reflect the true position of the operators at any checkpoint. All coordinates were recorded prior to and after resetting the readout.

2-15. Results and Analysis.

a. Phase A - long-range reconnaissance patrol. Results for this phase of testing were not conclusive. The LWL/WHS system was not properly compensated and calibrated (continued problems as discussed previously in this report) and the AGA system declination was erroneously set by the technical representatives (i.e., west declination was set rather than east). Results were not valid.

b. Phases B and C - day and night reconnaissance patrols.

(1) During the first week of testing in these phases of the subtest, it was evident that the operators still did not have complete confidence in the systems. Many times the operators would report the wrong road junction as the designated checkpoint when the system readout reflected they were 500 to 1,000 meters from the actual location. During the last week of testing, after having gained confidence in the system, the operators began to use the system as a navigation aid in conjunction with their map.

(2) At the end of the test, interviews were held with the operators. The operators stated that they had confidence that the AGA, ANS-150K was accurate to within 250 meters or less when fixing their position or that of an aggressor. It also provided a navigation aid and assisted their mission to a greater extent than the sole use of map and compass for the same situation. The operators that used the LWL/WHS systems did not gain this confidence due to the many failures of the system. They did, however, state that there were occasions, when the system was operational, that it provided a navigation aid not available when working with map and compass alone. The operators expressed an opinion that had the reliability of the system been better, they would have had the same confidence in the system as did the ANS-150K operators.

(3) On several occasions, situations developed where two operators became disoriented in the same area - one with map and compass; the

other with the ANS-150K or LWL/WHS system. In each cited example, the navigation system operator located himself without the aid of recognizable landmarks, determined the course to navigate out of the area, and subsequently found his way back to the prescribed course and checkpoints with complete assurance that he was at the correct location. Individuals placed in the same set of circumstances with only a map and compass were unable to locate themselves with sufficient accuracy to insure navigating effectively out of the area. They were unable to return to the prescribed course without assistance or the assurance that they were actually at the point they were instructed to locate.

(a) Example 1. A checkpoint was established at coordinates 80388885 (fig 2-4). The single dotted lines represent a trail system that the operators actually traveled to reach the checkpoint. This trail system was not on their map, but resembled the intersection of trails and improved dirt road at RJ349 which was in fact their objective (coordinate 80988817). Of the six operators that stopped at the checkpoint at coordinates 80388885, two operators with map and compass and two with land navigation systems and map stated they were at coordinates 80988817. The controller at the checkpoint instructed all operators to verify their position prior to continuing the course. The operators with map and compass stated again they were at coordinates 80988817 and continued the course. One of these two operators became lost on the continuation of the course due to his 1-kilometer error at the checkpoint. The second operator with map and compass became disoriented due to the error but was able to relocate himself when he encountered a more defined road junction which he could recognize and obtain a position fix. However, the two operators with navigation systems attempted to verify their location by plotting the navigation system readout (shown by the dotted X's in fig 2-4). Noting that the system was off approximately 1 kilometer from the position fix they had previously reported, they took a closer look at the contour of the area. They noted that although the turns in the road appeared similar, it did not follow the contours shown on the map. With this discovery, they corrected their reported location and stated they were located on the improved dirt road in the vicinity of coordinates 80388885. Two observations were made regarding this situation.

1. The operators had not developed sufficient confidence in the system to use it properly with the map. They attempted to navigate with a map only and disregarded or questioned the position accuracy of the system.

2. Navigation with the system provided an advantage over navigation with map and compass alone when attempting to determine a position fix from an outdated or incorrect topographic map.

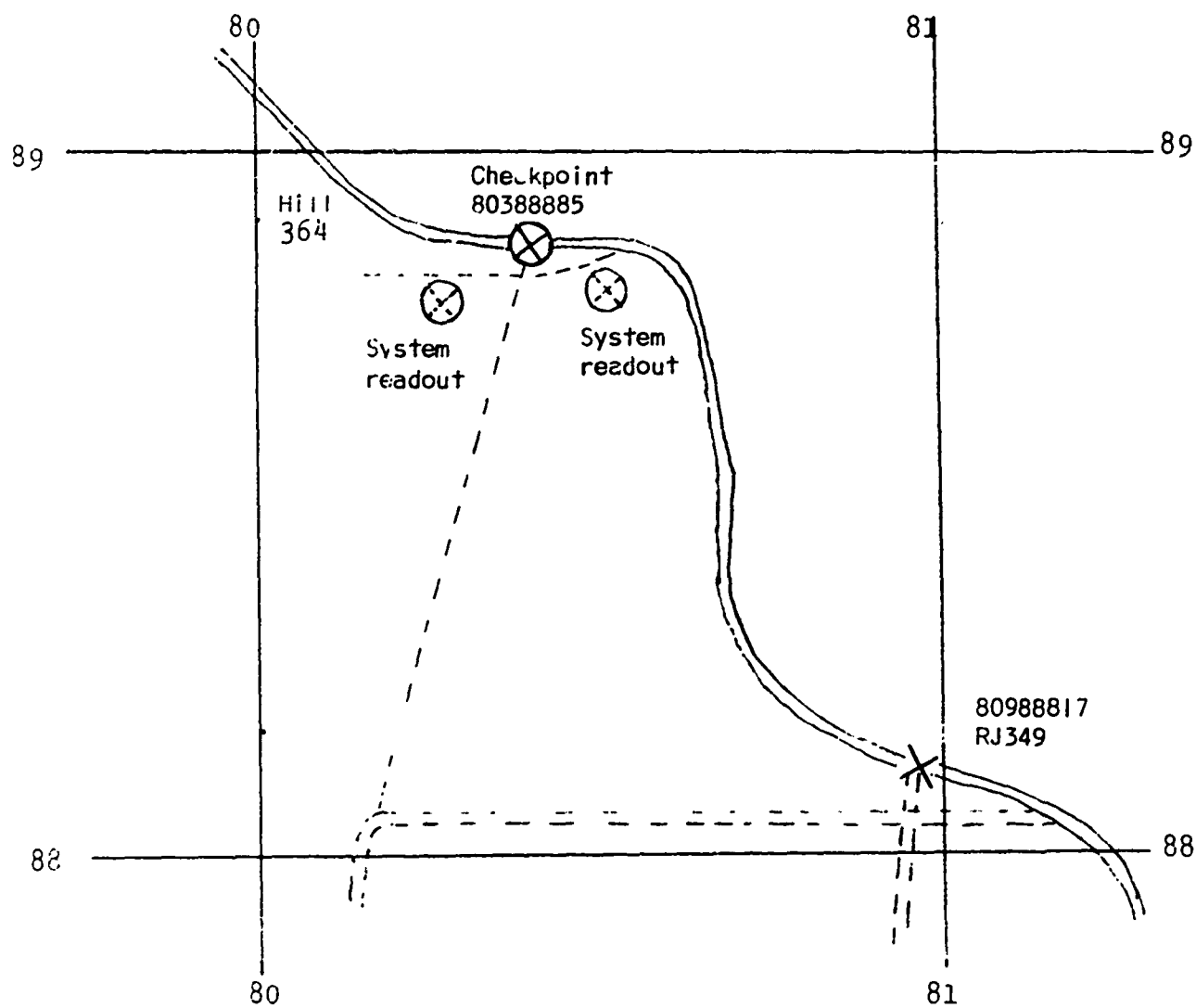


Figure 2-4. Sketch map of example 1,
Subtest IV, Reconnaissance.

(b) Example 2. One course had an aggressor activity in a location that forced the operators to leave the selected road net and proceed cross country for approximately 8 kilometers. Due to many abandoned trails, streams, and washed out areas not shown on the map, the operators were forced to travel a meandering course through the area. They had to backtrack on many instances, and rely heavily on their compass or navigation system to maintain their general direction of travel to the next checkpoint. The terrain was rugged and exceptionally dense with vegetation making it almost impossible to obtain an accurate position fix once in the area. One operator, using only a map and compass for navigating, became completely lost and exited the area approximately 7 kilometers from his objective. At the point of exit, he was several hundred meters off his available map coverage. He then proceeded along a road in the general direction he felt would get him back on his map coverage and the prescribed course. After approximately 10 to 12 kilometers of travel, still totally disoriented, he located a checkpoint on the course but was unable to advise the controller as to its true location. He was shown on his map (by the controller) where he was located and continued on with the course. A second operator in the same situation, but operating with a navigation system and a map, had difficulty in locating a route through the area and was forced by the terrain to exit the area at approximately the same location as the aforementioned operator using map and compass. However, the navigation system operator was able to plot his course throughout the cross-country segment of the course. He realized he had left his map coverage, was able to navigate back onto his map coverage (recognizing when he had done so by the system readout) and proceed without difficulty to the next checkpoint. Upon arriving at the checkpoint, he was able to locate his position accurately and proceed on the course without further incident. The time required to complete the map and compass course segment of the test was approximately 3 1/2 hours, whereas the operator with the navigation system completed this segment in approximately 1 1/2 hours.

(c) Example 3. Two operators, one with map and compass and one with a navigation system, encountered the same roadblock (fig 2-5 symbol (1)). Again, the terrain did not provide easily recognizable features other than the bends in the road and a trail leading off to the southwest of the primary route on which they were traveling. The operator, with the map and compass only, reported the roadblock as approximately 1 3/4 kilometers from its actual location (operators reported location noted by the symbol (2)). In comparison, the operator with the navigation system checked the readout of the system, plotted the readout, checked the surrounding terrain, made minor adjustment for system error, and reported his position to within 50 meters of the true location of the roadblock, (1) in figure 2-5.

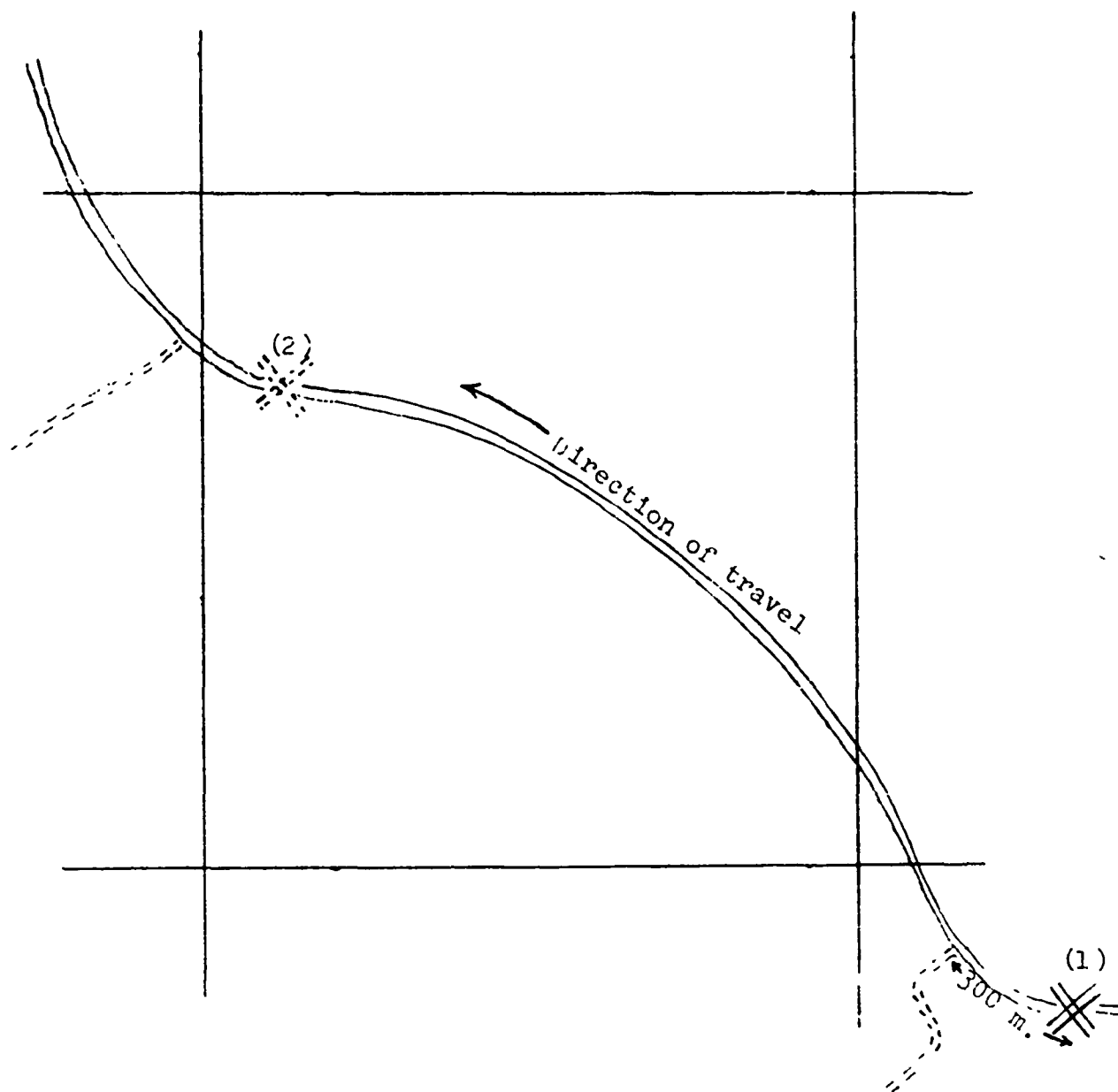


Figure 2-5. Sketch map of example 3,
Subtest IV - Reconnaissance.

(d) Example 4. On one night course, the operators traversed a pipeline right-of-way (not shown on the topographic map) as an alternate route to bypass a roadblock and proceed to the next checkpoint. One operator, with only a map and compass as navigation aids, arrived at what he thought to be the checkpoint, reported it by UTM coordinates, and proceeded along what he thought was the course. He had, in fact, encountered a similar road junction 1,200 meters north of the correct road. The road on which he was located did not appear on his map. When he continued, he was not following the prescribed route. He followed a cleared right-of-way for another underground pipeline that ran 1,000 meters to the west and parallel to the correct route. Due to this error, the operator missed two of his prescribed checkpoints. When the same set of circumstances developed for an operator with a navigation system, he reported that he was at the checkpoint. However, when he checked his system and plotted the coordinates on the map, he radioed back that he had made an error and was 1,200 meters north of the checkpoint and was about to proceed south to the prescribed point. Upon arriving at the checkpoint, it was determined that the system was within approximately 150 meters of the correct coordinates. The operator then again reported his location (correctly) and proceeded on the prescribed course.

(4) On several courses, the systems proved their value for command and control purposes. On varied instances, during day and night operations, operators went into areas where they could not find a route out due to the ruggedness of the terrain or their mission and route of travel changed by the test control headquarters. In either case, periodic readouts could be received from the navigation system aboard the vehicle and the operators movement directed by the control personnel by radio communications. In similar circumstances involving operators with map and compass only, control personnel either had to go into an area and search for the operator in question or rely on a navigation system vehicle to spot him and lead him out of the area.

(5) During one of the day courses, the operators were required by a change in the mission to negotiate a course that took them off their available map coverage, caused them to travel approximately 20 kilometers without map coverage, and to locate a checkpoint immediately upon returning to the area of their map coverage. The operators using the navigation systems had little trouble navigating by coordinates, using the system readout, and locating the point. The operators with map and compass eventually were able to complete the mission but had difficulty in determining at what point they had reentered the area of their map coverage. In all cases, the operators with map and compass traveled in excess of 4 kilometers on the map coverage before they could locate their position. Within 200 meters after returning to the area in which they had map coverage, the system operators were able to determine their location and subsequently the designated checkpoint.

(6) Figure 2-6 denotes the overall average miss distances of reported aggressor locations by the various combinations of navigation aids. It was noted that the ANS-150K provided the best aid during the day and was approximately equal to the map and VCS-500 onboard compass at night. It was observed that the map reading ability of the operators had improved greatly by the time the night operations were conducted (second week at Sam Houston National Forest). It was also noted that the operators paid closer attention to their maps during night operations than they did during daylight hours. In most cases, the use of only the map and compass produced the greatest errors.

(7) Figures 2-7 and 2-8 depict the total aggressor points reported by system, and the percentage less than 500 meters miss distance, greater than 500 meters but less than 1,000 meters, and greater than 1,000 meters for day and night operations. Overall, the ANS-150K produced the best results. The LWL/WHS system was producing its best accuracies during the night operations and is reflected by the results shown in figure 2-6. This was due to continued problems encountered the first week onsite at Sam Houston National Forest with the compass compensation of the LWL/WHS system. Both figures reflect that the VCS-500 onboard compass greatly enhanced the individuals' navigational abilities both during day and night operations as compared to the use of the map and lensatic compass.

(8) Although the operators felt that on occasions they could produce results with an onboard compass equal to those obtained with a navigation system, this was only feasible if their sole mission was navigation. To obtain such accuracies with the onboard compass they stated they had to devote their entire attention to the map and compass leaving little time for other duties such as performing a reconnaissance mission; however, with a navigation system they could devote all their attention to the tactical mission, referring to their map, with the aid of a coordinate readout from the navigation system, only at such time a position fix or location of an aggressor position was required.

(9) Throughout all phases of this subtest, operators were able to negotiate courses easier with the aid of navigation systems than with lensatic compass and map on comparative courses. This was stated by all operators during interviews at the end of the testing period. It was also stated by the operators that if a navigation system was not provided, onboard compasses on wheeled and tracked vehicles would provide a marked improvement for the individual navigating with the topographic map.

Average miss distance in meters						
System	Total		Day		Night	
	Total points reported	Average (meters)	Total points reported	Average (meters)	Total points reported	Average (meters)
AGA	22	320	6	144	16	385
LWL/WHS	36	529	10	727	26	453
Map and VCS-500	17	379	6	370	11	383
Map and compass	55	469	16	377	39	506

Figure 2-6. Subtest IV, average miss distance of reported aggressor locations.

System	Total points reported	Percent ≤ 500 m	Percent > 500 m	Percent $> 1,000$ m
AGA	6	100	-	-
LWL/WHS	10	30	60	10
Map and VCS-500	6	67	33	-
Map and compass	16	75	19	6

Figure 2-7. Subtest IV, total number and accuracy of aggressor locations reported during the day, compared by the percentage with a miss distance less than 500 meters, greater than 500 meters, and greater than 1,000 meters.

System	Total points reported	Percent ≤ 500 m	Percent > 500 m	Percent $> 1,000$ m
AGA	16	69	31	-
LWL/WHS	26	70	15	15
Map and VCS-500	11	73	27	-
Map and compass	39	57	33	10

Figure 2-8. Subtest IV, total number and accuracy of aggressor locations reported at night, compared by the percentage with a miss distance less than 500 meters, and greater than 1,000 meters.

Section V. TRAINING, LOGISTICS, AND HUMAN FACTORS

2-16 Training.

a. One week of intensive training (40 hours) was conducted in the classroom and in practical exercises on the equipment itself. The classroom portion was for 2 1/2 days and consisted of map reading, safety, general system operation and terminology, and a description of the type of testing to be performed. The second 2 1/2 days were spent in the motor pool and on nearby tank trails operating the equipment to be tested. This portion was designed to give the operators on-system training for basic operation, compensation, calibration, and general navigation procedures when using a navigation system in conjunction with the standard military topographic map.

b. Due to a delay in shipment, the AGA, ANS-150K was not available during the 1-week training period. Operators for the ANS-150K were briefed on the system in the classroom, then received field training on the general aspects of operation of land navigation systems in general on the LWL/WHS system. Actual hands-on training on the ANS-150K was conducted during the first week of testing during the calibration and verification of calibration phase.

c. Operator comments and observations by test control personnel indicated that the scope, time, and type of training could not have been conducted in less time, and the time spent on compensation and calibration (approximately 1 day) was not sufficient. It was noted that after the operator had received a week of training on the system, an additional 60 hours of actual use was required to develop operator confidence in the system and to develop an understanding of how to use the device as a navigation aid.

2-17. Logistics.

a. An NCO was assigned the task of monitoring the systems at all times during their operation. He maintained logs pertaining to operational time and downtime (hands-on maintenance time), repairs required, and other pertinent data that related to logistics.

b. Figure 2-9 depicts the operational time and downtime (hands-on maintenance time) for the systems.

c. Total miles driven by the vehicles in which the systems were mounted was approximately: ANS-150K, 4,170 miles; LWL/WHS system #1, 3,200 miles; system #2, 2,150 miles; and, VCS-500, 3,000 miles.

System	Fort Hood		Sam Houston		Total	
	Op time	Downtime	Op time	Downtime	Op time	Downtime
ANS-150K	93:06	4:24	104:55	2:00	198:01	6:24
LWL/WHS	55:36	21:53	106:55	0:00 ^a	162:31	21:53

^aOperational and downtime at Sam Houston National Forest reflects those hours that the test site was open. The technical representatives for the LWL/WHS system spent an additional 30 hours during nontest periods rewiring and resoldering the breadboard modules to assure operation of the equipment during the test periods.

Figure 2-9. Operational and downtime (hands-on maintenance time) of the navigation systems tested.

d. The types of equipment failures experienced during the testing included the following:

(1) AGA, ANS-150K.

(a) The temporary mounting used to mount the inverter and gyro to the M151A2 required modification to reduce vibration.

(b) The distance calibration circuitry would not allow sufficient variance on one navigation head to provide the needed adjustment. The navigation head and distance transmitter were replaced. The specific problem was not isolated during the test.

(c) Power cable connector from the power source to the inverter worked loose on two occasions and caused a power surge. This caused the gyro to become misaligned from its northing reference.

(d) Moisture got into the navigation head and caused a short.

(2) LWL/WHS.

(a) Wiring in compass broke on several occasions due to vibration.

(b) Distance transmitter on M151A2 would not function properly when the vehicle operated over 30 mph. A modification was required to reduce the rpm of the reed switch in the distance transmitter.

(c) Hard wiring on breadboard modules in the processor was continuously breaking from vibration.

(d) System would not hold compensation and calibration adjustments. This situation became worse through the weeks of testing as modules were rewired, size of wire changed, and other such modifications accomplished that caused a change in the circuitry of the system.

(3) In all cases, repairs could be made immediately by replacement of components or resoldering of wires onsite.

(4) Repair of the components on all systems did not require any special tools or equipment that would be common only to the repair of the systems. The technical representatives onsite used electronic repair tools commonly found in the Army signal equipment repair units. No operator preventive maintenance was performed on the systems during the entire test period.

2-18. Human Factors.

a. The operators of the ANS-150K developed confidence in their system at a much faster rate than those operating the LWL/WHS. Three factors that influenced the development of operator confidence were: demonstrated accuracy, repeatability, and reliability. All three of these factors were demonstrated by the ANS-150K, whereas the LWL/WHS engineering test model was deficient in demonstrated accuracy and reliability.

b. The operators did reflect a preference of the two types of systems tested (i.e., gyro system versus magnetic system) and their inherent advantages and disadvantages.

(1) The ANS-150K, gyro system provided the best demonstrated accuracies and instilled the greatest confidence in the user; therefore, it was the preferred system.

(2) The LWL/WHS would have been equally preferred if the demonstrated accuracy and reliability had been equal to the ANS-150K. The operators liked the simplicity of the LWL/WHS system. It could be turned on, coordinates set, and the vehicle moved without regard to any gyro settling time. Once underway, there were no adjustments required and no concern for realignment of the system or other such operator functions. The only operator function was correcting the readout, if desired, to correct for system error.

c. Equipment and procedure modifications.

(1) AGA, ANS-150K.

(a) The operators felt the compass heading readout was too difficult to read. It was suggested the 0.1° inner dial should have a cover on it so that it cannot be seen during navigation operations. The rapid spinning of the dial caused confusion to the operators. Several of the operators placed tape over this dial during test operations.

(b) The lack of symbols N, E, S, and W located on the 90°, 180°, 270°, and 0/360° point of the compass readout dial caused the operators to experience some difficulty when attempting to make a rapid reference to the dial to determine direction of travel when on the move. The use of these symbols is highly desired by the operators for navigation purposes.

(c) Although the calibration adjustment dials had scaled markings, they were not linear and had no direct correlation to specific numbers. This made calibration a trial-and-error situation and caused much difficulty and confusion to the operators.

(d) Some difficulty was experienced by the operators in setting the coordinates of their initial start position or when attempting to change the coordinate readout at a known point to correct the system error. This difficulty was derived due to the speed settings of the digit readout controls. The low speed adjustment needs to be slowed down to prevent overshooting the desired digit the operator is attempting to set.

