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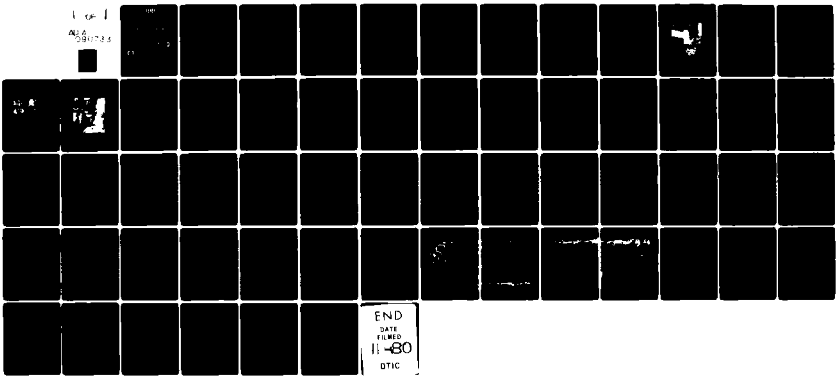

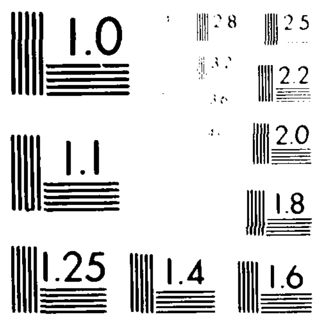

MICROCOPY RESOLUTION TEST CHART

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MEMORANDUM REPORT ARSCD-MR-80002

EVALUATION OF AN AVAILABLE GYROCOMPASSING LAND NAVIGATOR TO PROVIDE AN ARTILLERY SHOOT AND MOVE CAPABILITY

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SEPTEMBER 1980

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FIRE CONTROL AND SMALL CALIBER

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DOVER, NEW JERSEY

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

The test documented herein was conducted due to a continuing interest on the part of ARRADCOM to provide a shoot & move capability to enhance artillery survivability. It was not part of a preplanned program and was conducted in as austere a fashion as possible. Con-

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Gyrocompassing	Artillery
Navigation system	Self-propelled howitzer
Weapon laying	Armored personnel carrier
Fire control	North seeking
Position location	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results are document of a limited test conducted to demonstrate the capability of Gyro Technology to support weapon positioning and pointing requirements to provide a real time shoot and move capability. Such a system elininates the need to shoot from presurveyed position and, for the first time would allow for the conduct of accurate hasty emplacements, roving guns, dispersed artillery, and so on. A method is presented for providing the Artilleryman with continuously updated Universal Transverse Mercator (UTM) position

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18. SUPPLEMENTARY NOTES (Continued)

sequently data are limited but are sufficient to demonstrate feasibility of the principle.

20. ABSTRACT (Continued)

coordinates. It also provides the capability for laying a weapon on a preferred azimuth in essentially zero time. Following the laying procedure, the existing on carriage fire control (pantel and quadrant) may then be used to lay on subsequent targets.

The system used to demonstrate this capability was the Singer Kearfott ANS 2000 land navigator. The evaluation was conducted in both an M109A1 155 mm self-propelled howitzer, and an M113 armored personnel carrier.

Results obtained are extremely encouraging and demonstrate the soundness of both the technology and the weapon laying technique.

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SUMMARY

Results are documented of a test conducted to demonstrate the capability of gyro technology to support weapon position and pointing requirements for an artillery shoot and move capability. The equipment used in the evaluation was the Singer Kearfott ANS-2000 land navigator, a system based on gimbal stabilized gyrocompassing technology. The system was successfully demonstrated in both an M109A1, 155 mm, self-propelled howitzer and in an M113 armored personnel carrier. The test was conducted at Fort Sill, OK, during the period 16 through 20 July 1979, and was accomplished with the active support of the Directorate of Combat Development, U.S. Army Field Artillery School.

Based on the test, it is concluded that the system, and hence gyro technology, is sufficiently developed to support a totally on carriage, self-contained position location/tube pointing capability which exhibits no external signature and requires no external stimulus.

It is further concluded that with the simple installation of such a navagator and retention of the existing optical fire control techniques, such a capability can be extended to our presently fielded weapons almost immediately. Thus, individual weapons can be randomly moved, emplaced, and layed at will with no need for prior survey. The Universal Transverse Mercator (UTM) coordinates of the weapon and the grid azimuth of the tube are instantaneously known upon occupation of a position.

Not so obvious is that the addition of such a system to artillery systems such as self-propelled (SP) weapons and forward observer vehicles (FOV's) provides a definite advantage over radio based systems in that it has an inherent capability to provide heading and angular references relative to a horizontal plane; information essential to the solution of target location and gunnery problems.