(e) The readout device on the M151A2, 1/4-ton truck was mounted flush in a vertical position on the dashboard of the vehicle. This required the operator to lean forward over the device to obtain a UTM readout or heading reference. The readout device should be mounted at an angle towards the operator to allow reference to the system without changing his position in the vehicle.

(2) LWL/WHS.

(a) Although the calibration controls were not usable by the operator on the engineering test model, it was suggested that they should be placed on the handset for ease of access to the operator should a production model be developed. The present design reflected that some of these controls would be located on the processor of the system.

(b) The operator suggested that a bracket be devised for the handset/readout device that would allow it to be affixed to the vehicle if the operator did not desire to hold it or fasten it to his web gear.

It was noted that during travel or when the operator was out of the vehicle and not using the handset, it had to be laid loose in the vehicle and was subject to damage.

(c) The operators felt that a quick disconnect plug should be placed on the dash of the M151 for connecting the handset/readout device. This would alleviate the need for a cable to be stretched from the back seat (where the processor is located) to the front of the vehicle. Presently, the cable is subject to damage when personnel get in or out of the back seat of the M151, 1/4-ton truck.

(3) The operators felt the "course-to-steer" needle on the LWL/WHS system's heading reference readout was very advantageous when traveling cross country. This feature allowed them to preset a desired direction of travel when traversing rugged terrain and maintain a general direction of travel to a specific point. They felt that such a feature should be incorporated into any navigation system that might be considered for Army use.

Section VI. ONBOARD COMPASS

2-19. Aviation Electric, VCS-500, Onboard Compass.

a. The Aviation Electric, Limited, of Montreal, Canada, provided one VCS-500, onboard compass, by unsolicited proposal for evaluation during this test. The system was mounted in a M151A2 test vehicle. This test vehicle was used for map and compass runs during subtests III and IV to provide comparative data for similar runs with the land navigation systems. These runs also provided data as to the value of an onboard compass as a navigation aid as compared to the use of the standard lensatic compass presently provided for navigation purposes.

b. The onboard compass was operated during the electromagnetic and magnetic phase of subtest II. The system traveled 1,000 meters on a magnetic north/south course, recording any variance in direction indicated every 100 meters.

(1) Baseline data reflected a variance in the readout from 0° and 180° of approximately $\pm 3^\circ$.

(2) When the test vehicle with the system was driven alongside an M113A1, it was noted that a variance of $\pm 4^\circ$ to 6° occurred.

(3) Operating the test vehicle alongside an M60A2 tank resulted in a variance of $\pm 5^\circ$ to 10° . At 5 meters from the tank, the effect dropped to $\pm 4^\circ$ to 8° and at 15 meters the effect was no longer noted.

(4) Operating the test vehicle adjacent to or within 5 meters of the M60A2 when the onboard radios of the M60A2 were transmitting resulted in an additional $\pm 2^\circ$ to 4° variance.

(5) The variances noted above were maximized when the test vehicle was traveling south. Minimum variance was noted when traveling north. When the test vehicle was traveling north, the flux-valve compass was to the outside, away from the M60A2. When traveling south, the flux-valve compass was adjacent to the M60A2.

c. It was noted by the operator that the card type dial readout remained extremely steady when the vehicle was traversing rough terrain. No problems were experienced while reading the direction of travel from the dial.

d. The use of an onboard compass provided a convenience to the operator in that he did not have to get out of his vehicle each time he desired to take an azimuth for navigation purposes. It also enabled him to maintain a reference as to his direction of travel while moving.

e. The use of an onboard compass was compared to the use of the standard lensatic compass in conjunction with the topographic map for navigation purposes. The onboard compass produced more mission completions and closer estimates as to the test operators' position or the position of the aggressor. The use of the onboard compass reduced the amount of time required for an operator to determine desired direction of travel and provided him with a continual reference as to heading, thus assuring him that he was in fact maintaining his desired course direction. The onboard compass was especially desirable when navigating cross country (off roads and trails).

f. The capability of the VCS-500 to provide a grid reference for heading, rather than a magnetic heading as with the lensatic compass reduced azimuth errors (no conversion by the operator required for magnetic to grid azimuth) and assisted the operator in rapid orientation of his map to the surrounding terrain.

APPENDIX A

METHODOLOGY FOR ACCURACY COURSE SUMMARY (SUBTEST III)

A-1. Purpose. This appendix describes the applied methodology for this subtest.

A-2. Accuracy Courses. The accuracy courses used at Fort Hood tested the navigation systems' ability to accurately report coordinates of checkpoints over a variety of courses. The courses were closed loop and open end over both level and rough terrain. All of the courses were negotiated several times in each direction by each of the navigation systems mounted in both armored personnel carriers and in 1/4-ton trucks. These data were reduced to determine radial miss distance between the reported coordinate location and the surveyed coordinate location for each checkpoint. The evaluation criteria specified in the Outline Test Plan and the Positioning and Navigation System - Materiel Need (PANS-MN) are percent error for distance traveled; consequently, the miss distance calculated for each checkpoint is tied to the distance traveled by the test vehicle. Using this ordered pair of numbers, the data were sorted keeping the distance traveled constant. The resultant grouping of data gave listings of several miss distances for each unique distance traveled. The most meaningful expression of these data is an average miss distance for each distance traveled. This is in essence a condensation of several ordered pair of numbers (miss distances, and distance traveled), to a single representative number combination of one average miss distance for each distance traveled which was then used as a basis for input to a least square curve fitting procedure which yields a power curve equation ($Y = aX^b$) that best fits the data collected in the field. The power curve equation can be used as a general expression to determine what miss distance (Y) can be expected for any given distance traveled (X).

A-3. Technique Employed. The technique employed in any least square curve fitting route is to take a collection of data points such as those collected from field experimentation and solve the equation (In this case a power curve $Y = aX^b$) for the best values of a and b for the given set of data (YI, XI) where Y is the average miss distance, and X is the distance traveled.

A-4. Application of Equations. In the case of both the AGA and LWL/WHs vehicle land navigation systems, 50 ordered pairs of average miss distance and distance traveled were used in the solution of the equation $Y = aX^b$ for the best a and b. It should be noted that other types of equations were evaluated in reaching the conclusion that the power curve best fits the field data. Other equations tried were a linear equation

of the form $Y = mX+B$ and an exponential of the form $Y = ae^{bX}$. The technique used to calculate the coefficients a and b for the power curve $Y = aX^b$ was to first linearize the equation into $\ln Y = B \ln X + \ln a$ and solve for a and b where

$$b = \frac{N \sum (\ln X_i \ln Y_i) - \sum \ln X_i \sum \ln Y_i}{N \sum (\ln X_i)^2 - (\sum \ln X_i)^2}$$

$$\text{and } \ln a = \frac{\sum \ln Y_i}{N} - \frac{\sum \ln X_i}{N} b$$

subject to the conditions $X > 0$ and $Y > 0$ and $i = 1; \dots, N$.

In this case $N = 50$ data points for both the ANS-150K and LWL/WHS.

Reference: Statistical Theory and Methodology in Science and Engineering by K. A. Brownlee - John Wiley & Sons, 1965.

APPENDIX B

GRAPHIC RESULTS OF SUBTEST II - CALIBRATION, ELECTROMAGNETIC/
MAGNETIC ENVIRONMENT

Note: Circles indicate 30, 60, and 90 meters, 1 percent, 2 percent, and 3 percent error for distance traveled, respectively.

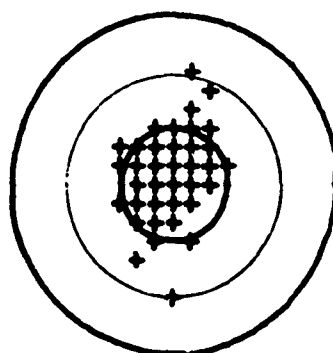


Figure B-i. Calibration verification data from the AGA vehicle land navigation system (Scale 1" = 100 meters).

Legend: + indicate runs made traveling east

⊙ indicate runs made traveling west

A=12 Jun, B=18 Jun, C=1 Jul, D=3 Jul

Note: Circles represent 30, 60, and 90 meters from the surveyed finish point. Circles inscribed around the system readout plots (A-D) have a radius of 30 meters.

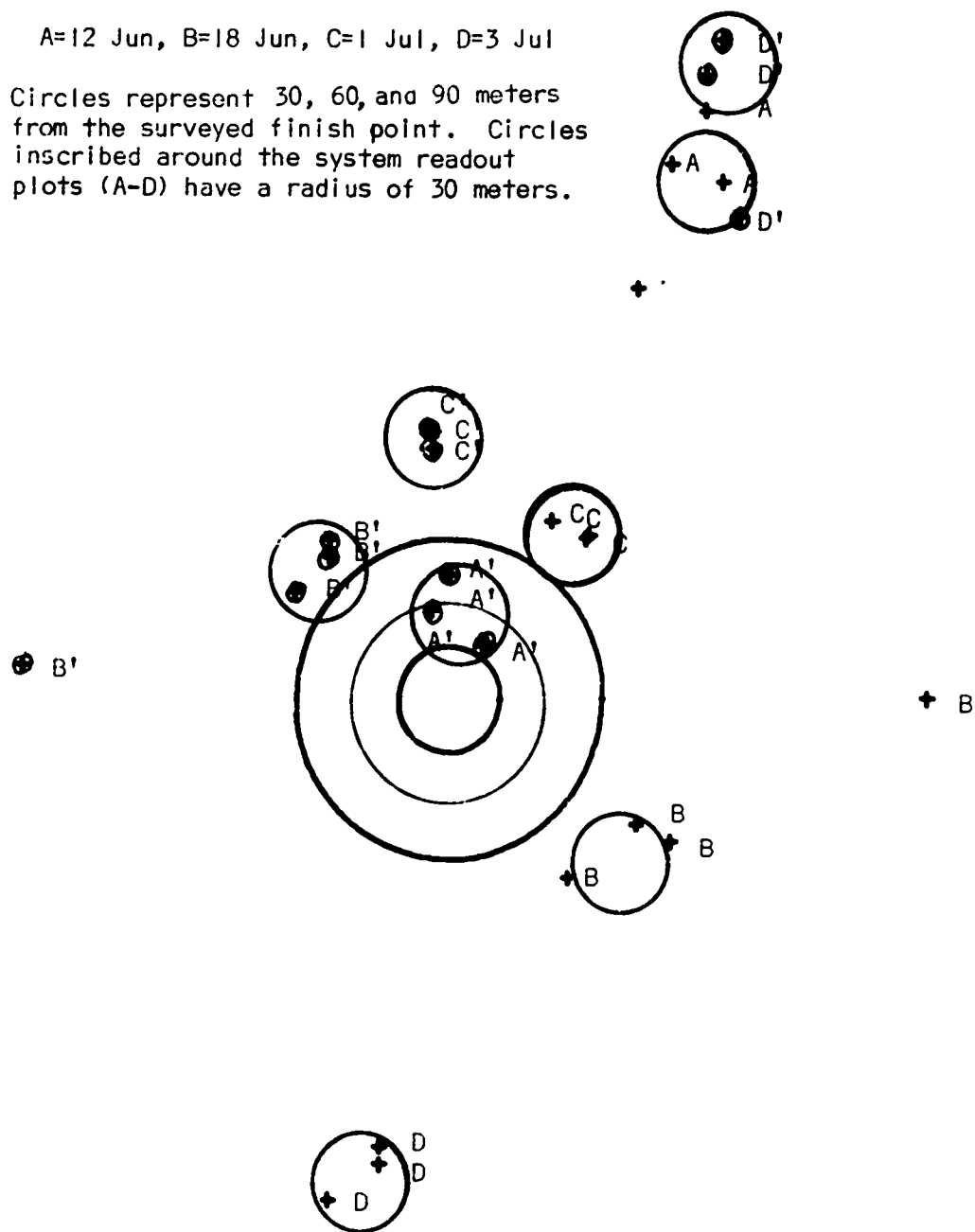
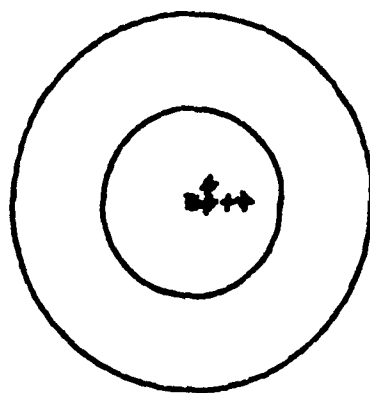


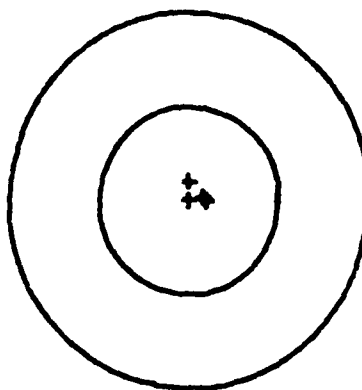
Figure B-2. Selected data from the calibration verification runs of the LWL/WHS vehicle land navigation system depicting repeatability for a given direction.



Legend: +Denotes the AGA system location.

Note: Circles indicate 50 and 100 meters from the surveyed location of the finish point (Scale 1" = 100 meters).

Figure B-3. Miss distance of all baseline runs for the AGA vehicle land navigation system traveling the 1,000-meter course.



Legend: +Denotes the AGA system location.

Note: Circles indicate 50 and 100 meters from the surveyed location of the finish point (Scale 1" = 100 meters).

Figure B-4. Miss distance of all runs for the AGA vehicle land navigation system traveling the course with its internal radios continuously keyed.

Legend: + denotes the AGA system location.

Note: Circles indicate 50 and 100 meters from the surveyed
 location of the finish point (Scale 1" = 100 meters).

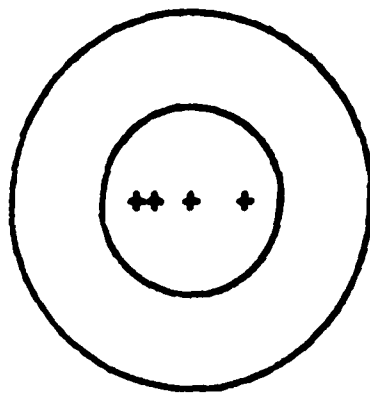


Figure B-5. Miss distance of all runs for the AGA vehicle land navigation system with an M60A2 tank traveling a parallel course hub-to-hub and to the east of the test vehicle.

Legend: + denotes the AGA system location.

Note: Circles indicate 50 and 100 meters from surveyed
 location of the finish point (Scale 1" = 100 meters).

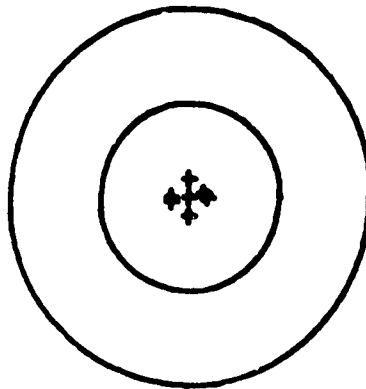


Figure B-6. Miss distance of all runs for the AGA vehicle land navigation system with an M60A1 tank traveling a parallel course 5 meters to the east of the test vehicle.

Legend: + denotes the system readouts location when traveling north.

Note: Circles represent 50, 100, 150, and 200 meters from the surveyed finish point (Scale 1" = 100 meters).

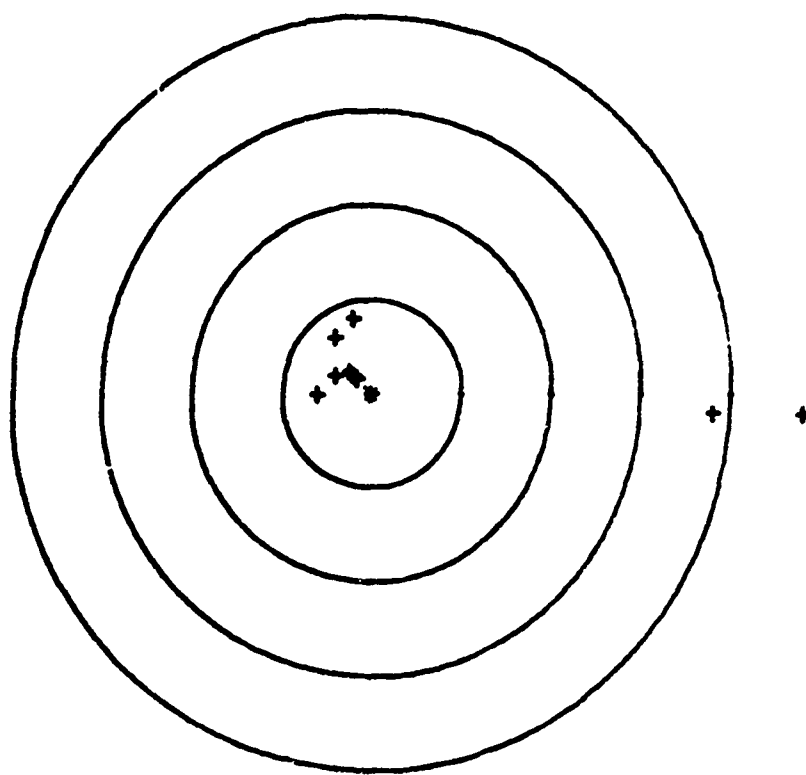


Figure B-7. All runs on the electromagnetic subtest for the LWL/WHS vehicle land navigation system traveling north during baseline data runs.

Legend: +: denotes the system readout location when traveling south.

Note: Circles represent 50, 100, 150, and 200 meters from the surveyed finish point (Scale 1" = 100 meters).

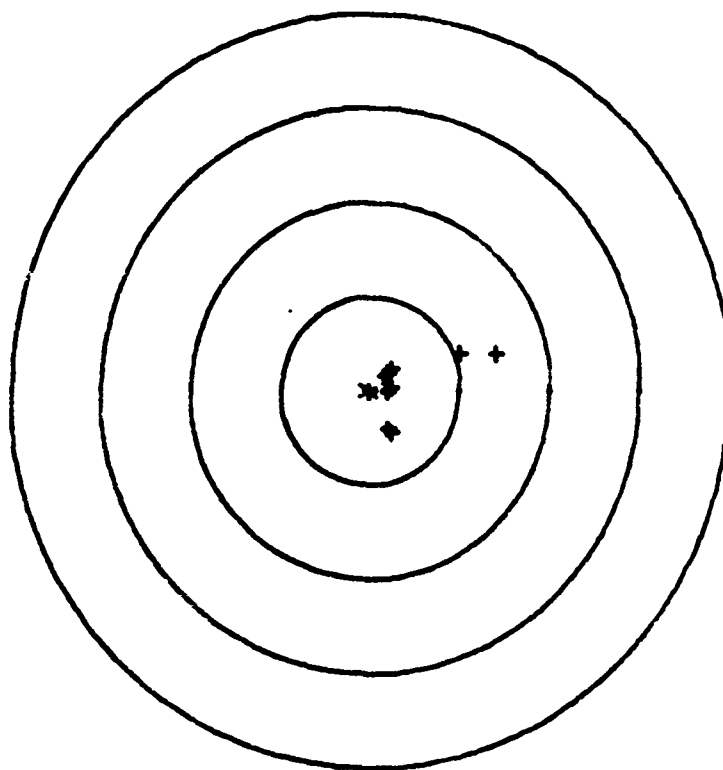


Figure B-8. All runs on the electromagnetic subtest for the LWL/WHS vehicle land navigation system traveling south during baseline data runs.

Legend: ⊕ denotes the system readout when traveling south
+ denotes the system readout when traveling north

Note: Circles represent 250, 500, 750, and 1,000 meters from the surveyed finish point (Scale 1" = 500 meters).

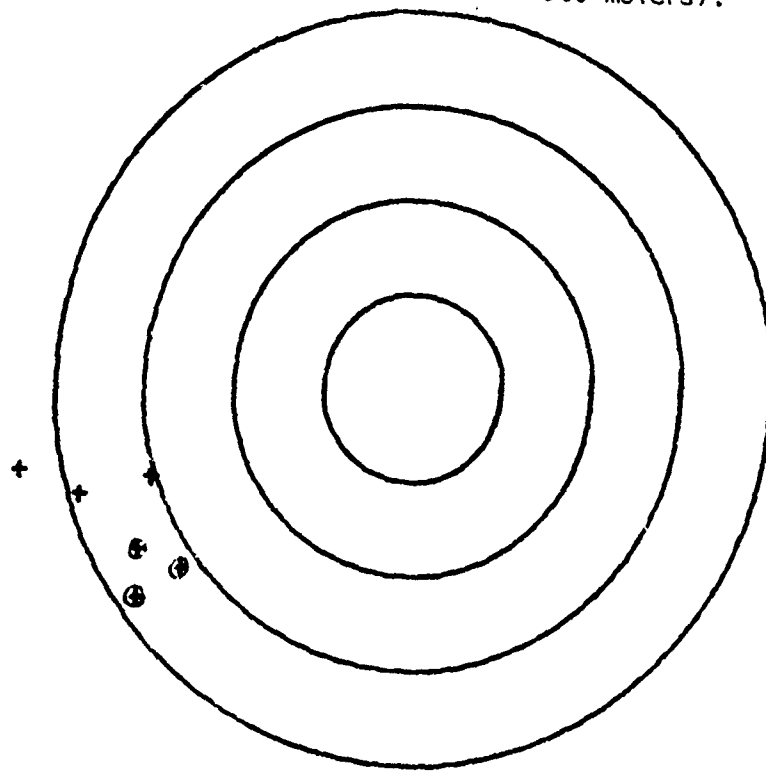


Figure B-9. Miss distance for the LWL/WHS vehicle land navigation system on the electromagnetic subtest with the internal radios continuously keyed.

Legend: ⊕ denotes the system readout when traveling south.
+ denotes the system readout when traveling north.

Note: Circles represent 50, 100, 150, and 200 meters from the surveyed finish point (Scale 1" = 100 meters).

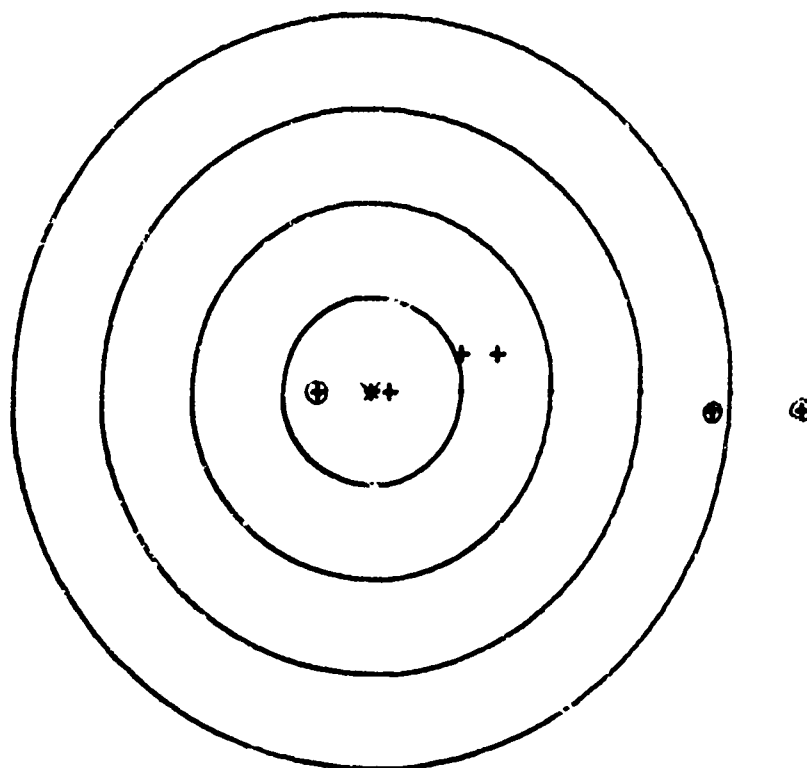


Figure B-10. Miss distance for the LWL/WHS vehicle land navigation system on the electromagnetic subtest with an M60A2 tank traveling a parallel course hub-to-hub to the east of the test vehicle, with radio transmitting.

Legend: ⊕ denotes the system readout when traveling south.
+ denotes the system readout when traveling north.

Note: Circles represent 50, 100, 150, and 200 meters from the surveyed finish point (Scale 1" = 100 meters).

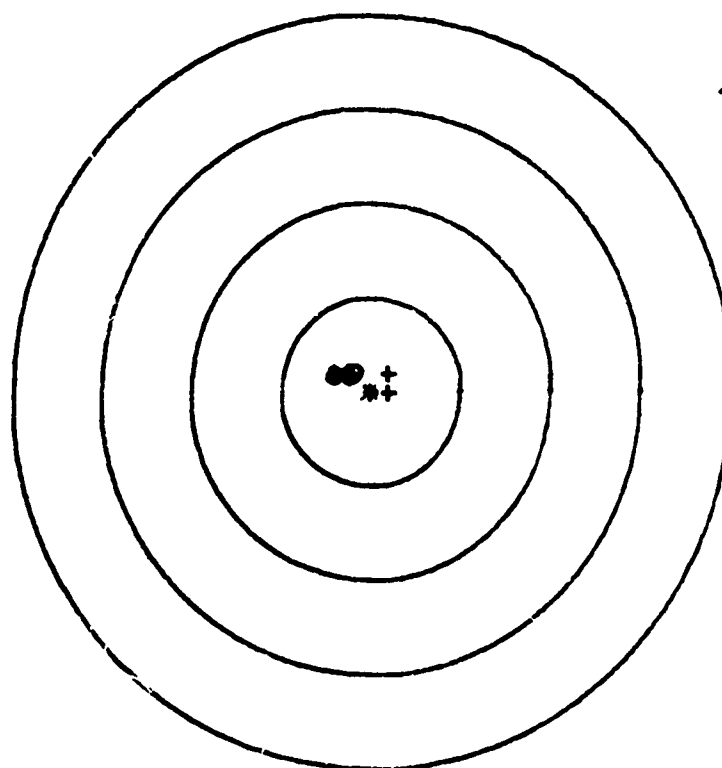


Figure B-11. Miss distance for the LWL/WHS vehicle land navigation system on the electromagnetic subtest with an M60A2 tank traveling a parallel course at 5 meters to the east of the test vehicle.

Legend: ⊕ denotes the system readout when traveling south.
+ denotes the system readout when traveling north.

Note: Circles represent 50, 100, 150, and 200 meters from the surveyed finish point (Scale 1" = 100 meters).

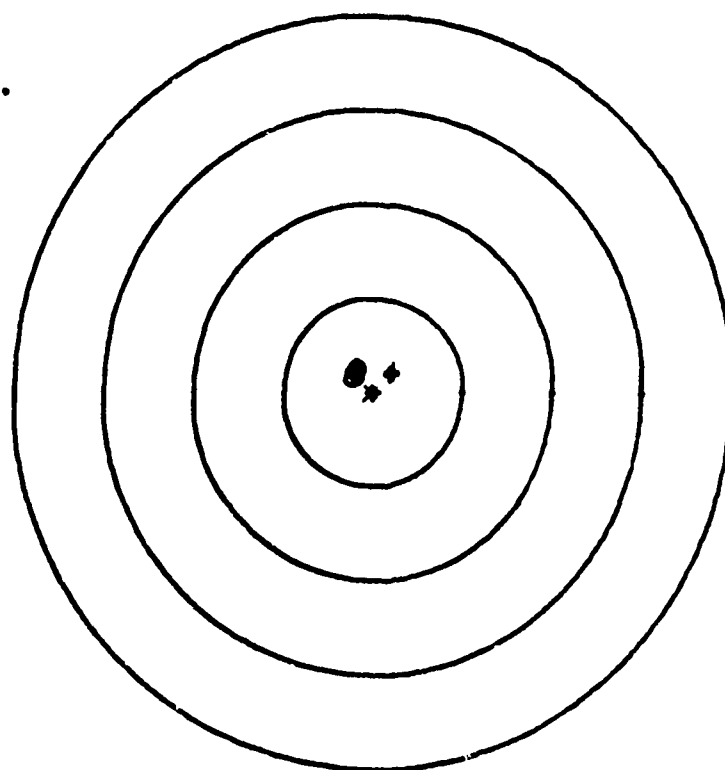


Figure B-12. Miss distance for the LWL/WHS vehicle land navigation system on the electro magnetic subtest with an M60A2 tank traveling a parallel course at 10 meters to the east of the test vehicle.

Legend: ⊕ denotes the system readout when traveling south.
+ denotes the system readout when traveling north.

Note: Circles represent 50, 100, 150, and 200 meters from the surveyed finish point (Scale 1" = 100 meters).

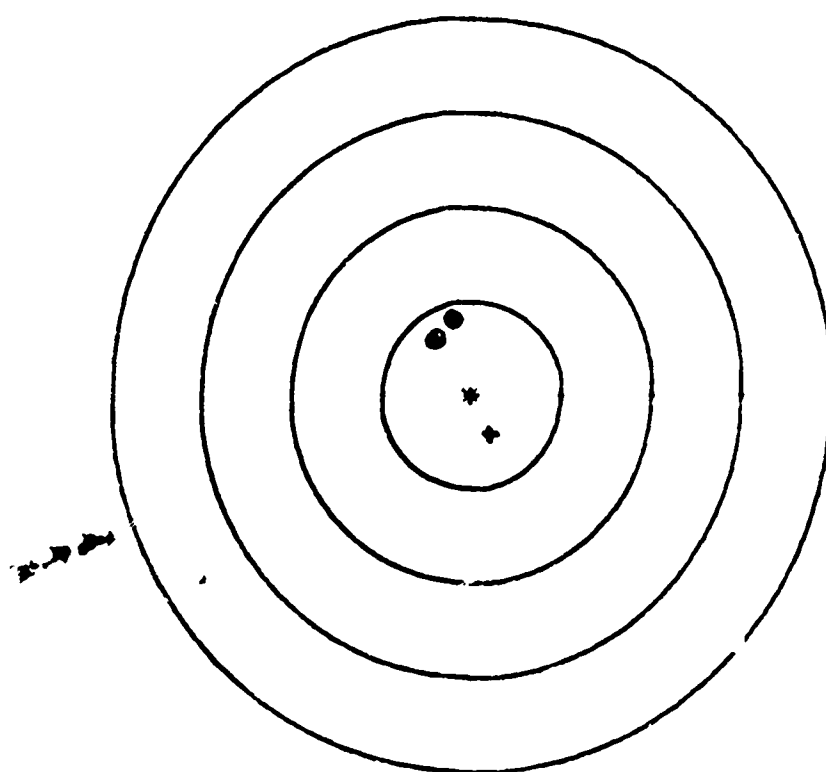


Figure 9-17. Min distance for the LWL/WHS vehicle land navigation system on the electromagnetic subtest with an M60A1 tank traveling a parallel course at 15 meters to the east of the test vehicle.

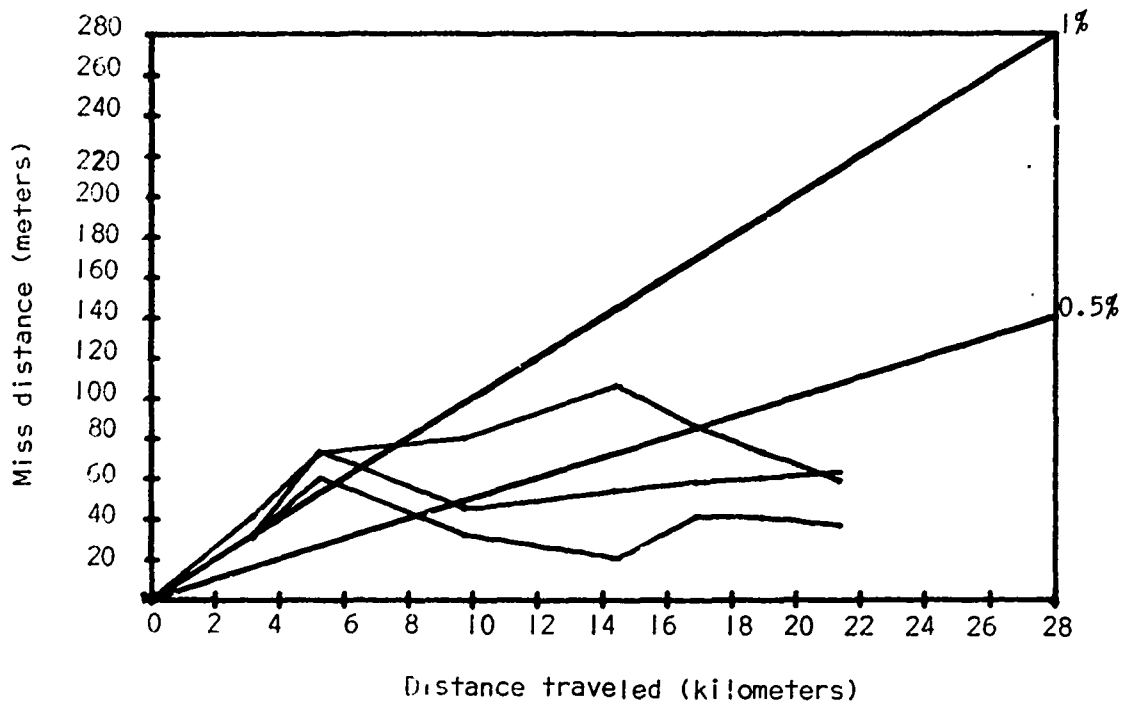


Figure 1-14. The effect on the AGA vehicle land navigation system if towing a 1/4-ton trailer containing a 1,427 pound load of metallic cargo.

Legend: + denotes the system readout:
 The letter A = hub-to-hub with an M60A2 tank
 B = 5 meters from an M60A2 tank
 C = 10 meters from an M60A2 tank
 D = 15 meters from an M60A2 tank
 E' = internal magnetic load
 A = traveling south
 A' = traveling north

Note: Circles represent 50, 100, 150, and 200 meters from the surveyed finish point (Scale 1" = 100 meters).

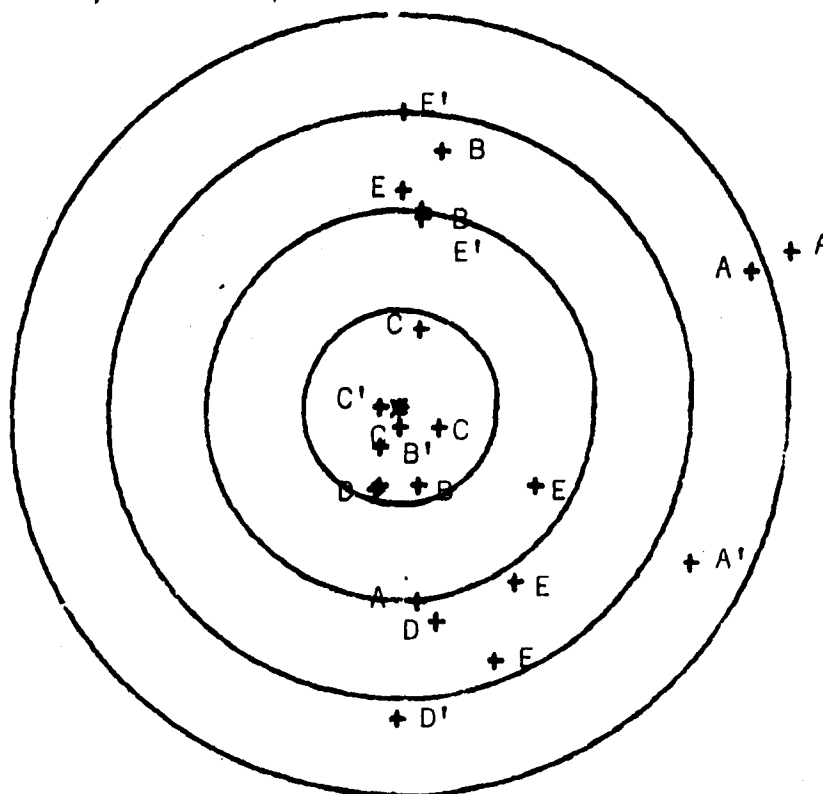


Figure B-15. All miss distances for the LWL/WHS vehicle land navigation systems during the magnetic environment subtest.

APPENDIX C

GRAPHIC RESULTS OF SUBTEST III - SYSTEM ACCURACY

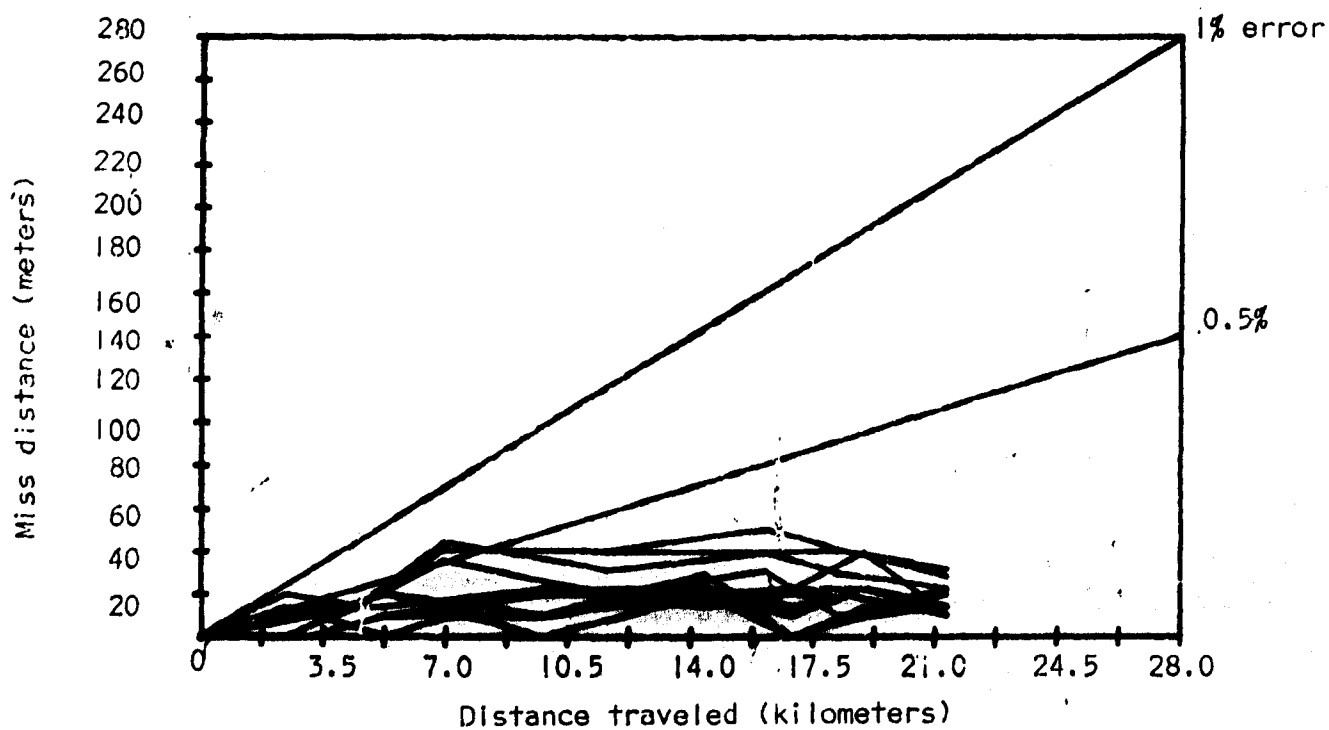


Figure C-1. Miss distance and percent error for distance traveled for runs conducted by the AGA vehicle navigation system mounted in the M113A1 traversing the closed loop, level course.

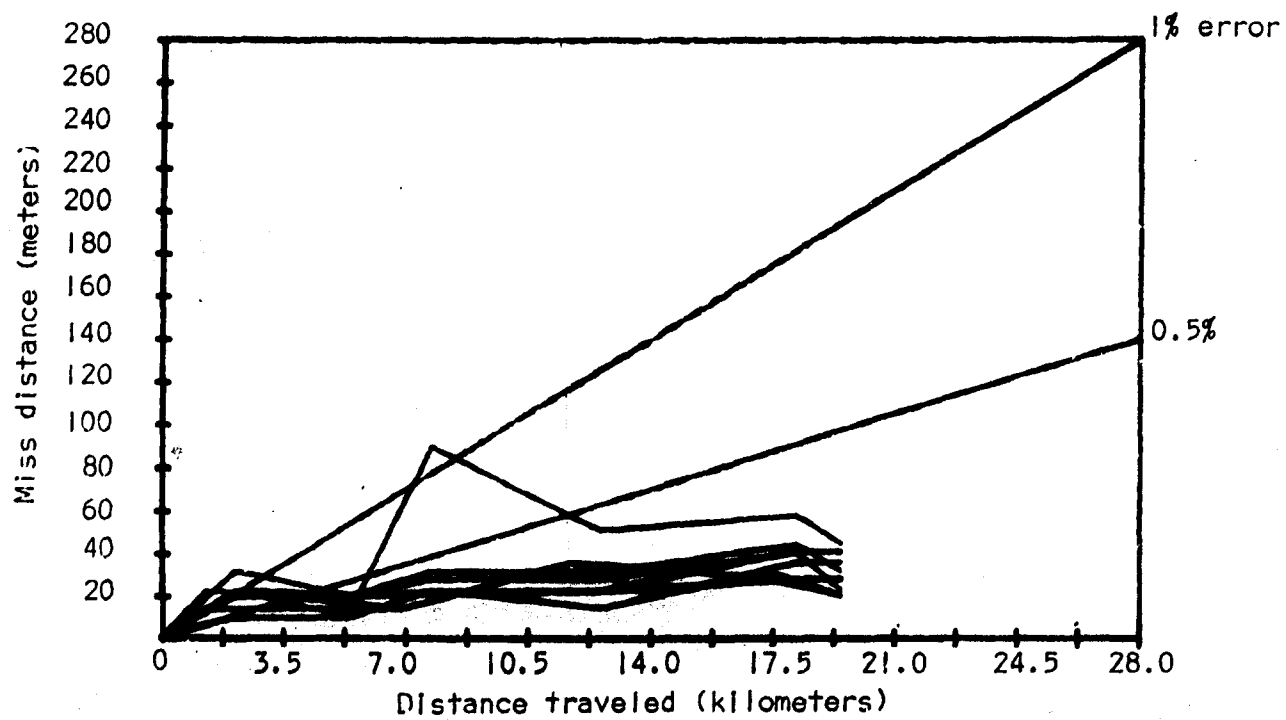


Figure C-2. Miss distance and runs conducted by the AGA vehicle navigation system mounted in the M113A1 traversing the closed loop, rough course.

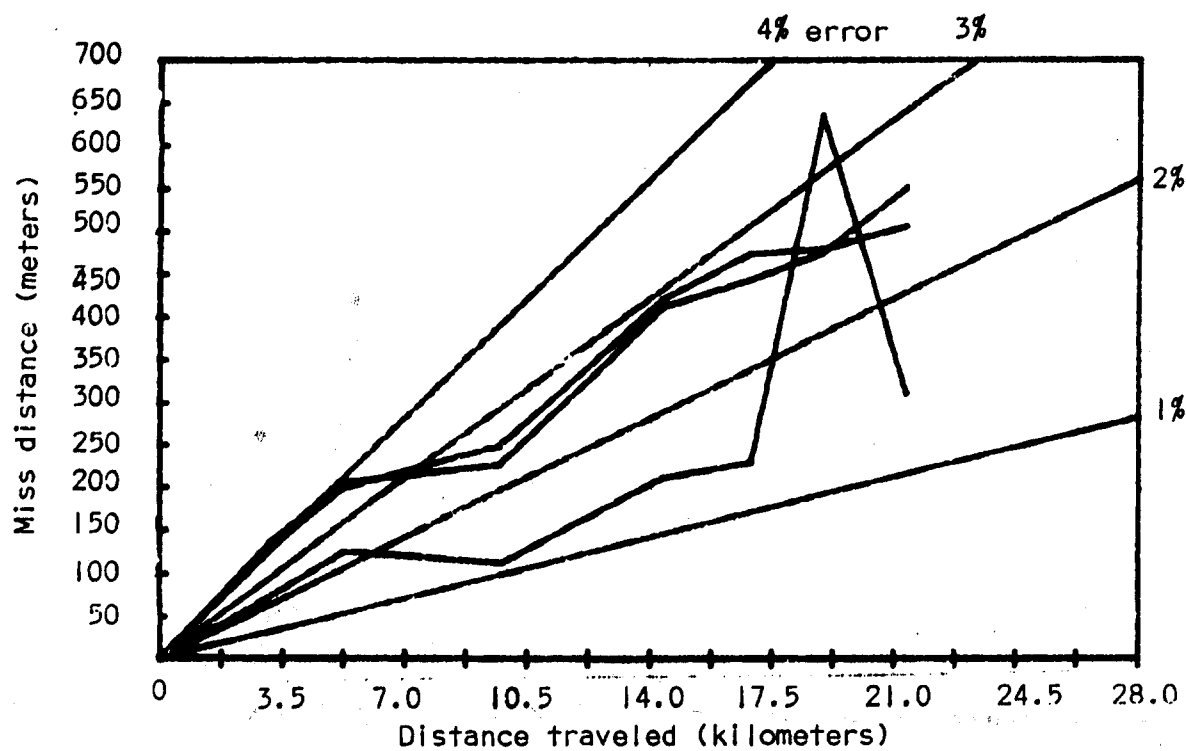


Figure C-3. Miss distance and runs conducted by the LWL/WHS vehicle navigation system mounted in the M113A1 traversing the closed loop, level course.

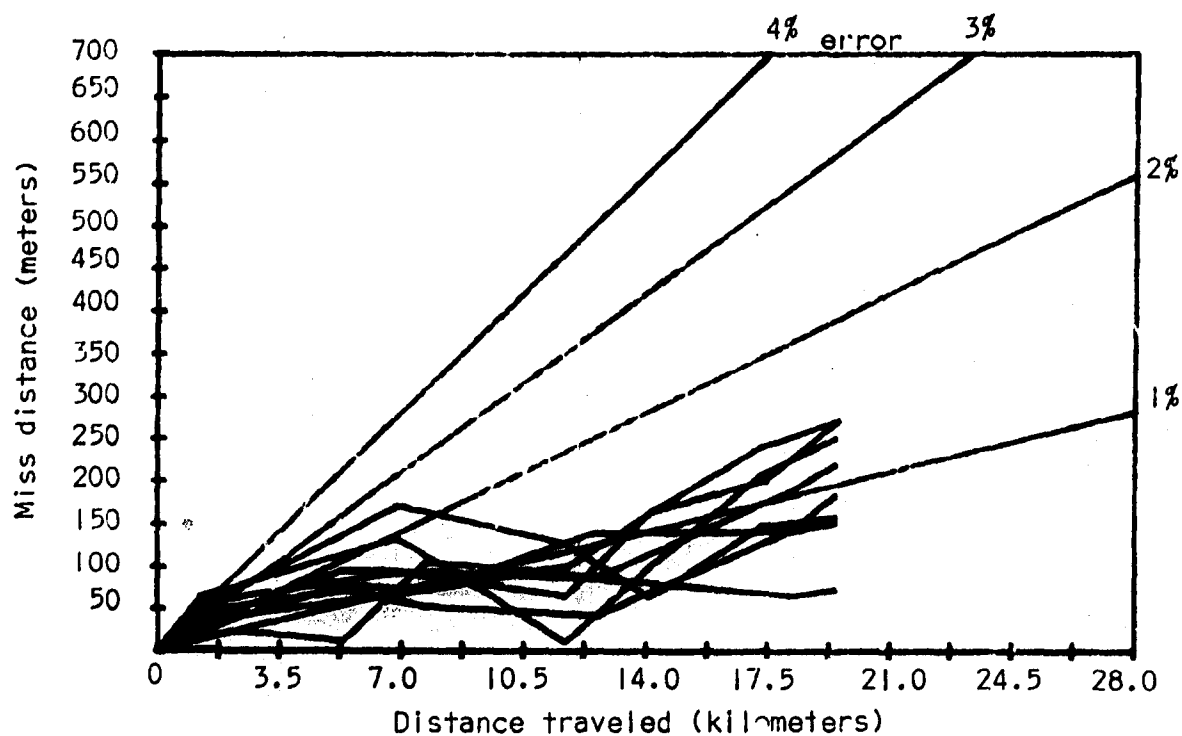


Figure C-4. Miss distance and runs conducted by the LWL/WHS vehicle navigation system mounted in the M113A1 traversing the closed loop, rough course.