It was demonstrated that the navigation system can easily be moved from one type vehicle to another requiring only that after installation, the heading reference unit be mechanically alined and a new odometer scale factor be established. This is a very simple procedure easily accomplished in the field by relatively unskilled personnel.

Of particular significance is that during the test

there were three instances when significant disagreement existed between anticipated and indicated test results (700 meters, 40 meters and 200 mils respectively). In all three cases, the issues were resolved in favor of the navigator. From this it is concluded that three errors that would have gone undetected in the absence of the navigator had been avoided, thereby indicating an additional advantage of error reduction. Although it has been concluded that the technology has been adequately demonstrated, further data must be obtained to statistically characterize the system. The conclusions drawn are based on a 1 week test program and consequently on limited test data. However, based on the limited data, an accuracy projection of 0.25% of distance travelled can be made.

It is recommended that the system be further evaluated.

BACKGROUND

In March of 1979, the Fire Control Division of ARRADCOM's Fire Control and Small Caliber Weapon Systems Laboratory (FC&SCWSL) asked the Department of Combat Development (DCD), U.S. Army Field Artillery School if they would consider a cursory investigation of a concept wherein a land navigator could be used not only for position location, but also to provide gun tube azimuth. The concept would eliminate the need for presurvey of firing points and the need for laying howitzers by way of an aiming circle as is presently done. After laying the weapon via the navigator, the present fire control techniques (collimator, pantel, aiming posts, etc.) could be used. This concept allows for rapid emplacement, frequent moves, terrain emplacement and dispersed weapons; in effect; all those characteristics considered essential to survival on the modern battlefield while requiring minor modification to the weapon and full retention of our present capability. DCD was receptive to the concept and offered their support.

As a follow up action, ARRADCOM contacted the Singer Kearfott Company to solicit their support through the loan of a land navigation system on a no cost to the Government basis. The selection of Singer to support the effort was based on a prior request on their part to demonstrate their system on a howitzer and due to the very favorable test results obtained by the U.S. Army Engineering Topographic Laboratory (USAETL) over a 6 month period in both an M113 armored personnel carrier and an M151 jeep. Singer volunteered their support through the loan of the necessary hardware as well as the necessary personnel to install and support it in the field.

Based on these facts, a mutually agreed upon schedule of 16 through 20 July 1979, was established as the time frame in which the investigation would be conducted.

System Description and Installation

Description

The navigation system provided by Singer was the ANS-2000. It consists of three major components:

1. Distance Transmitter Unit (DTU).
2. Heading Reference Unit (HRU) and HRU Control Electronics (packaged as two separate items).

3. Navigator unit

as shown in figure 1.

In operation, these components interact as follows. The DTU is an optical pulse generator similar to an incremental shaft angle encoder which is driven by the vehicle's odometer input cable. Its function is to generate an electrical pulse train whose frequency is proportional to vehicle speed. The HRU, which contains a single dual axis gimbal stabilized gyro, provides an electrical output which indicates the instantaneous direction in which the vehicle's fore and aft centerline is pointing with respect to true north thus providing the heading of the vehicle. The outputs from the DTU and HRU are input to the navigator unit wherein a microprocessor uses the information to solve a set of navigation equations which ultimately provide a continuous updated output of present vehicle position for presentation of an LED display. A block diagram of the ANS-2000 System is shown in figure 2.

In addition to housing the microprocessor, the navigator unit also contains an operator's display and control panel which is the sole operator interface for the system. The panel provides for the following:

Operating Modes

Align North - places unit in the gyrocompass mode to allow automatic HRU alignment to true north.

Nav - places unit in the navigation mode wherein continuous updating of vehicle position is provided.

Align South - places unit in the gyrocompass mode to allow automatic HRU alignment to true south (allows further refinement of heading accuracy and for a periodic system calibration).

Input Functions (switch selectable)

Easting/Northing (E, N) - provides a means for initializing or updating system by inputting known vehicle position.

Distance (DIST) - provides a means of re-

Figure 1. ANS-2000 system as tested in the M109 SP howitzer. Moving counter-clockwise is the display/control unit (white box in foregroUrd), control elect-ronics, and heading reference unit.