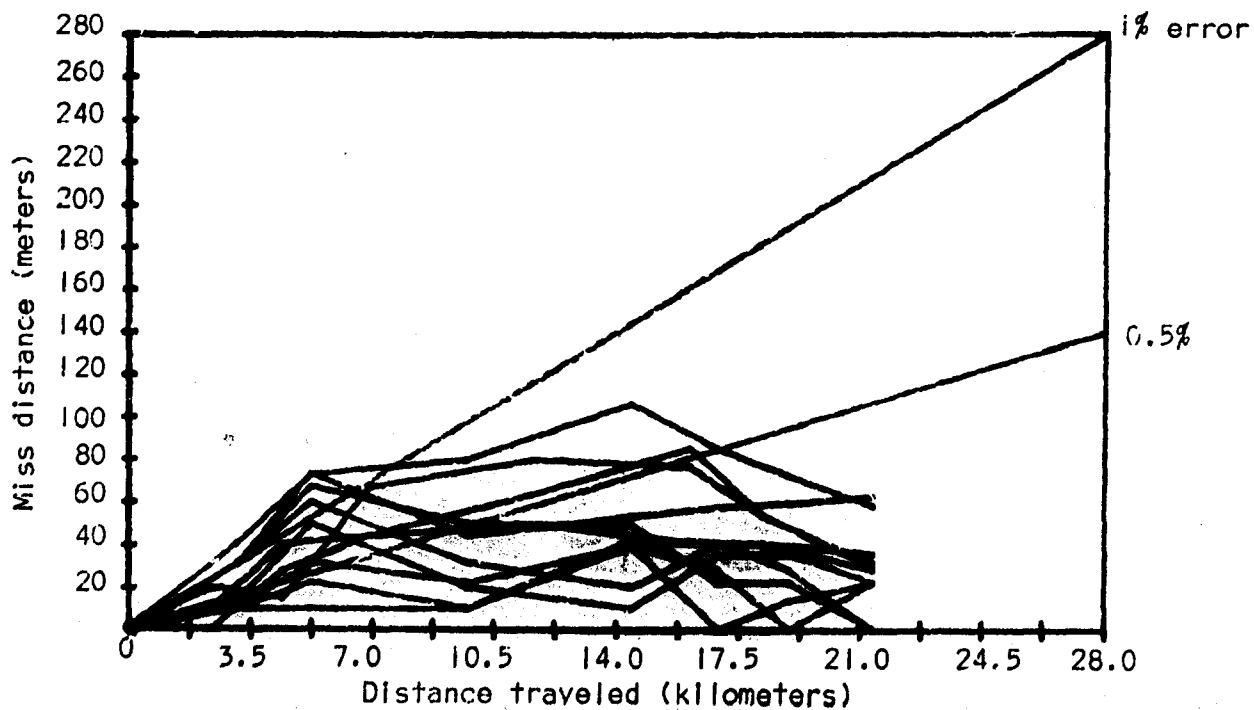


Figure C-5. Miss distance and runs conducted by the AGA vehicle navigation system mounted in the M151A2 traversing the closed loop, level course.

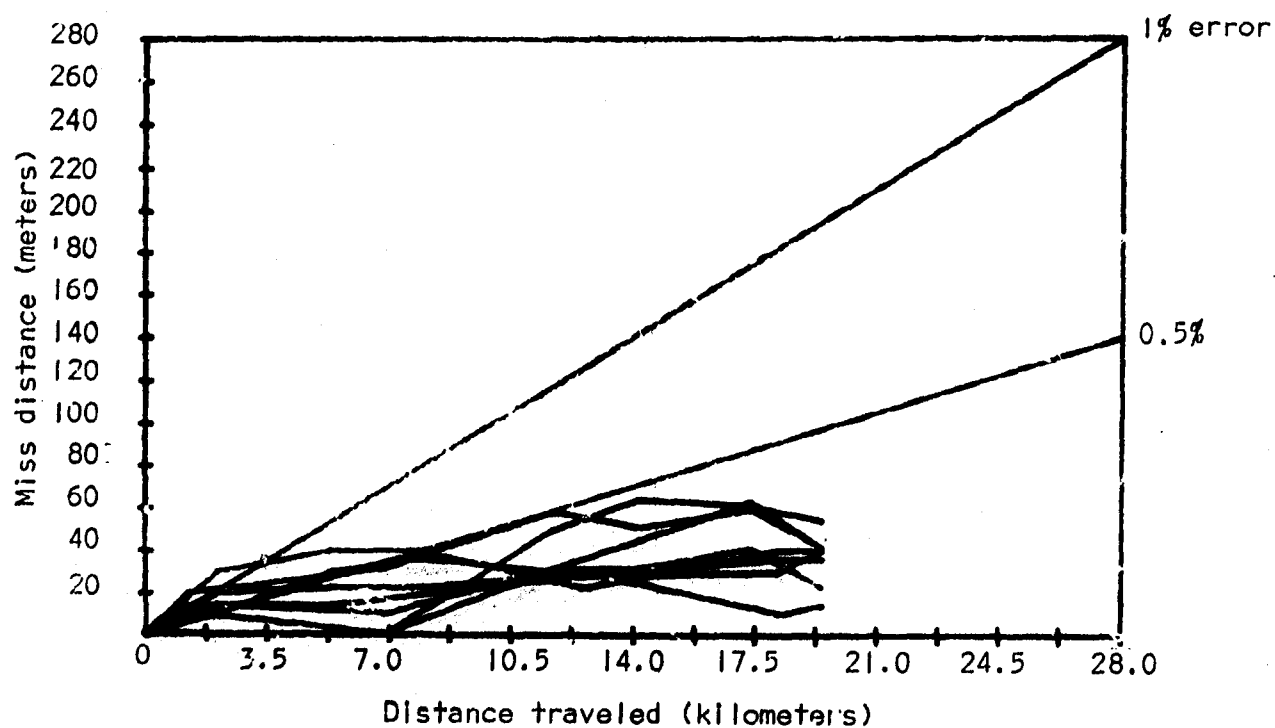


Figure C-6. Miss distance and runs conducted by the AGA vehicle navigation system mounted in the M151A2 traversing the closed loop, rough course.

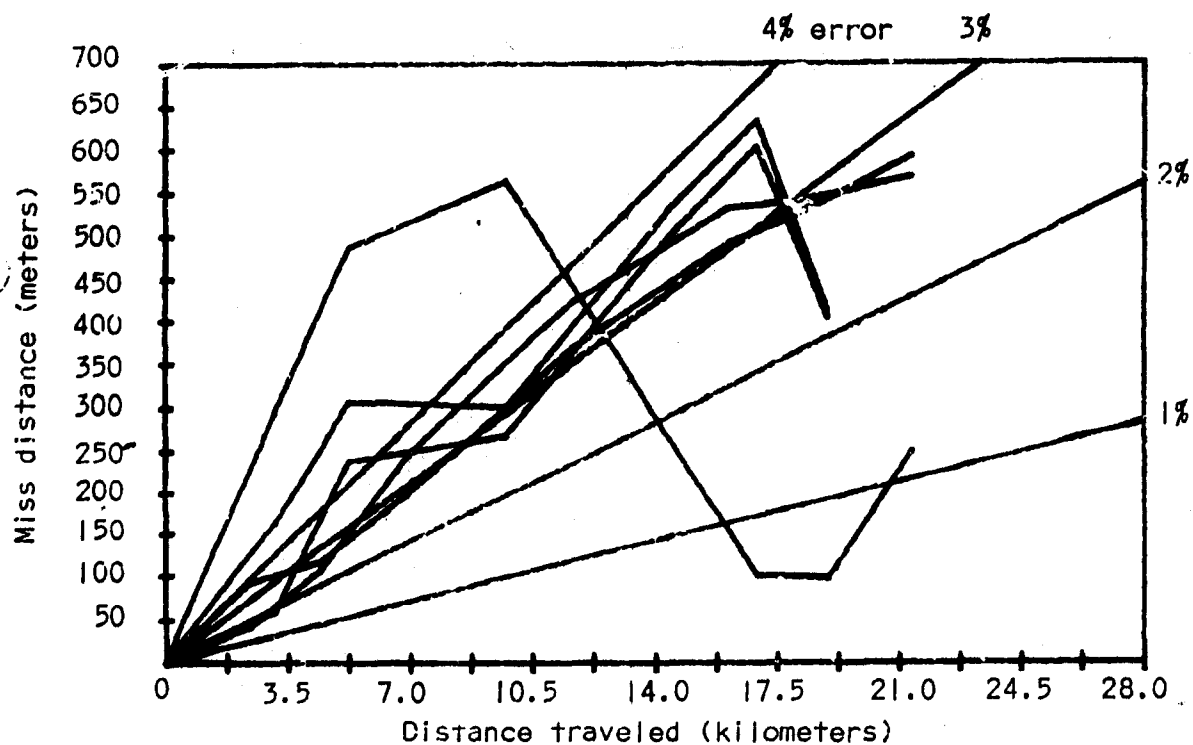


Figure C-7. Miss distance and runs conducted by the LWL/WHS vehicle navigation system mounted in the M151A2 traversing the closed loop, level course.

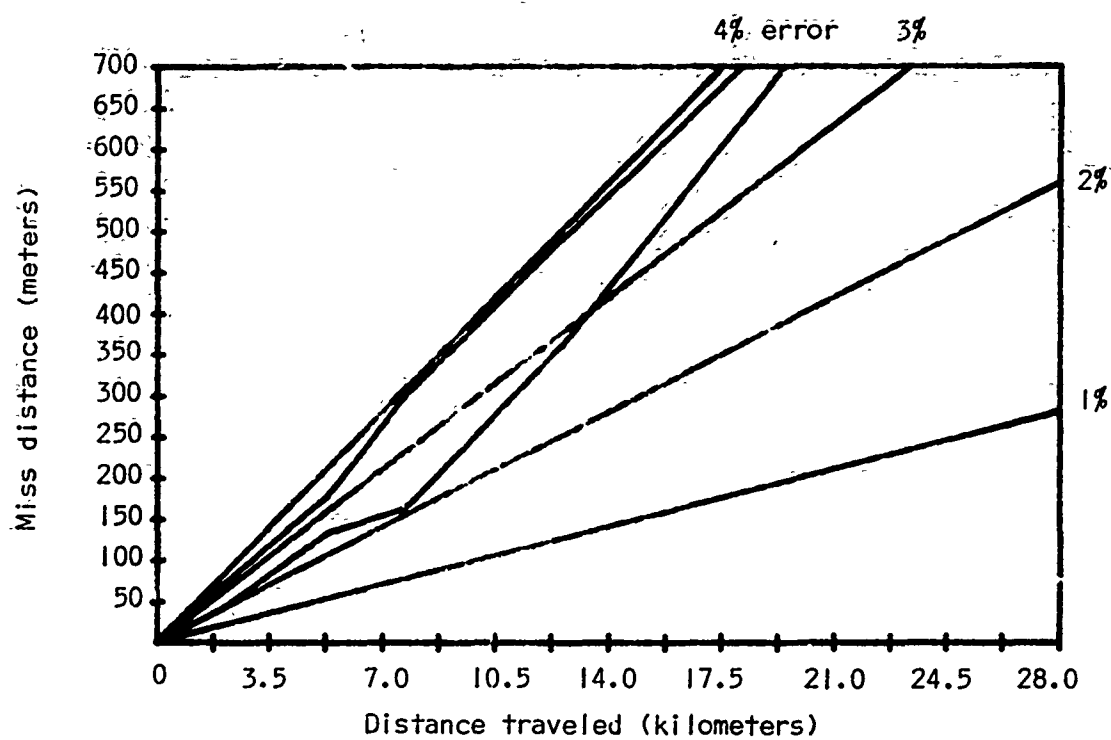


Figure C-8. Miss distance and runs conducted by the LWL/WHS vehicle navigation system mounted in the M151A2 traversing the closed loop, rough course.

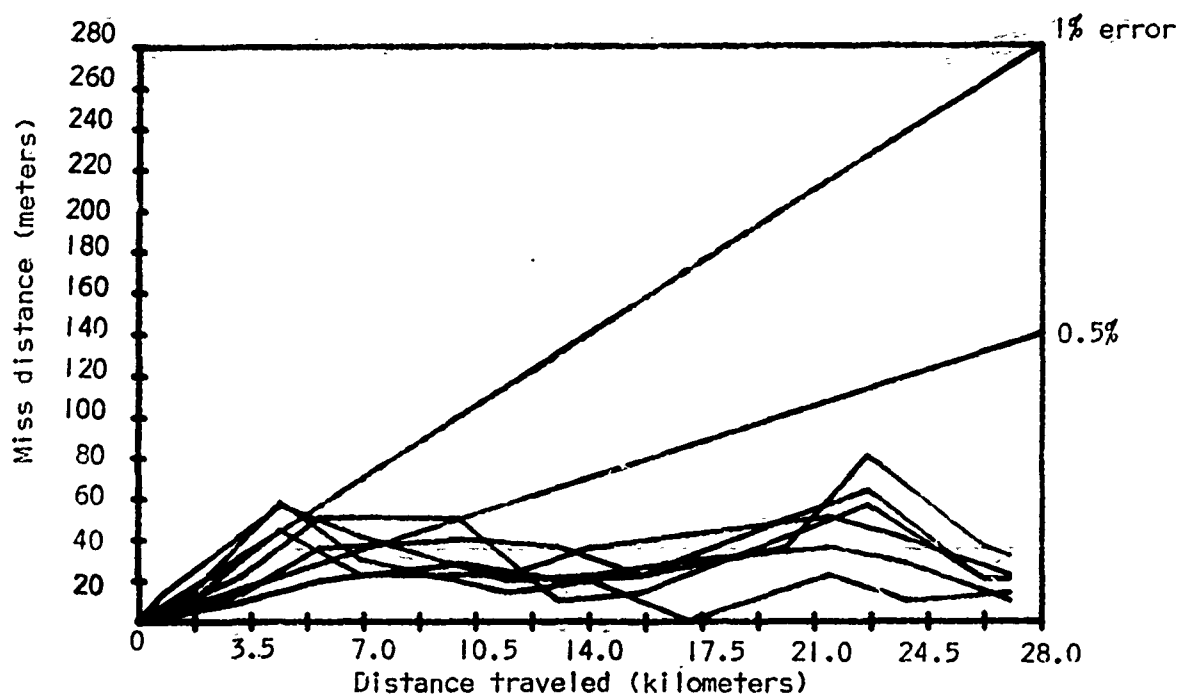


Figure C-9. Miss distance and runs conducted by the AGA vehicle navigation system mounted in the M13A1 traversing the open end, level course.

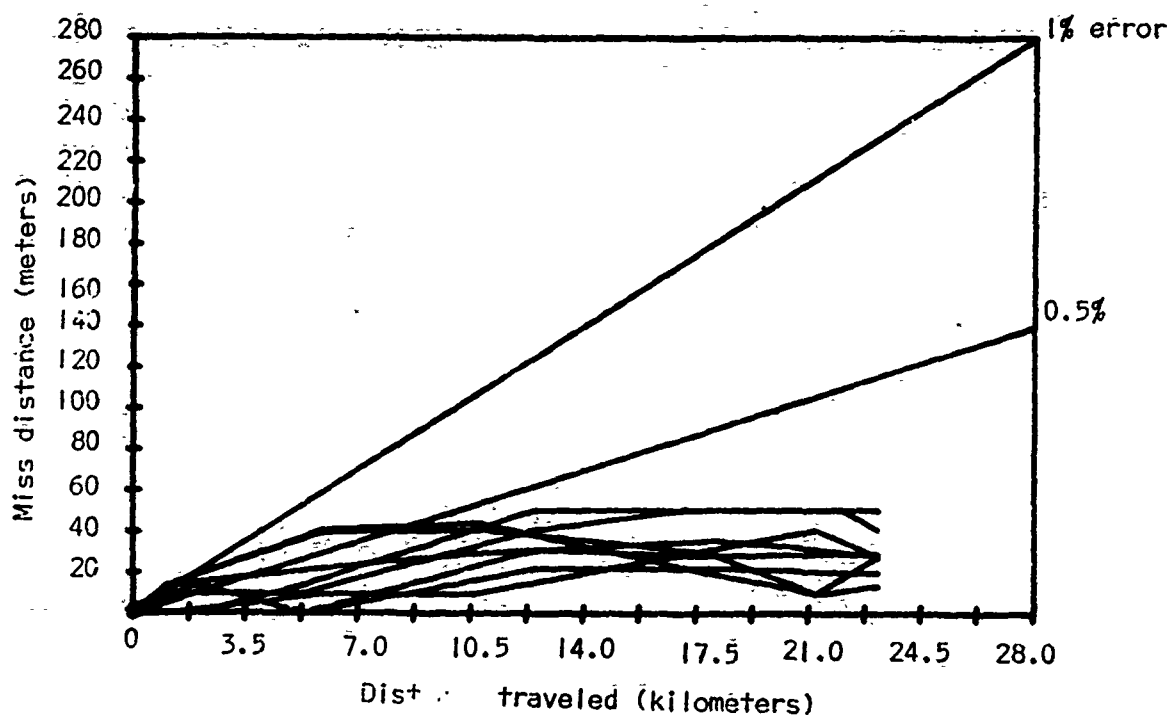


Figure C-10. Miss distance and runs conducted by the AGA vehicle navigation system mounted in the M113A1 traversing the open end, rough course.

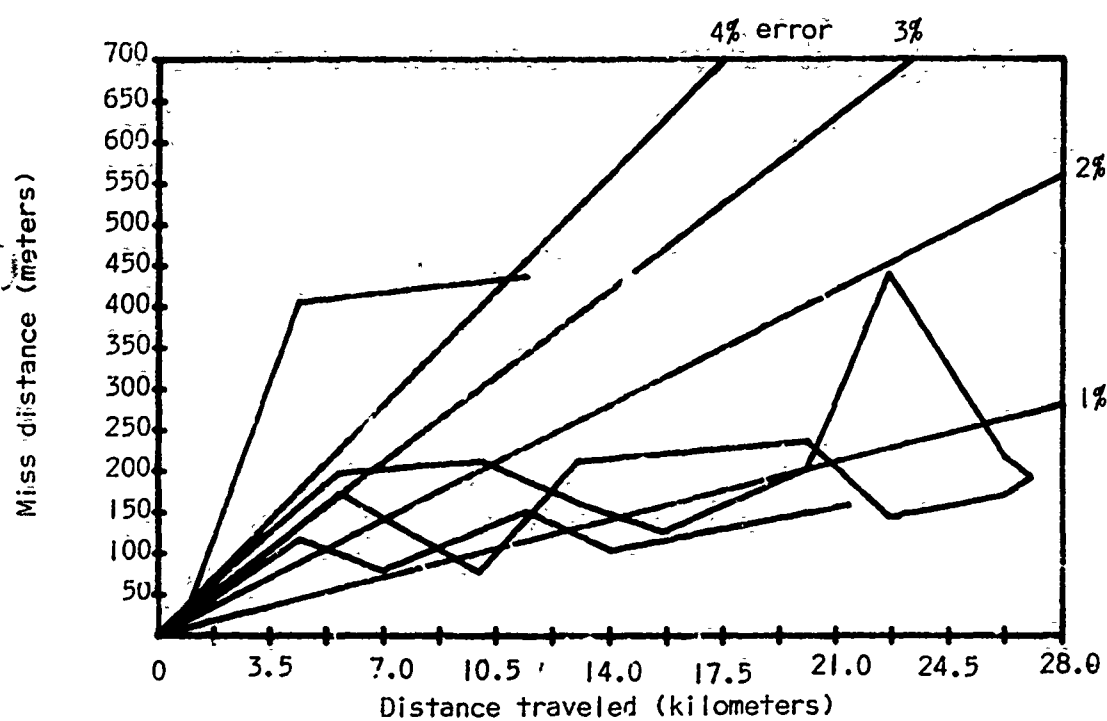


Figure C-11. Miss distance and runs conducted by the LWL/WHS vehicle navigation system mounted in the M113A1 traversing the open end, level course.

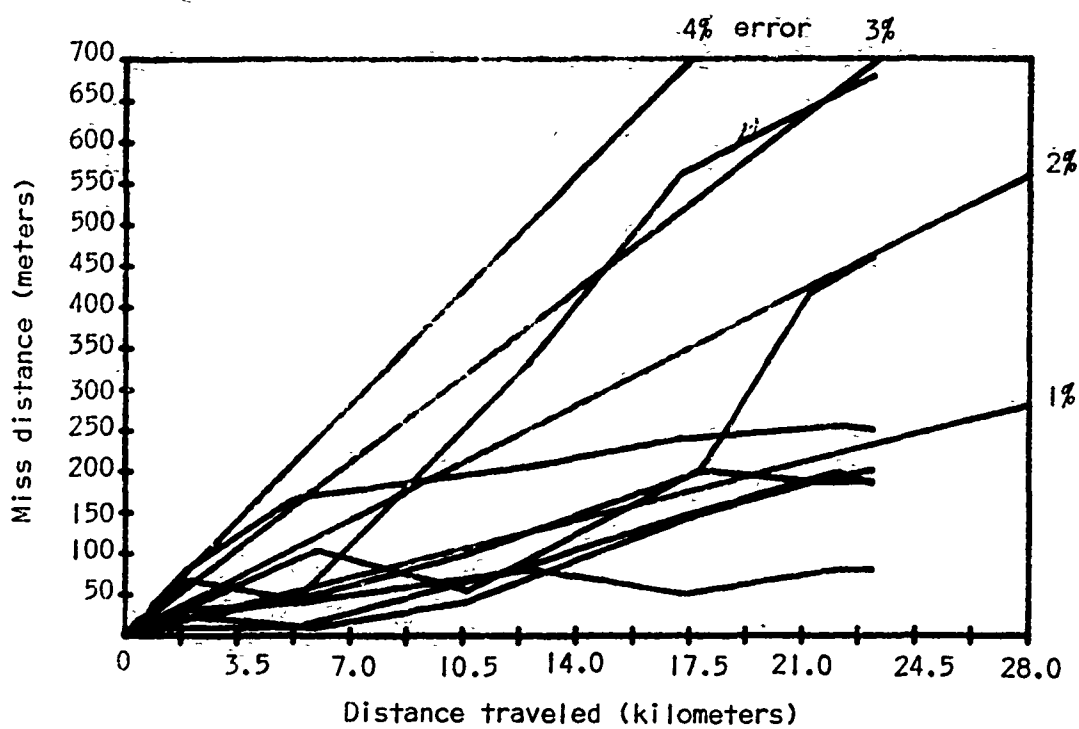


Figure C-12. Miss distance and runs conducted by the LWL/WHS vehicle navigation system mounted in the M113A1 traversing the open end, rough course.

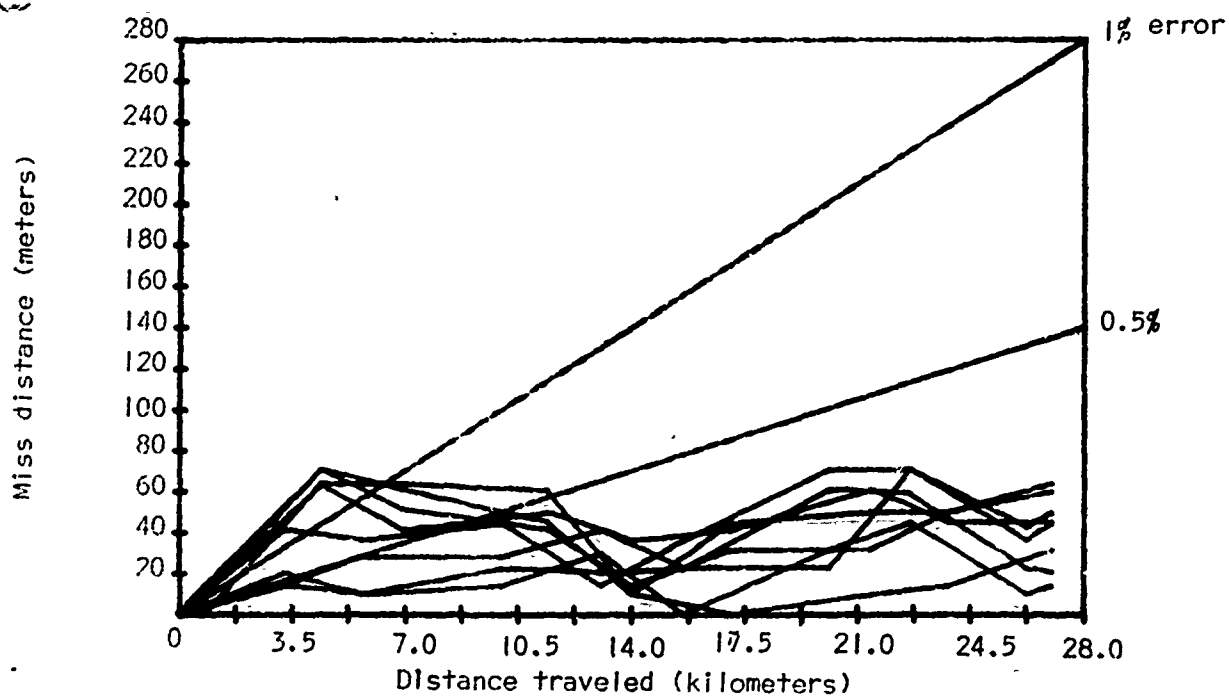


Figure 6-13. Miss distance and runs conducted by the AGA vehicle navigation system mounted in the MI51A2 traversing open end, level course.

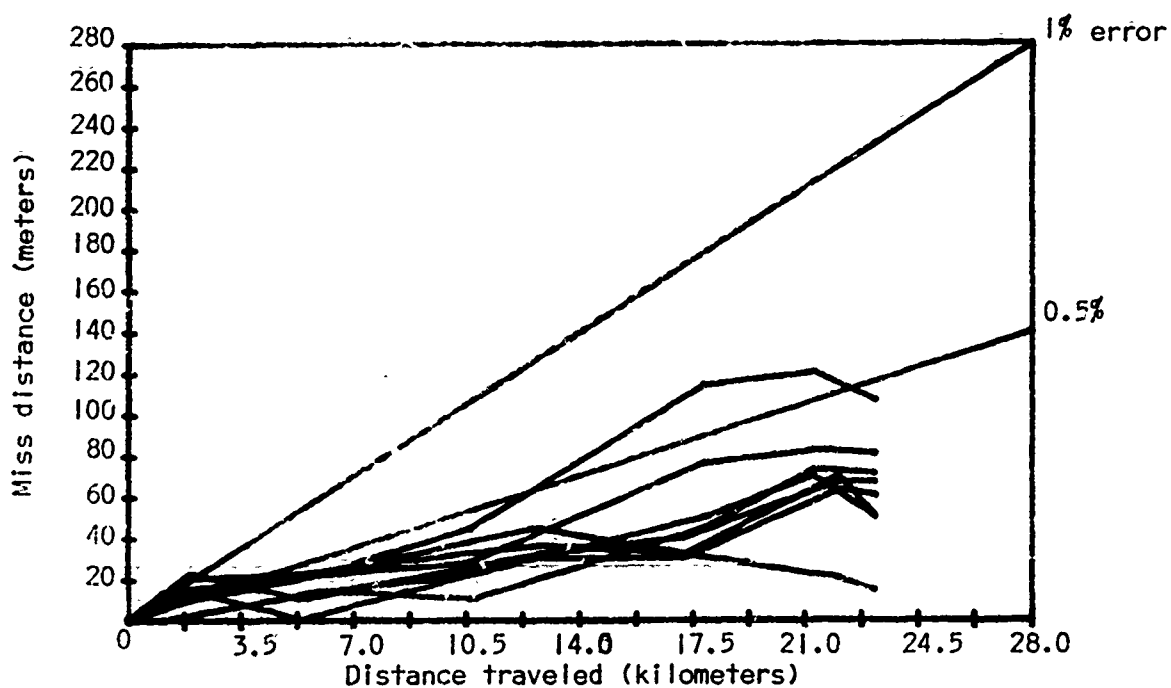


Figure C-14. Miss distance and runs conducted by the AGA vehicle navigation system mounted in the M151A2 traversing the open end, rough course.

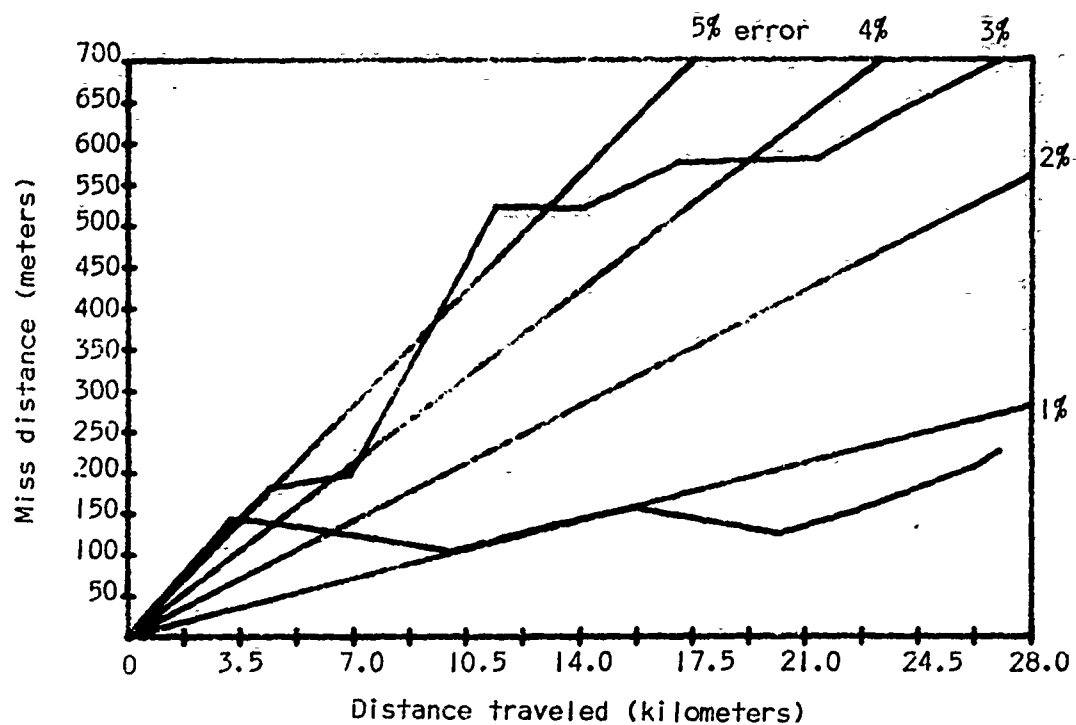


Figure C-15. Miss distance and runs conducted by the LWL/WHS vehicle navigation system mounted in the M151A2 traversing the open end, level course.

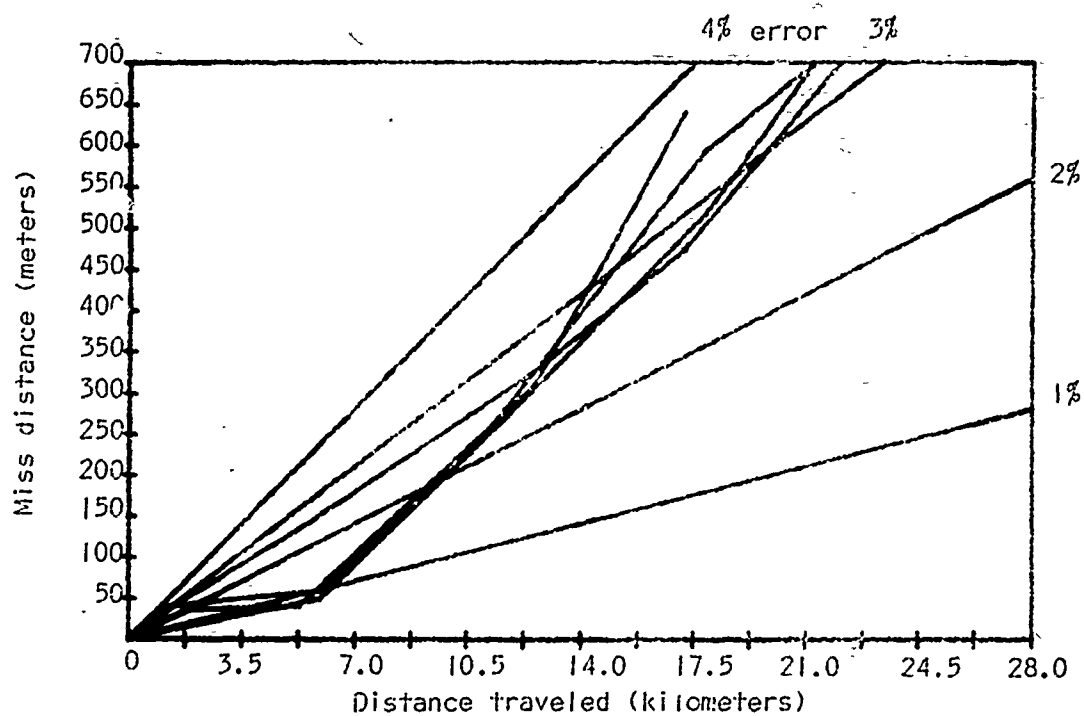


Figure C-16. Miss distance and runs conducted by the LWL/WHS vehicle navigation system mounted in the M151A2 traversing the open end, rough course.

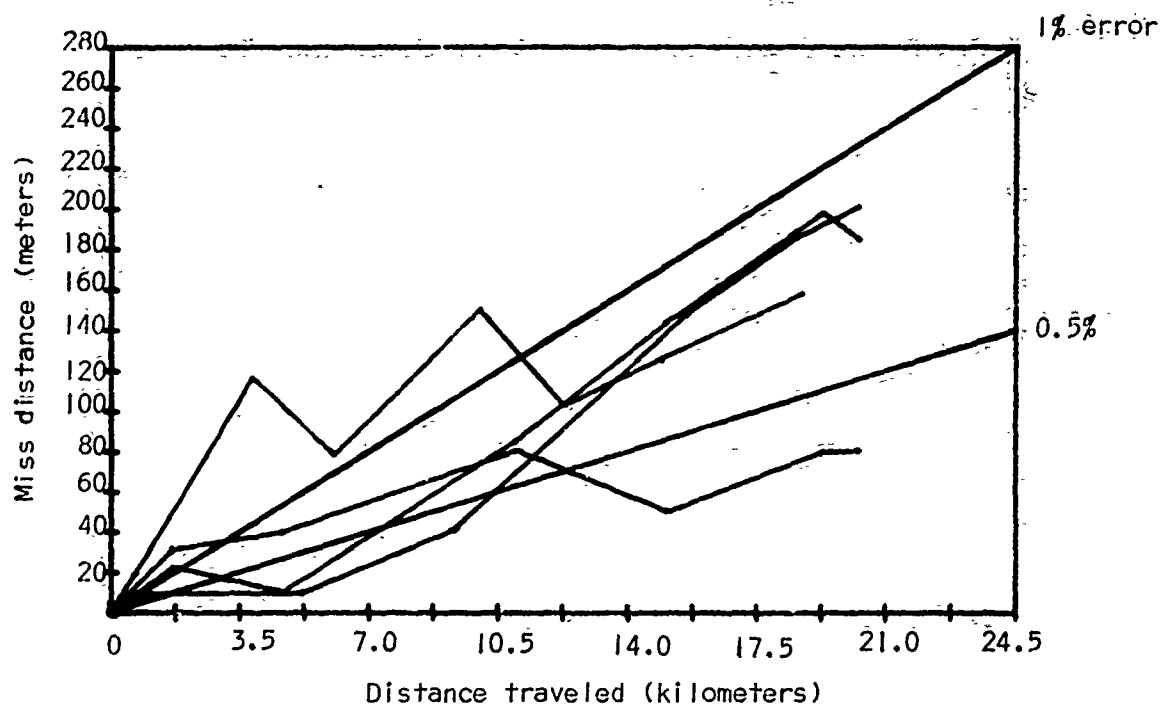


Figure C-17. Sample accuracies (miss distance and percent error for distance traveled) of the LWL/WHS vehicle land navigation system mounted in an M113A1.

(S) = First run of the day.
 (F) = Last run of the day.

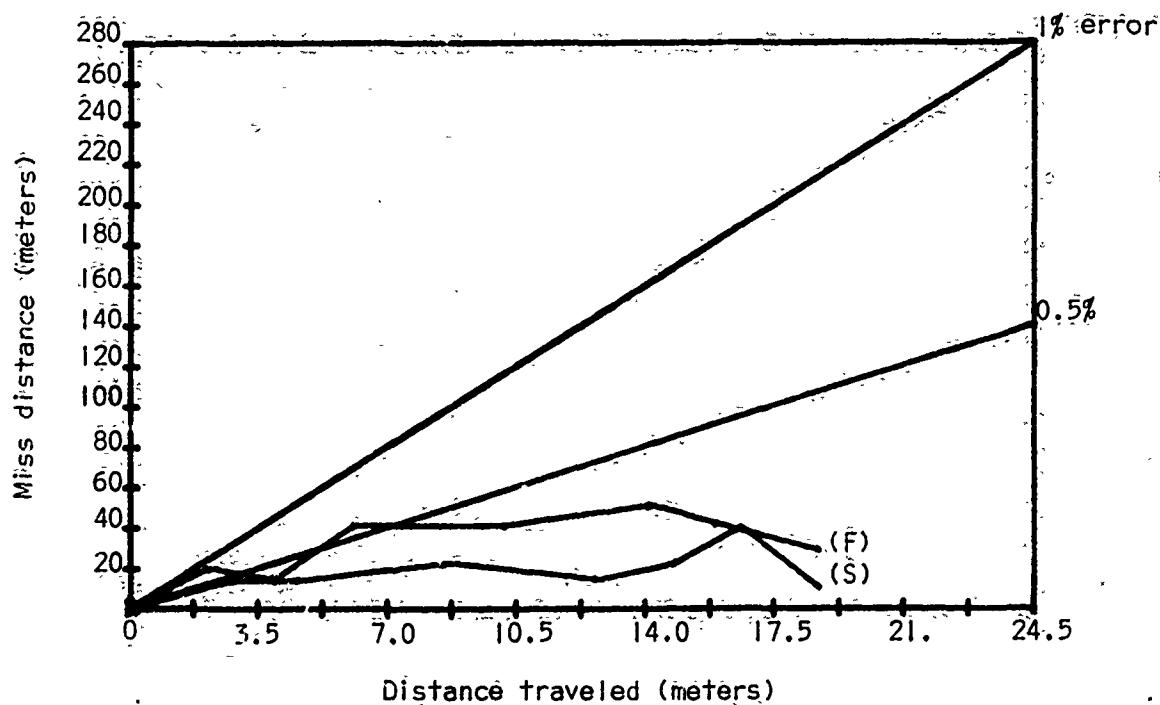


Figure C-18. Miss distance and percent error for distance traveled for the ANS-150K vehicle navigation system at the start of the day and after 7 1/2 hours of continuous operation with no gyro realignment for a drift.

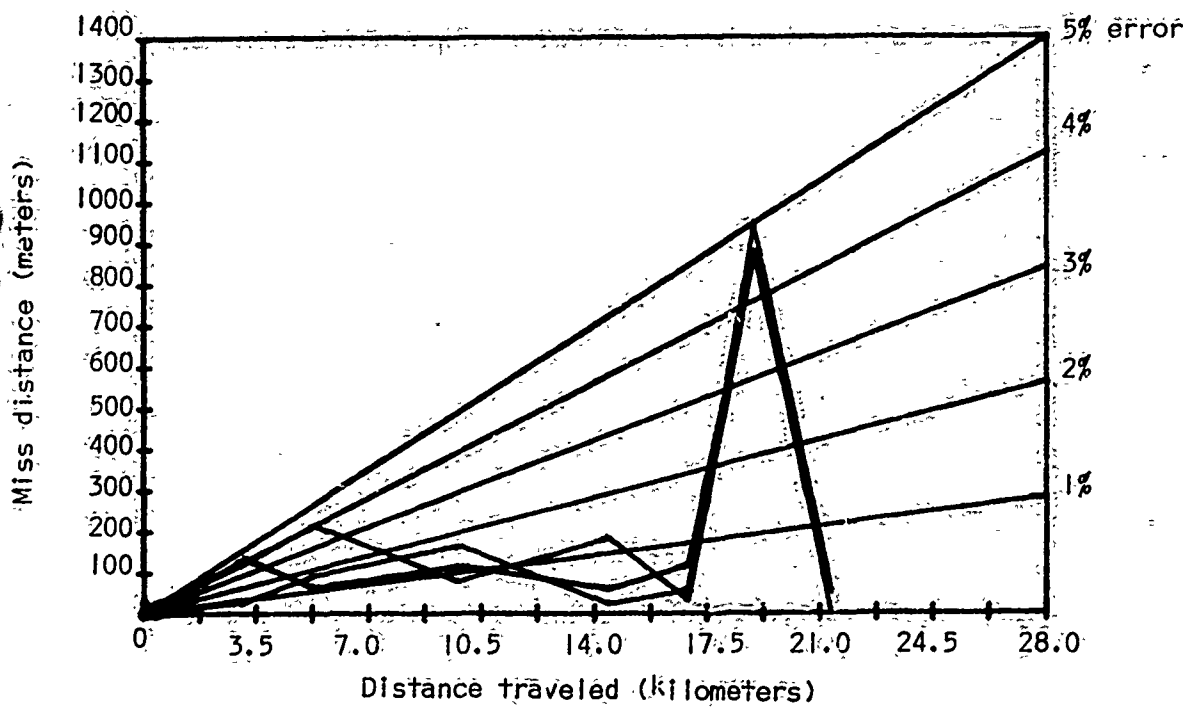


Figure C-19. Miss distance and runs conducted using a map and compass in the M151A2 traversing the open end, level course.

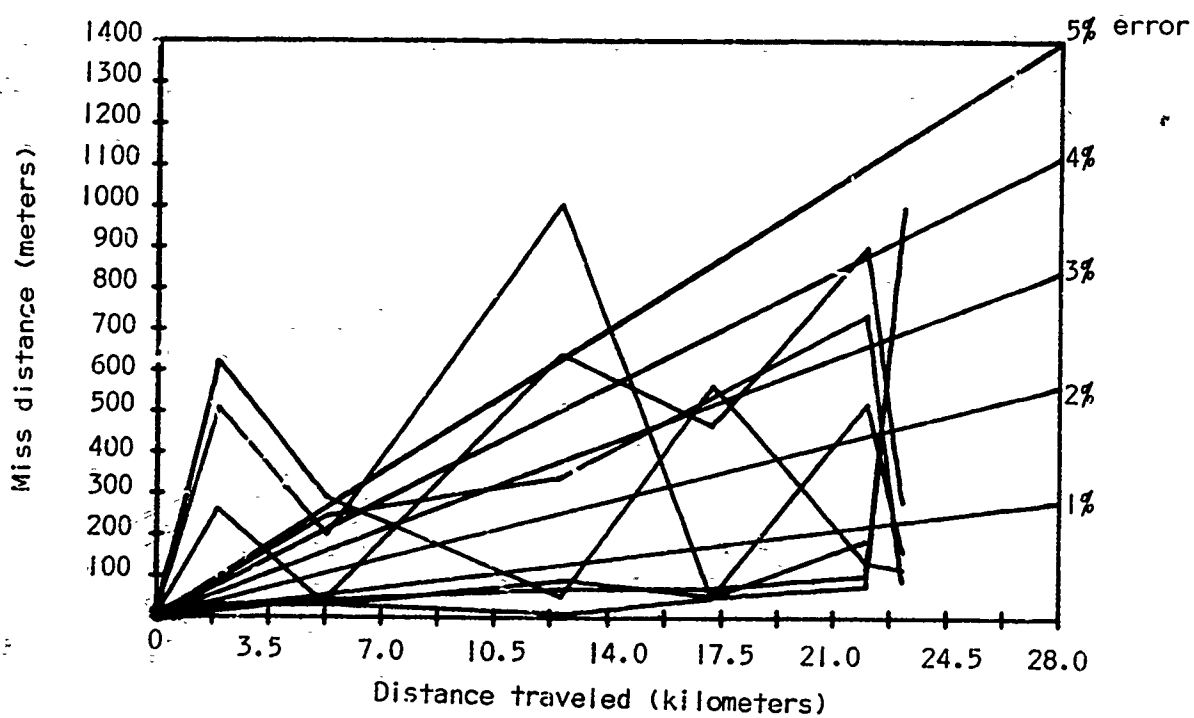


Figure C-20. Miss distance and runs conducted using a map and compass in the M151A2 traversing the open end, rough course traveling south.

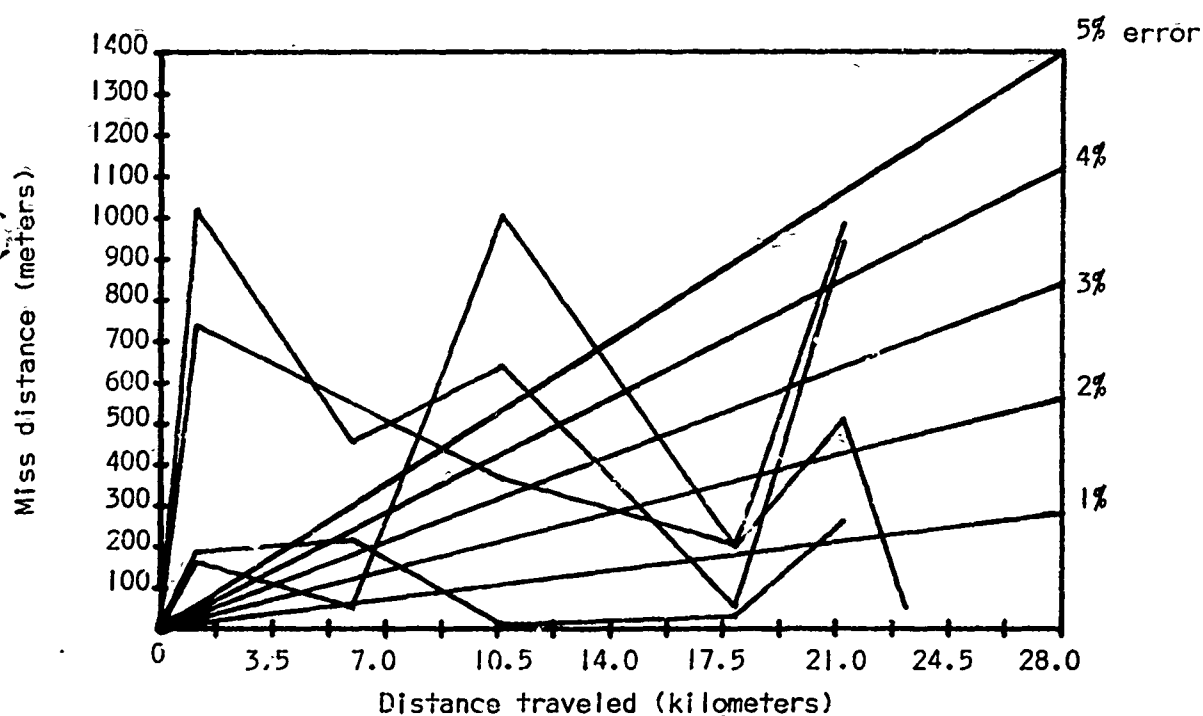


Figure C-21. Miss distance and runs conducted using a map and compass in the M151A2 traversing the open end, rough course traveling north.