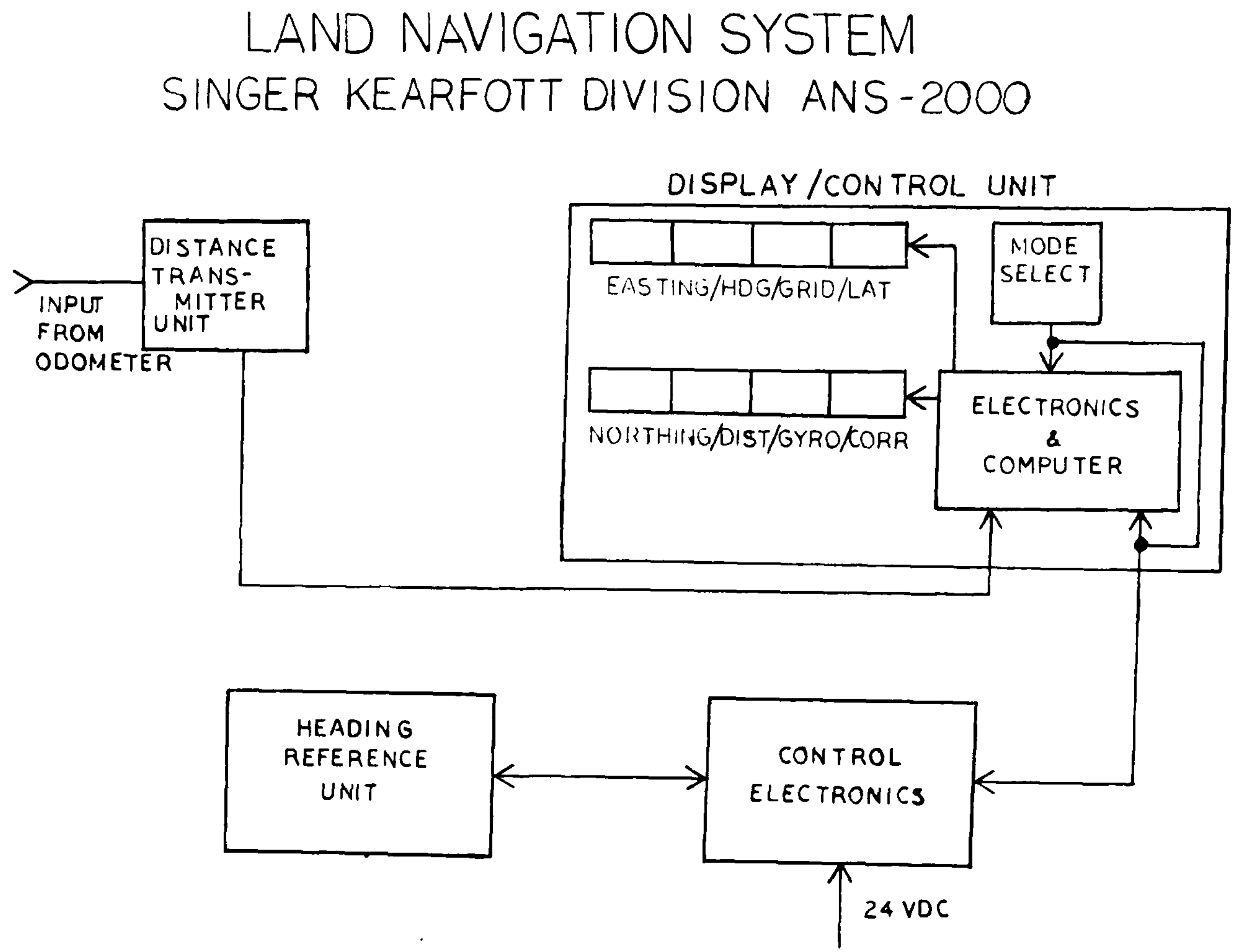


Figure 2. Schematic of navigator system.

setting the distance travelled as determined by the computer to zero.

Grid Correction (GRID) - provides a means of inputting the grid to allow the computer to operate in the UTM coordinate system.

Scale Factor (CORR) - provides a means of correcting the velocity scale factor to compensate for vehicle and terrain variations.

Latitude (LAT) - provides a means for inputting vehicle latitude for use in applying appropriate earth rate correction to the HRU.

Output Functions (switch selectable)

Easting/Northing - provides a continuously updated display of vehicle position with one meter resolution.

Heading/Distance - provides a continuous display of heading with respect to grid north and continuously updated output of actual distance travelled.

Grid/Gyro - provides a display of the grid convergence as input by the operator and continuously updated output of vehicle heading with respect to true north.

Latitude/Correction - provides display of the scale factor and latitude as input by the operator.