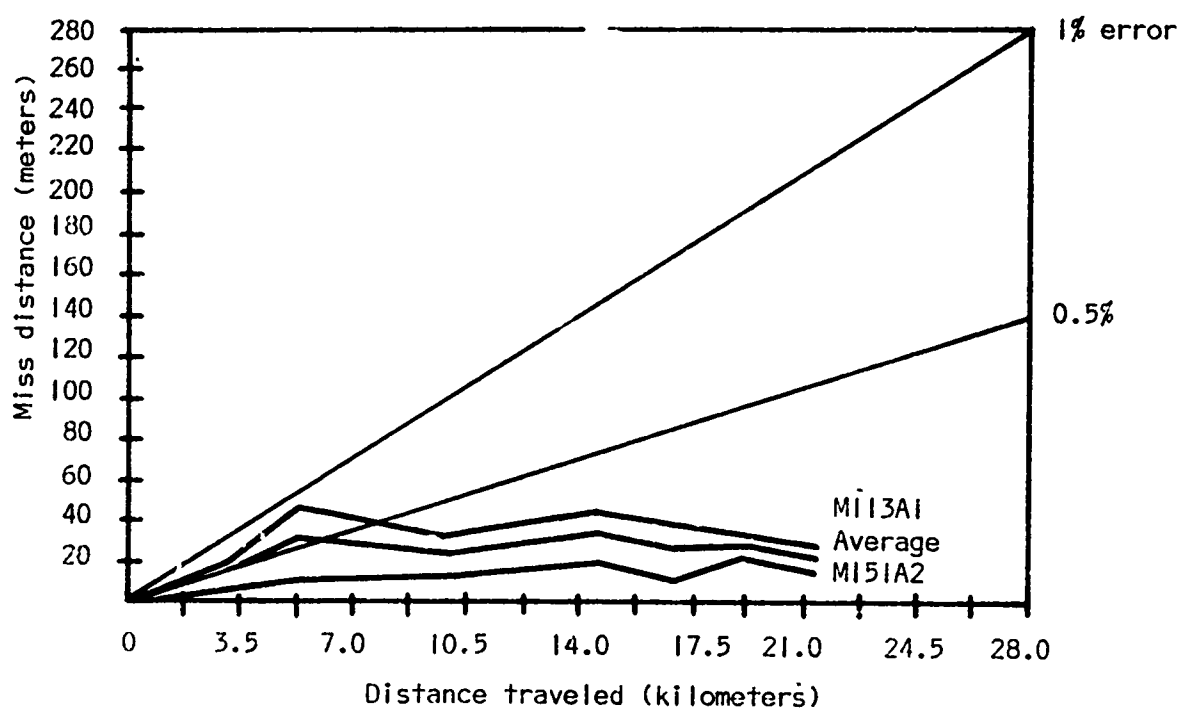


Figure C-22. Average miss distance and percent error for distance traveled for the AGA vehicle navigation system mounted in an M113A1 and M151A2; and the system average for the closed level course traveling clockwise.

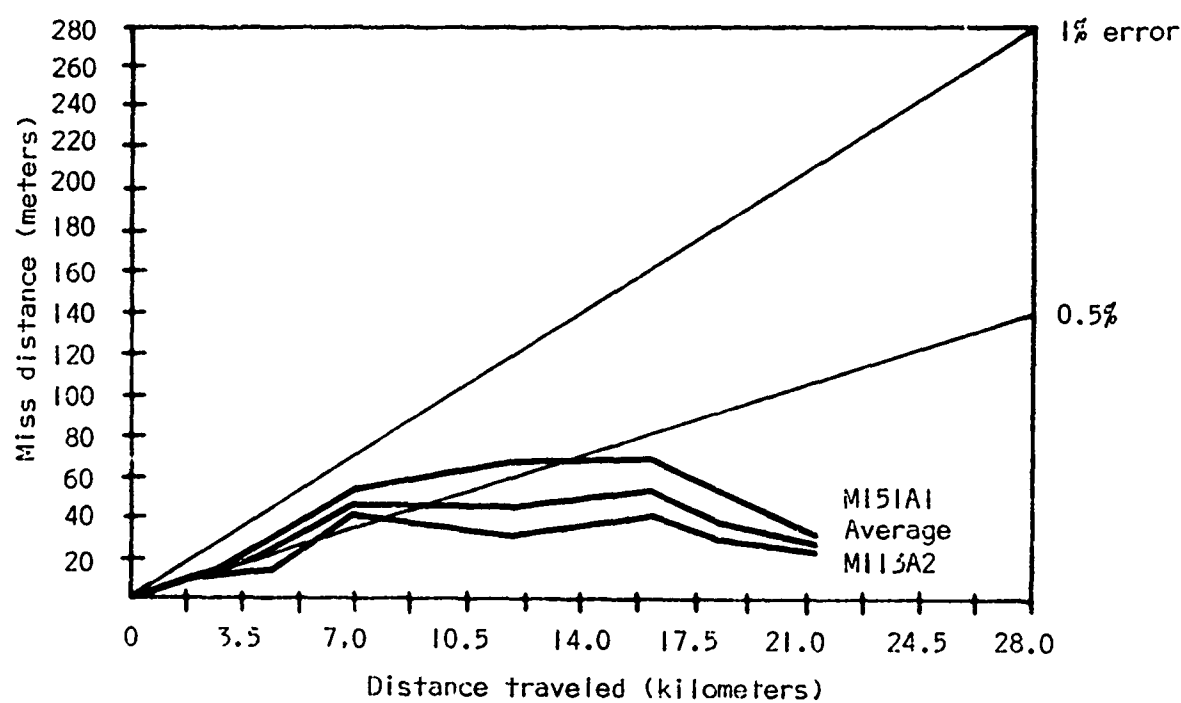


Figure C-23. Average miss distance and percent error for distance traveled for the AGA vehicle navigation system mounted in an MI13A1 and MI51A2; and the system average for the closed level course traveling counterclockwise.

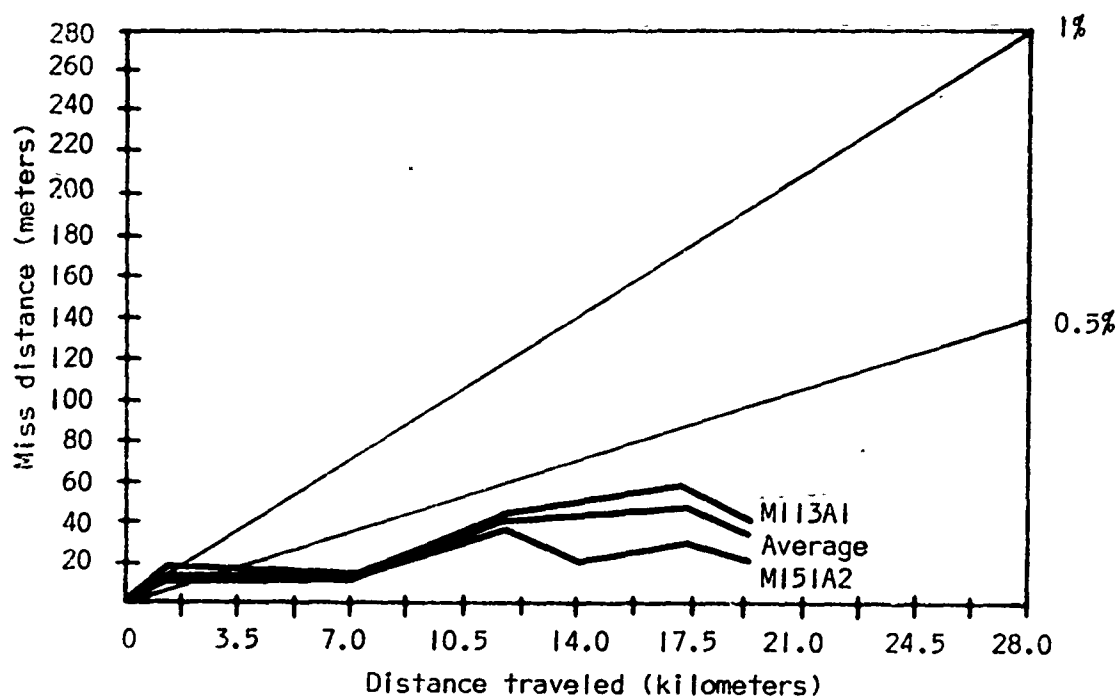


Figure C-24. Average miss distance and percent error for distance traveled for the AGA vehicle land navigation system mounted in an M113A1 and M151A2; and the system average for the closed rough course traveling clockwise.

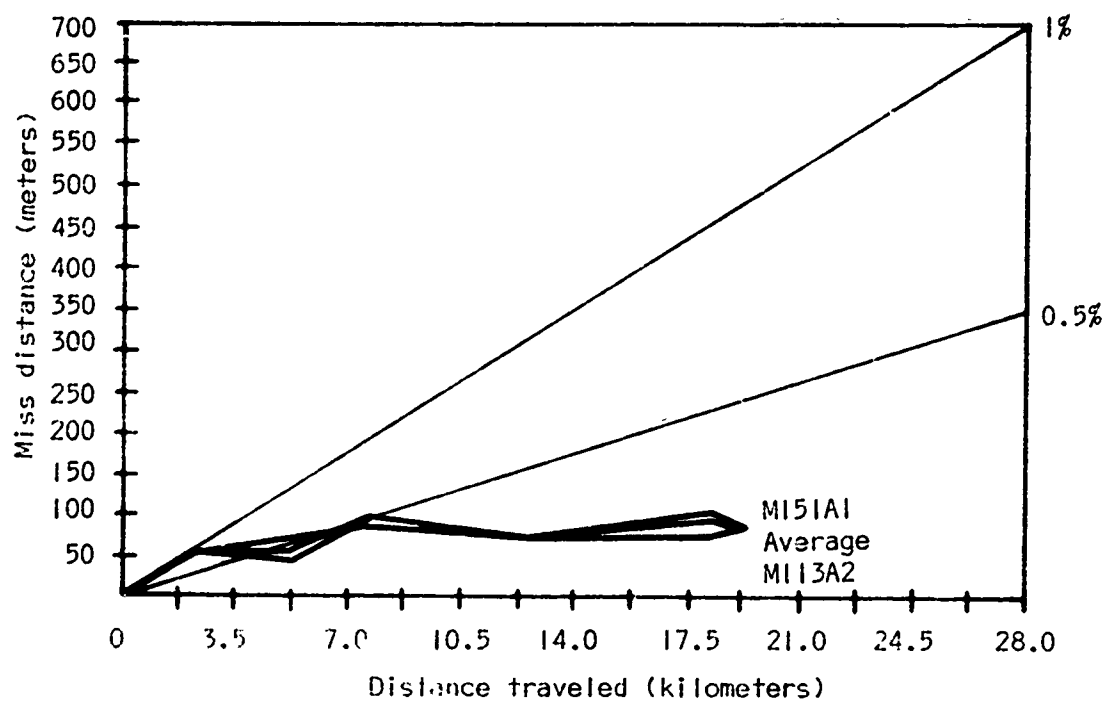


Figure C-25. Average miss distance and percent error for distance traveled for the AGA vehicle land navigation system mounted in an MI13A1 and MI51A2; and the system average for the closed rough course traveling counterclockwise.

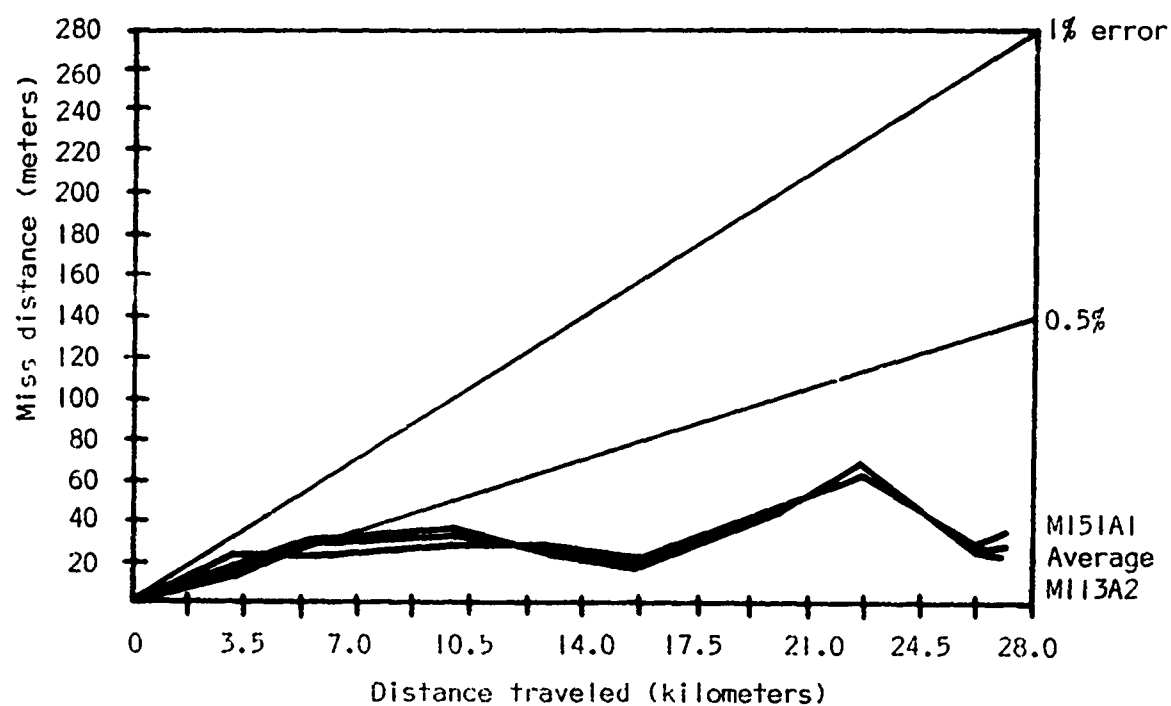


Figure C-26. Average miss distance and percent error for distance traveled for the AGA vehicle navigation system mounted in an M113A1 and M151A2; and the system average for the open level course traveling north.

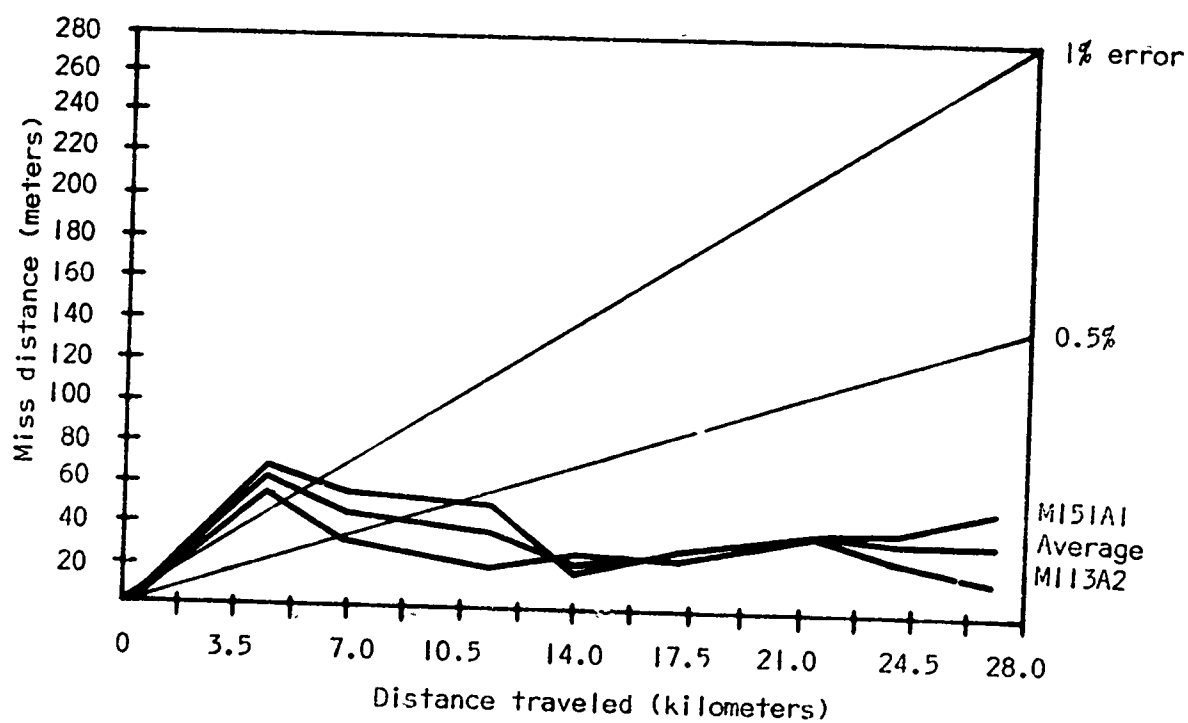


Figure C-27. Average miss distance and percent error for distance traveled for the AGA vehicle navigation system mounted on an MI13A1 and MI13A2; and the system average for the open level course traveling south.

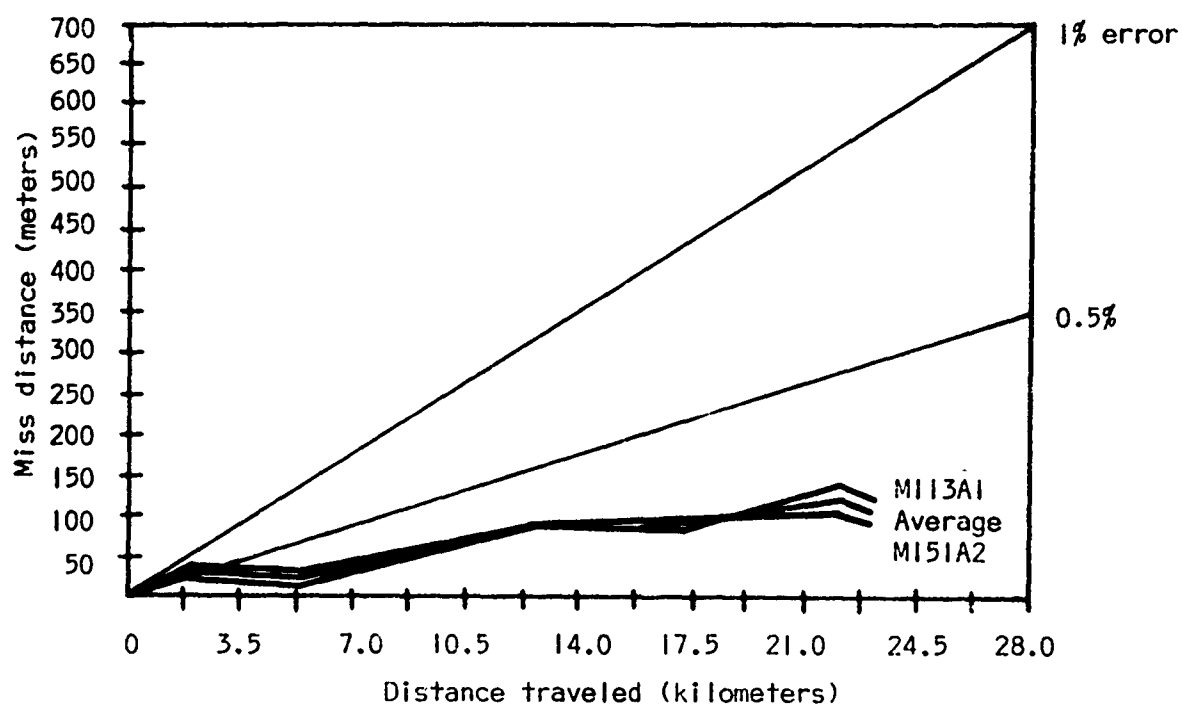


Figure C-28. Average miss distance and percent error for distance traveled for the AGA vehicle land navigation system mounted in an MI13A1 and MI51A2; and the system average for the open rough course traveling north.

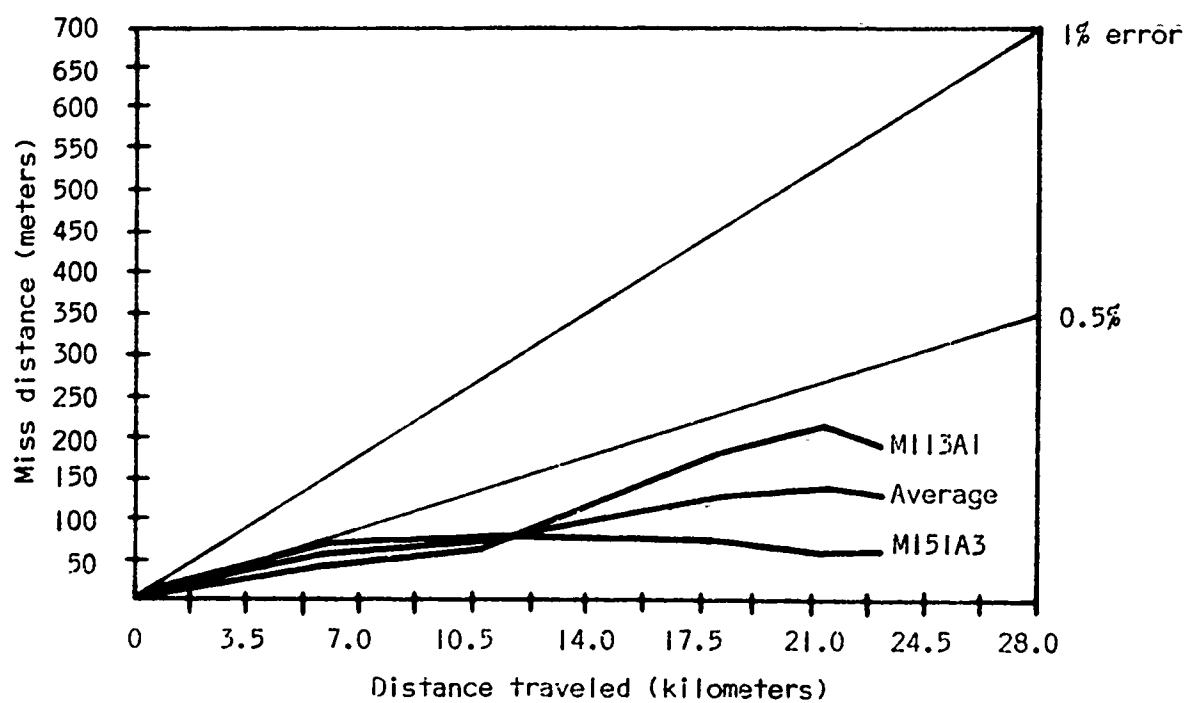


Figure C-29. Average miss distance and percent error for distance traveled for the AGA vehicle land navigation system mounted in an MI13A1, and MI51A3; and the system average for the open rough course traveling south.

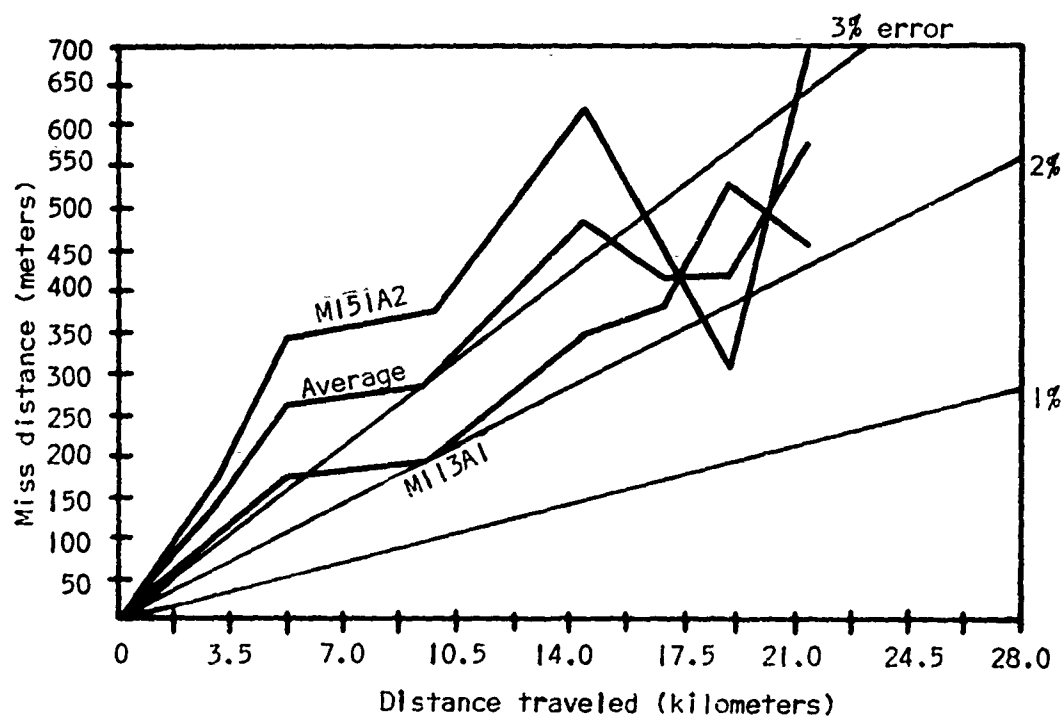


Figure C-30. Miss distance and percent error for distance traveled for the LWL/WHS vehicle land navigation system on the closed level course traveling clockwise.

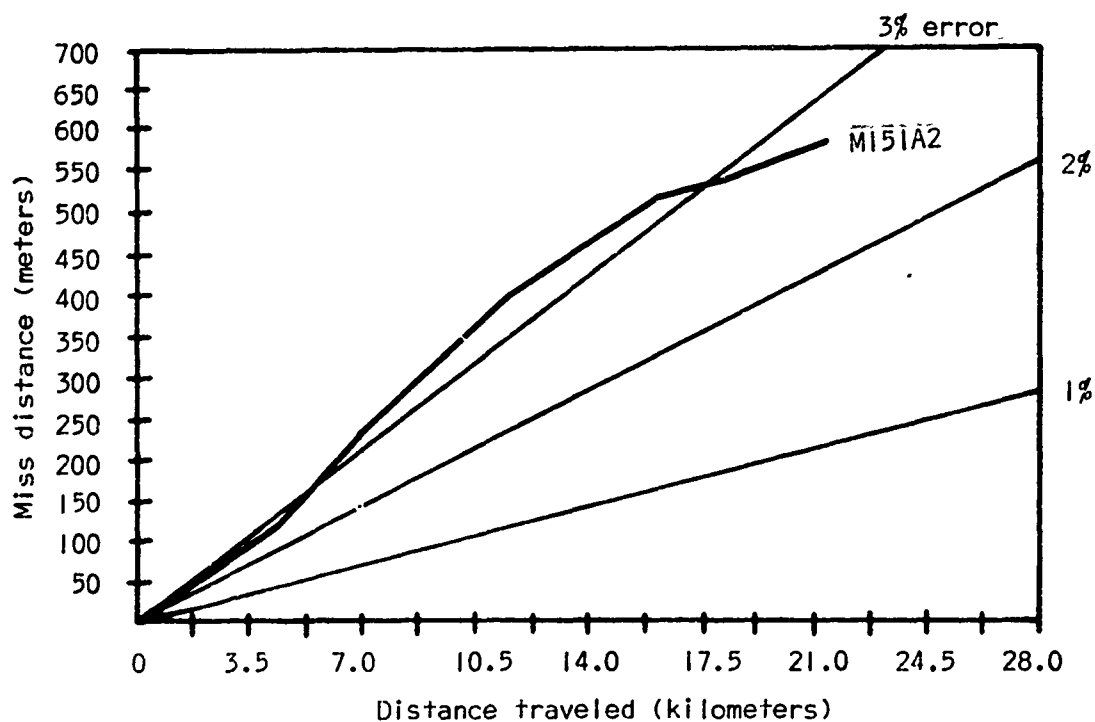


Figure C-31. Miss distance and percent error for distance traveled for the LWL/WHS vehicle land navigation system on the closed level course traveling counterclockwise.

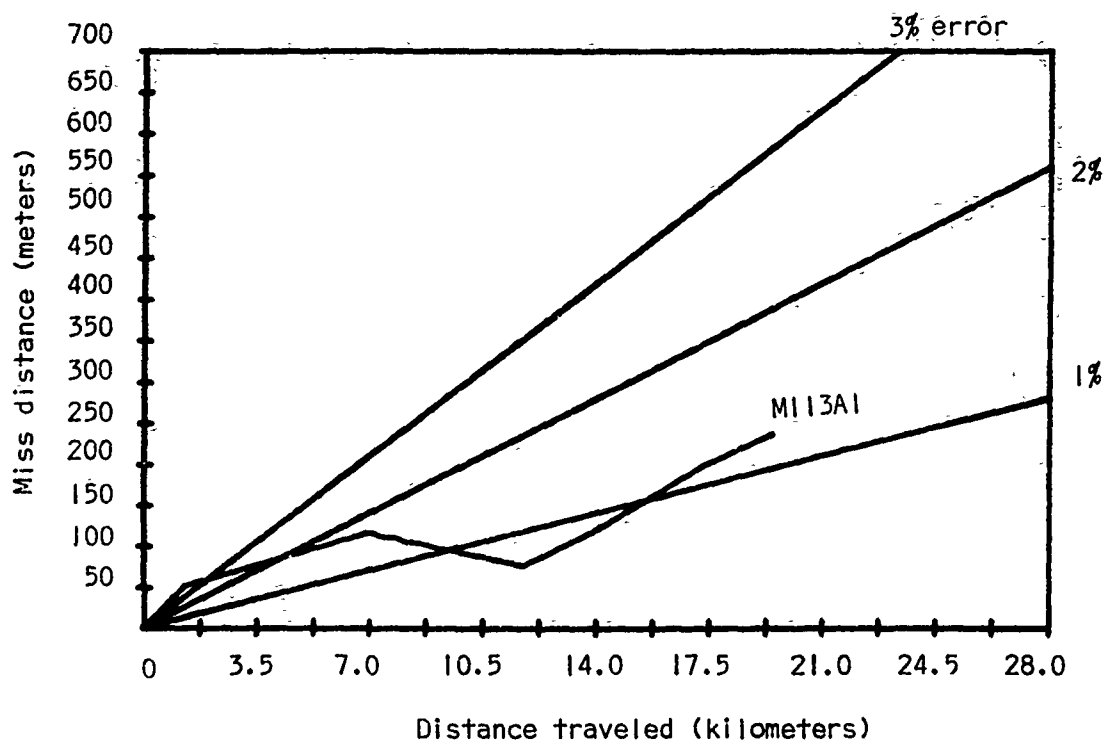


Figure C-32. Miss distance and percent error for distance traveled for the LWL/WHS vehicle land navigation system on the closed rough course traveling clockwise.

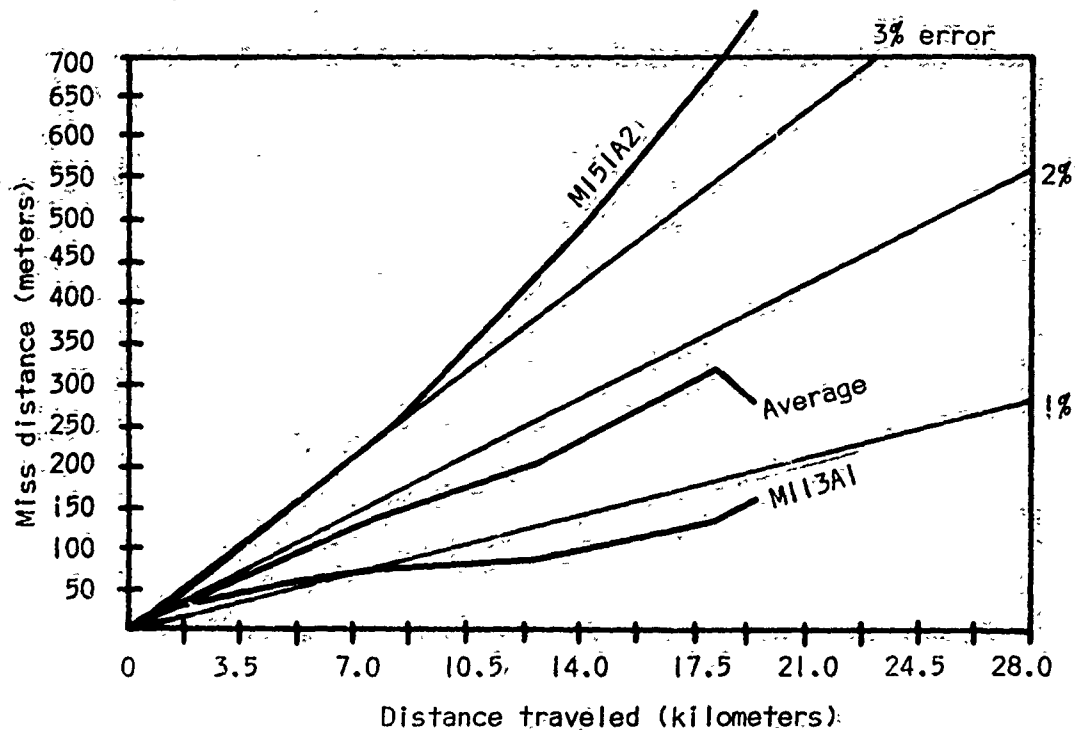


Figure C-33. Miss distance and percent error for distance traveled for the LWL/WHS vehicle land navigation system on the closed rough course traveling counterclockwise.

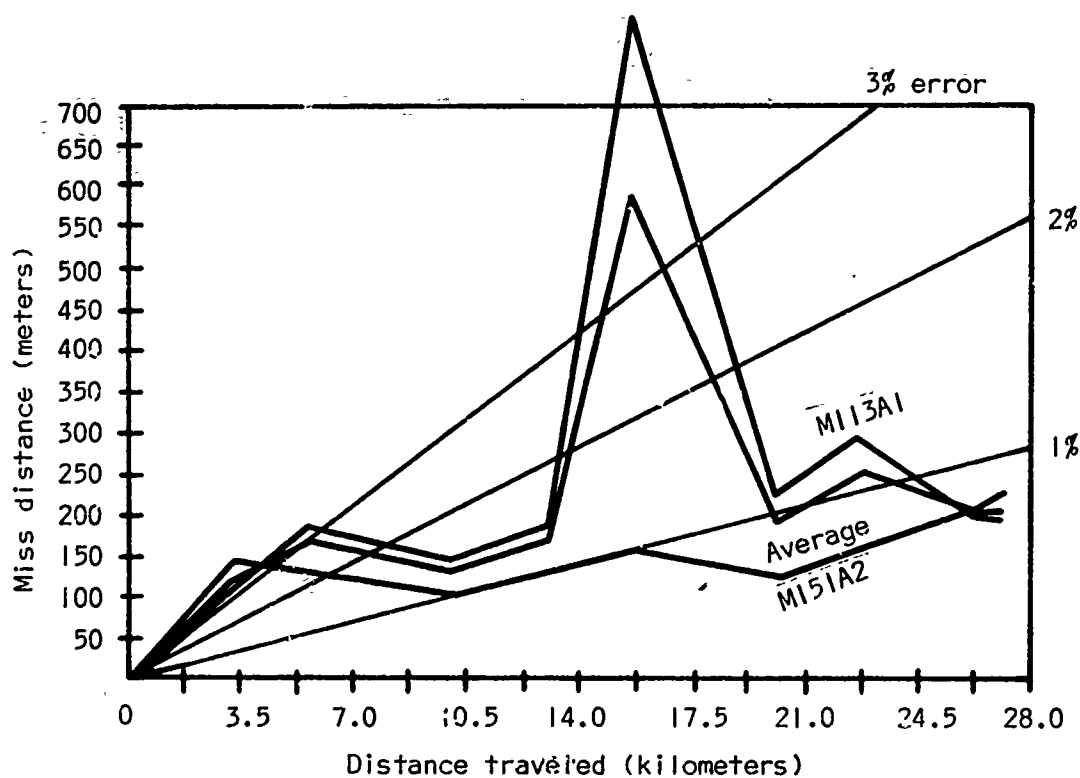


Figure C-34. Miss distance and percent error for distance traveled for the LWL/WHS vehicle land navigation system on the open level course traveling north.

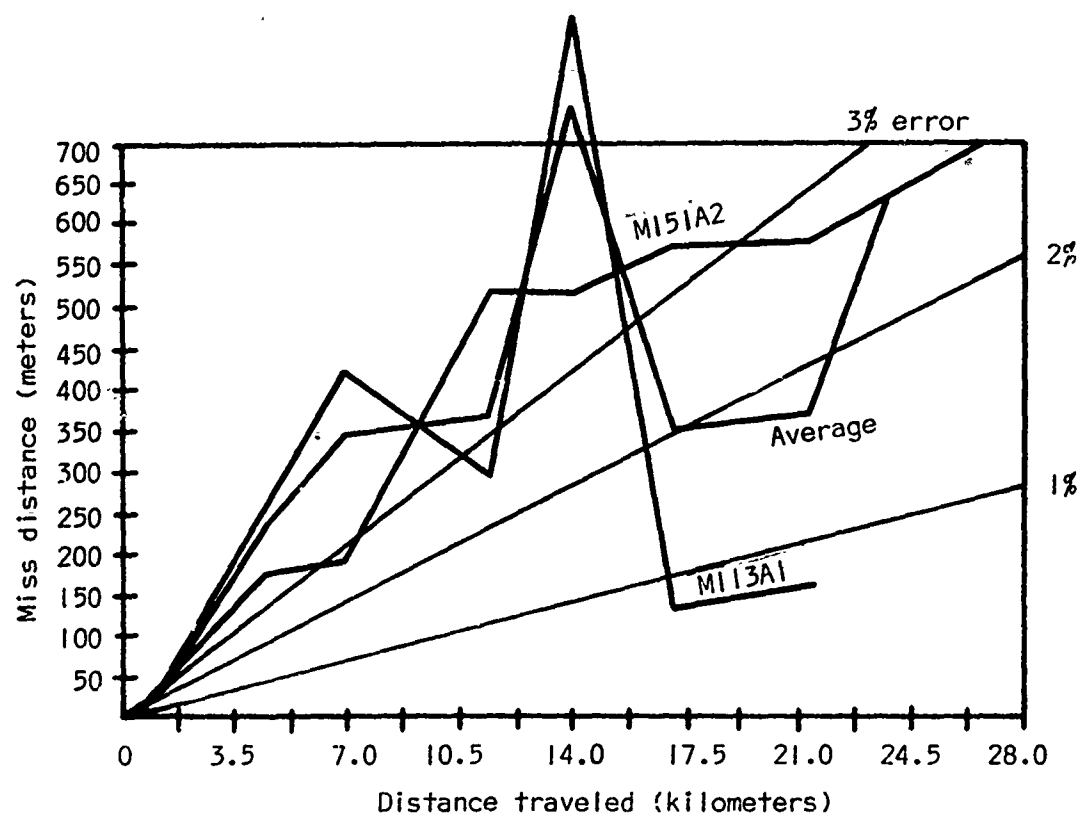


Figure C-35. Miss distance and percent error for distance traveled for the LWL/WHS vehicle land navigation system on the open level course traveling south.

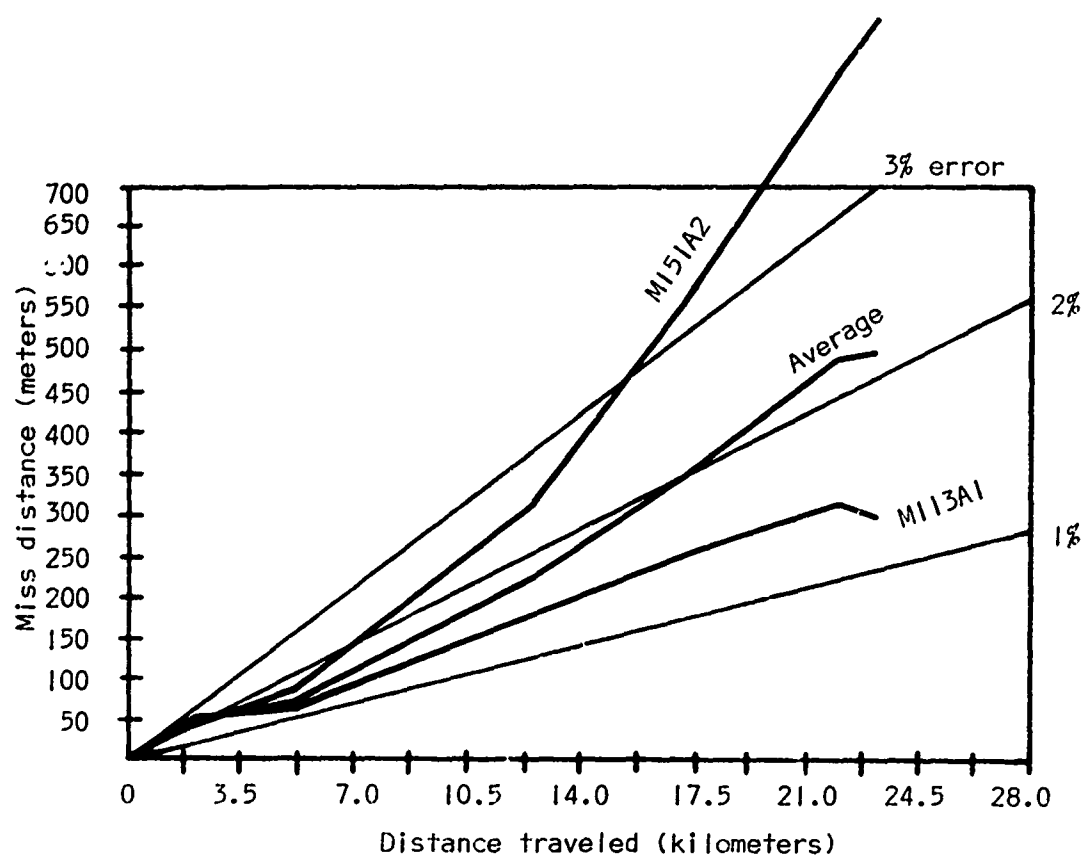


Figure C-36. Miss distance and percent error for distance traveled for the LWL/WHS vehicle land navigation system on the open rough course traveling north.

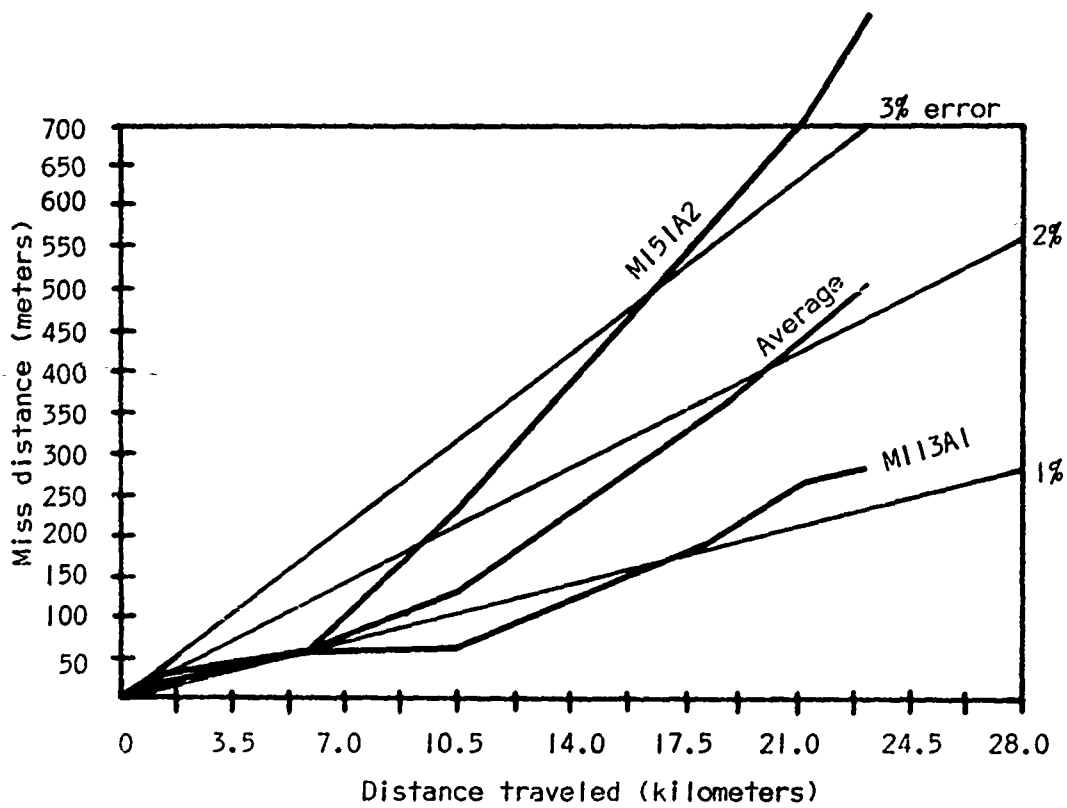


Figure C-37. Miss distance and percent error for distance traveled for the LWL/WHS vehicle land navigation system on the open rough course traveling south.



Figure C-38. Data point 5463 4625
average miss distance,
map and compass,
123.6 meters.



Figure C-39. Data point 2629 4621
average miss distance, map
and compass, 122 meters.



Figure C-40. Data point 3268 4753
average miss distance,
map and compass, 88 meters.

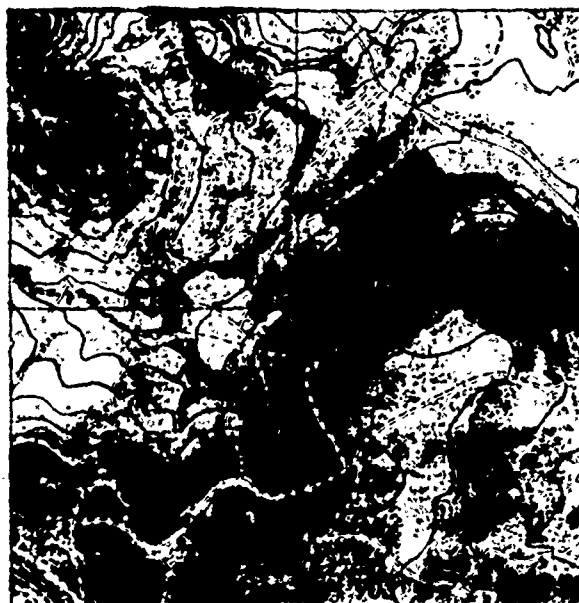


Figure C-41. Data point 3250 4901
average miss distance,
map and compass, 370.7 meters.

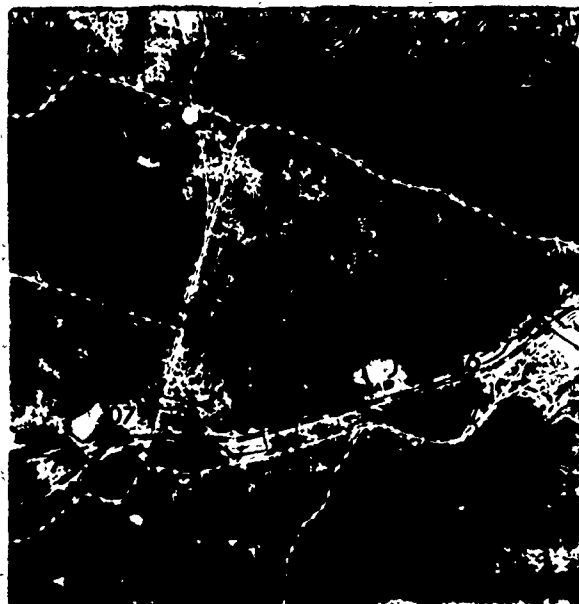


Figure C-42. Data point 2864 4870
average miss distance,
map and compass, 366 meters.



Figure C-43. Data point 3291 4454
average miss distance,
map and compass, 378.8 meters.

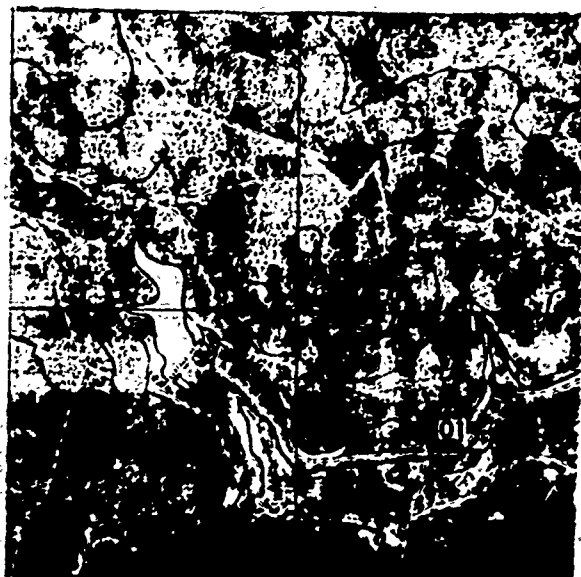


Figure C-44. Data point 3331 4547 average miss distance,
map and compass, 898.7 meters.



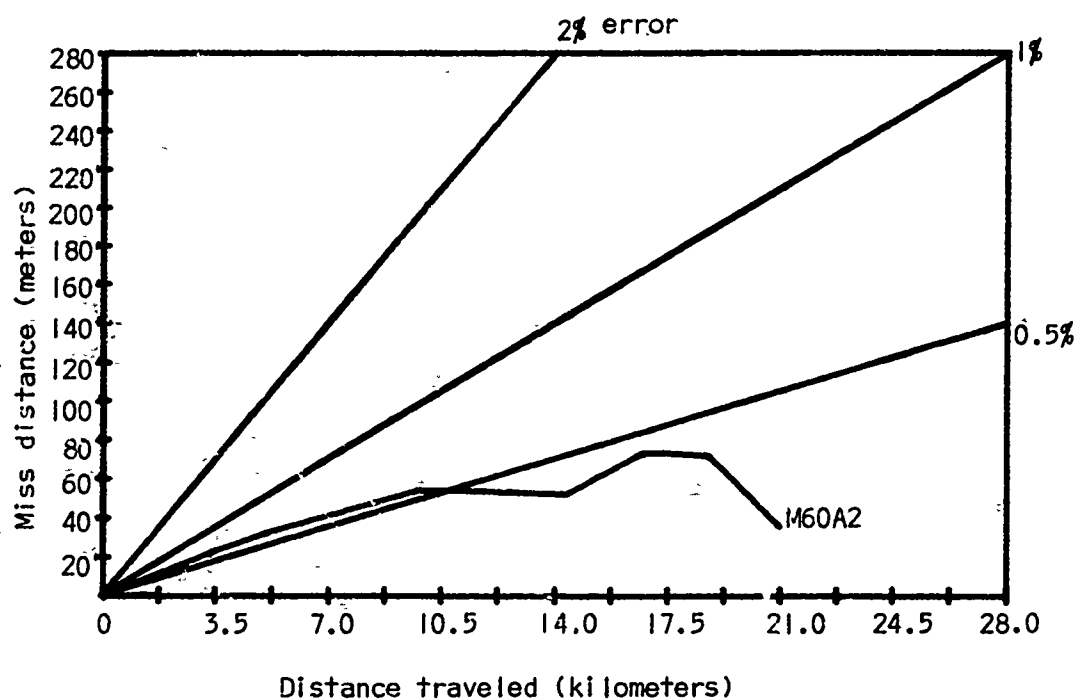
Figure C-45. Data point 3513 4802 average miss distance,
map and compass, 644 meters.



Figure C-46. Data point 3096 5035 average miss distance,
map and compass, 703 meters.

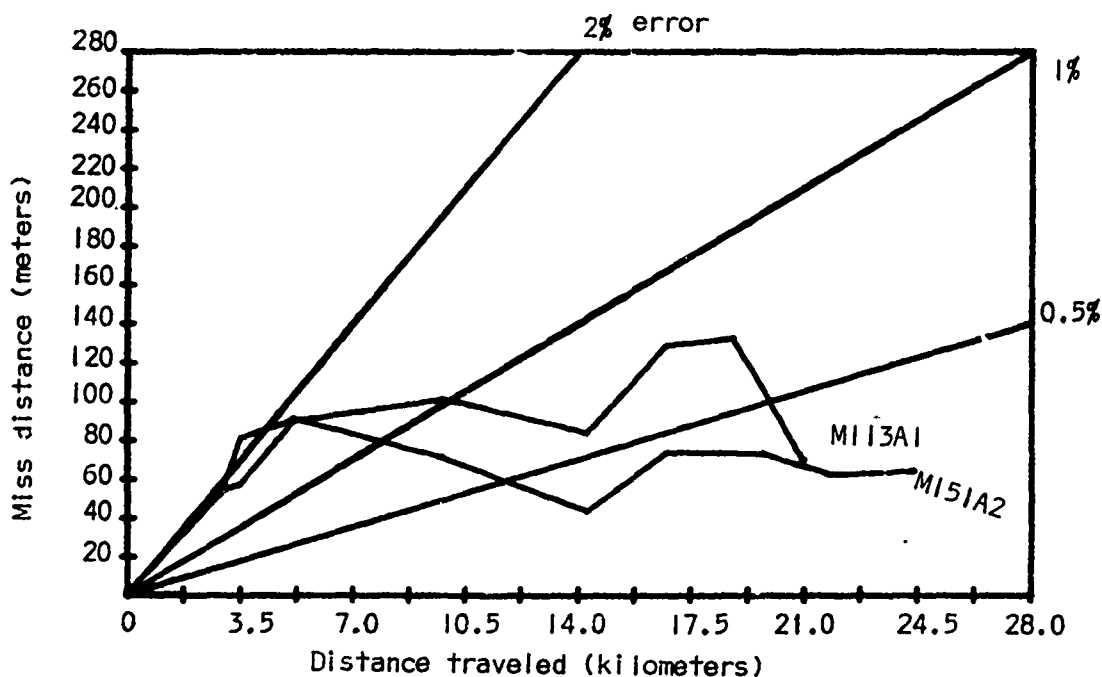
APPENDIX D

GRAPHIC RESULTS OF SUBTEST III - SYSTEM ACCURACY
(LNS-500 SERIES, AVIATION ELECTRIC, LTD.) TEST FM 194



Note: The LNS-516 is comprised of a north seeking gyro slaved to directional gyro for heading input.

Figure D-1. Average miss distance and percent error for distance traveled for the LNS-516 (full gyro system) vehicle navigation system mounted in an M60A2 on the closed level course traveling clockwise.



Note: The LNS-517 is comprised of a flux-valve compass salved to a directional gyro for heading input.

Figure D-2. Average miss distance and percent error for distance traveled for the LNS-517 (hybrid system) vehicle navigation system mounted in an MI13A1 and MI51A2 on the closed level course.

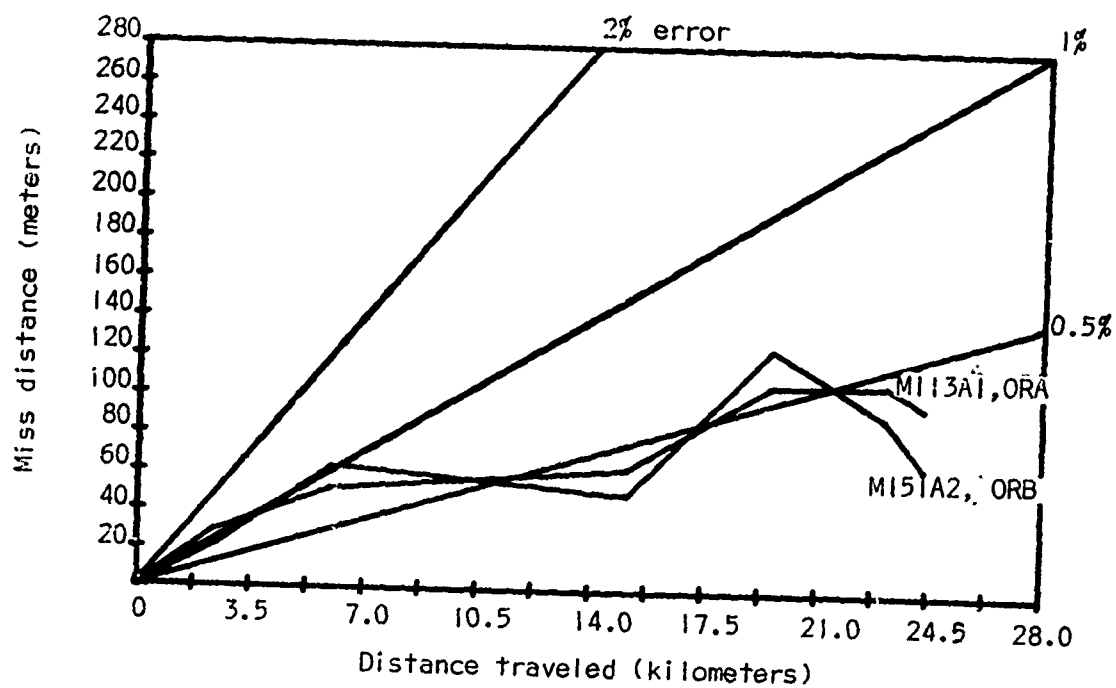


Figure D-3. Average miss distance and percent error for distance traveled for the LNS-517 vehicle navigation system mounted in an MI13A1, on the open rough course traveling clockwise (ORA), and MI51A2 traveling counterclockwise (ORB).

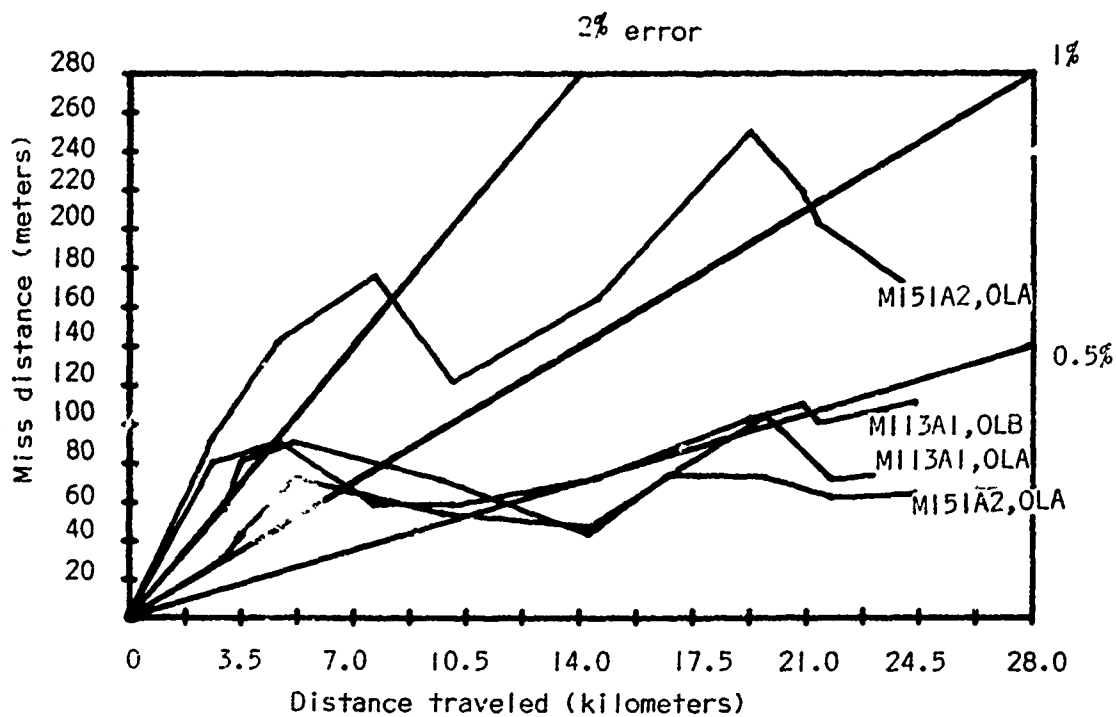


Figure D-4. Average miss distance and percent error for distance traveled for the LNS-517 vehicle navigation system mounted in an MI13A1, and MI51A2 on the open level course traveling both clockwise (OLA) and counterclockwise (OLB).

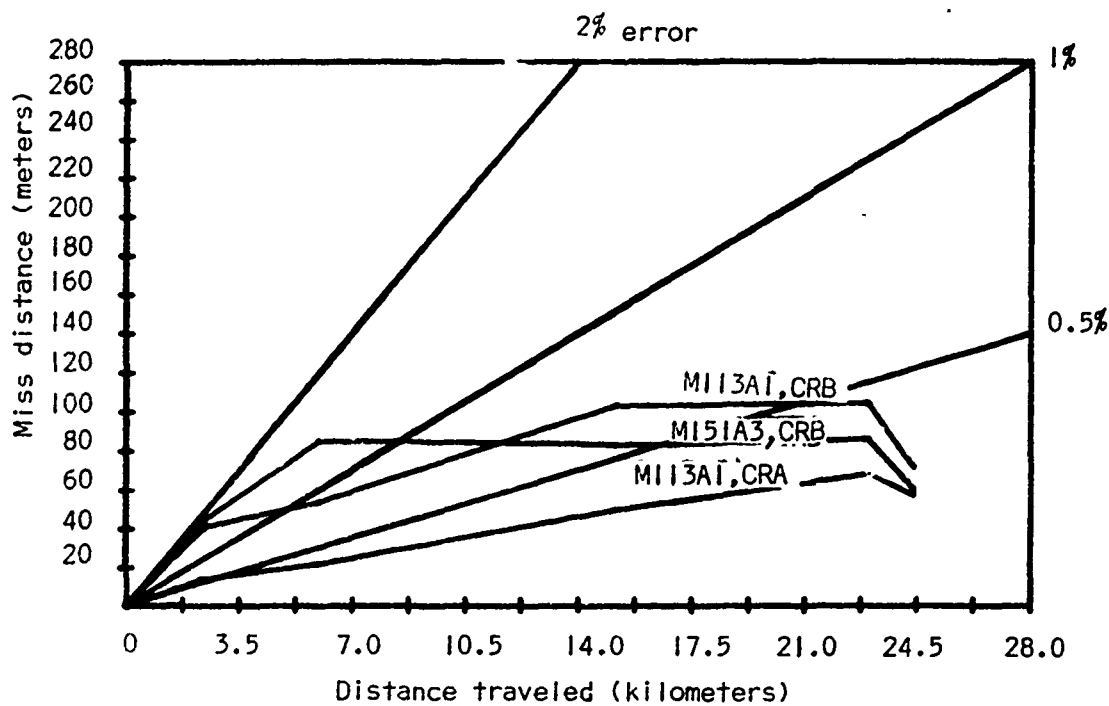
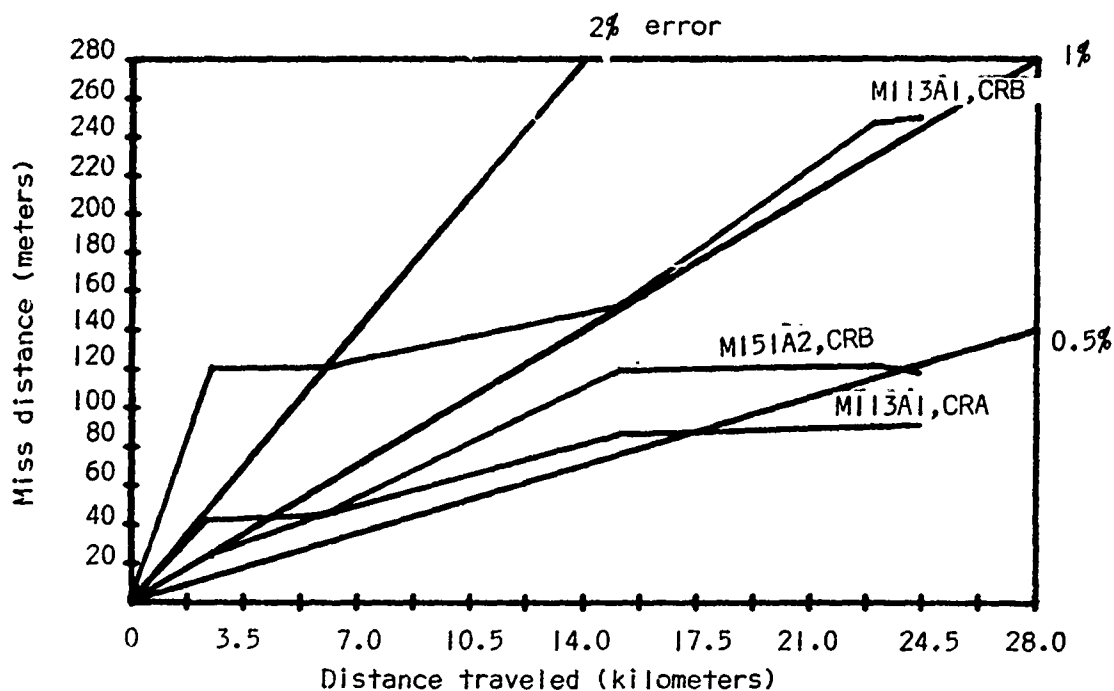


Figure D-5. Average miss distance and percent error for distance traveled for the LNS-517 vehicle navigation system mounted in an MI13A1, and MI51A2 on the closed rough course traveling both clockwise (CRA) and counterclockwise (CRB).



NOTE: The LNS-518 utilizes only a flux-valve for heading input.

Figure D-6. Average miss distance and percent error for distance traveled for the LNS-518 (magnetic system) vehicle navigation system mounted in an MI13A1, and MI51A2 on the closed rough course traveling clockwise (CRA) and counterclockwise (CRB).

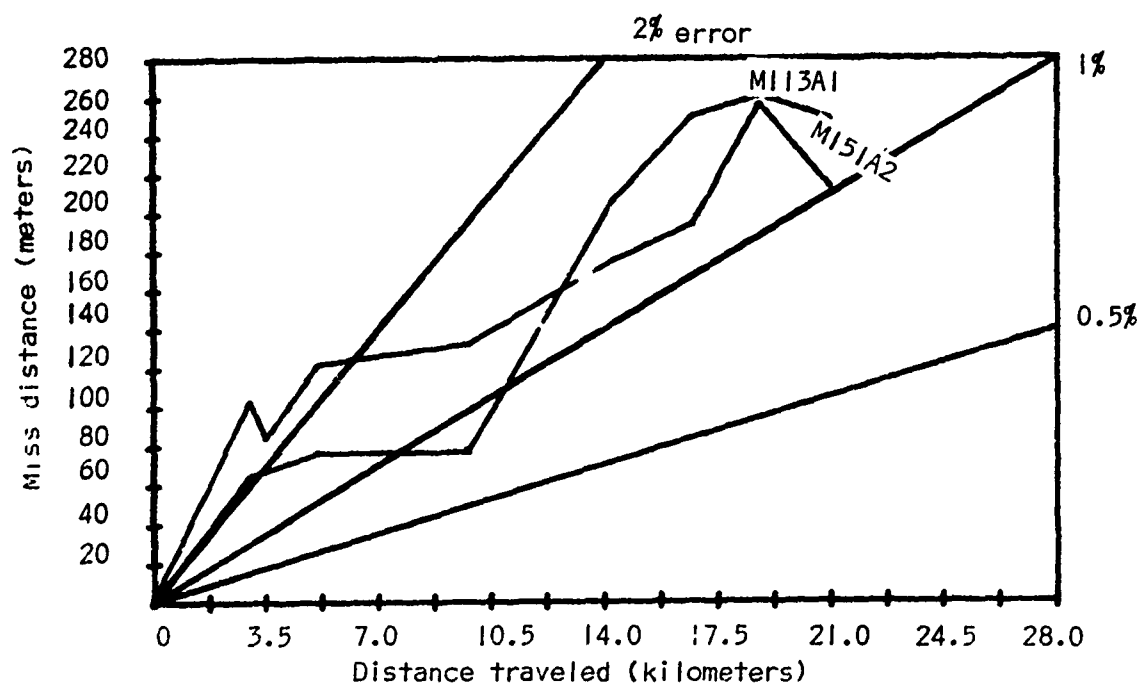


Figure D-7. Average miss distance and percent error for distance traveled for the LNS-518 vehicle navigation system mounted in an M113A1, and M151A2 on the closed level course.

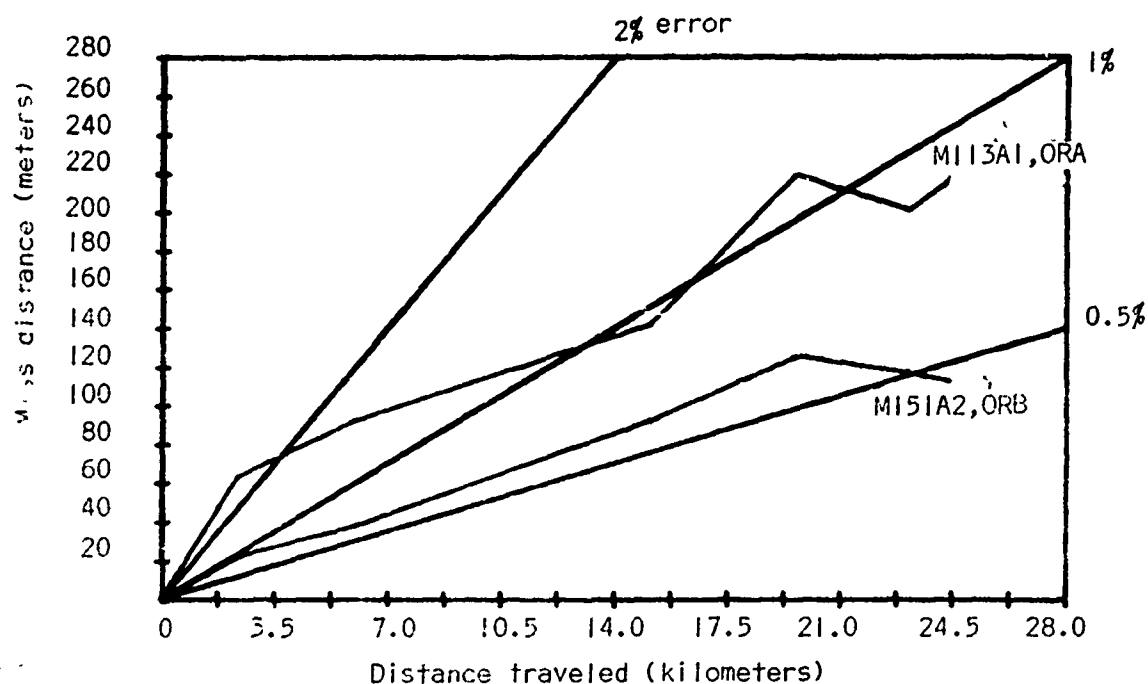


Figure D-8. Average miss distance and percent error for distance traveled for the LNS-518 vehicle navigation system mounted in an MI13A1 on the open rough course traveling clockwise (ORA), and MI151A2 traveling counterclockwise (ORB).

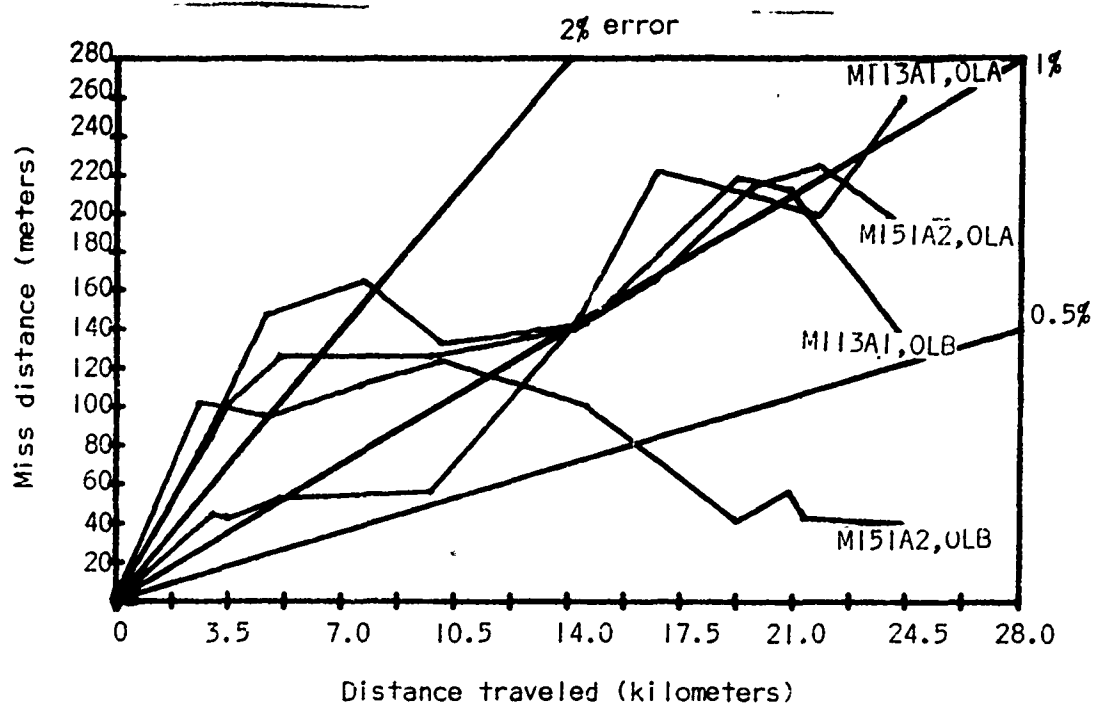


Figure D-9. Average miss distance and percent error for distance traveled for the LNS-518 vehicle navigation system mounted in an MI13A1, and MI51A2 on the open level course traveling clockwise (OLA) and counterclockwise (OLB).

RFI - radio frequency interference
TSARC - Test Schedule and Review Committee
UTM - Universal Transverse Mercator
VCS - Vehicle Compass System
WHS - Westinghouse Corporation