Installation

Prior to the test, it was determined to be desirable to investigate the system in both an M113 armored personnel carrier and in an M109 howitzer. To facilitate ease and rapidity of installation, all components except the DTU were mounted on a single 30 x 18 x 1 inch aluminum plate which in turn was bolted in the respective vehicles using existing bolt holes. In the M113, it was bolted to the left sponson just under the vehicle's radio equipment as shown in figure 3. In the M109, it was bolted to the floor directly under the gun shield and in front of the heater as shown in figure 4. From a human engineering

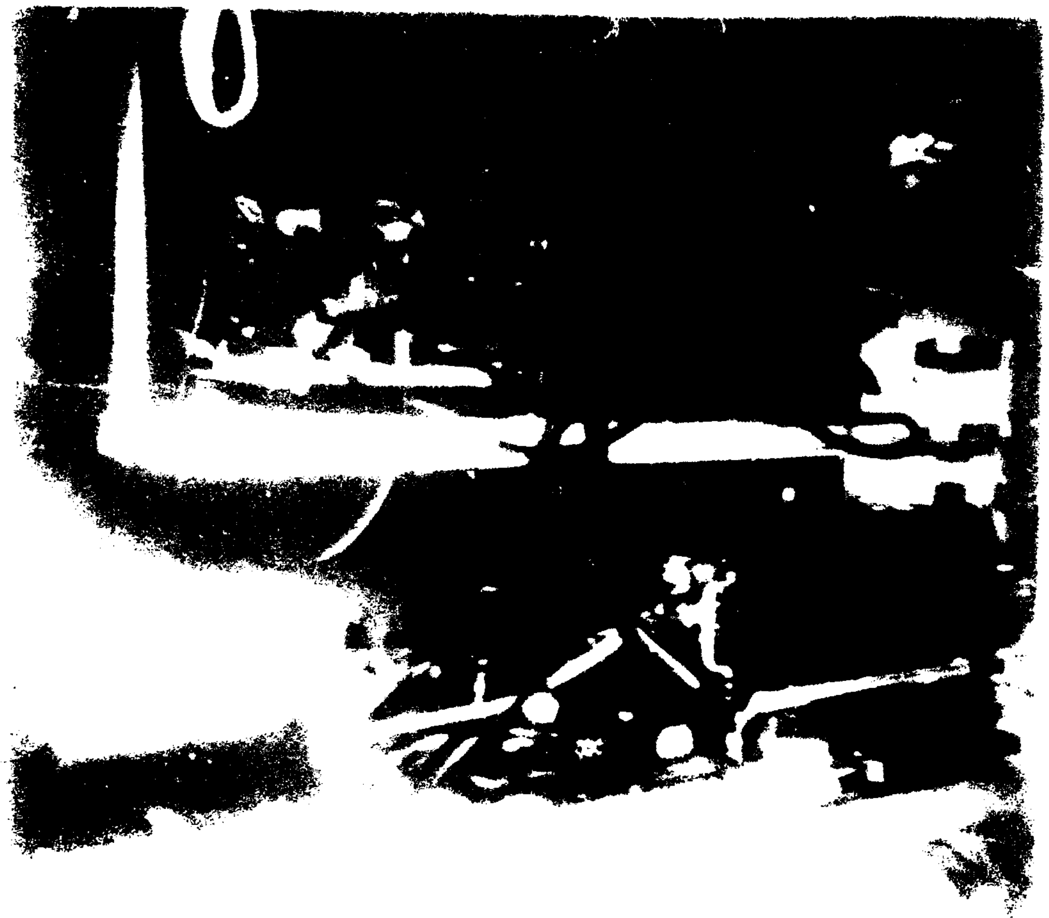


Figure 3. ANS-2000 system mounted to upper left sponson, below radio equipment in M113 vehicle.

Figure 4. ANS-2000 system bolted to the floor of the M109 SP howitzer. Display/control unit can be seen directly beneath the cannon breach.

standpoint, these were less than ideal locations but were adequate for the cursory investigation that was conducted.

In both vehicles, the DTU was mounted in close proximity to the odometer to assure ready access to the odometer cable. An electrical cable then connected the DTU to the navigator unit.

In both cases, power for the system was derived from the vehicle's batteries. In the M113 power was taken from the connector socket located on the operator's instrument panel, while in the M109 it was taken from a terminal board located under the turret ring on the right side of the vehicle. Except for the navigation system's integral voltage regulator, no provisions were made to isolate or precondition raw power as taken from the vehicle's electrical system. Using this overall installation approach, it was found that the system could be installed in approximately 1 hour.

Conduct of the Test

The purpose of the test was to determine the navigator's ability to perform in an M109 and M113 and to investigate its vehicle's ability to determine gun tube position upon occupation of a position.

The checkpoints to be used were part of the PADS test course. The actual test points and the routes to be followed in driving to them were at Fort Sill's discretion and were unknown to Singer and ARRADCOM until actual arrival at the checkpoint. The course persented every type of terrian imaginable including mud, rock, improved and unimproved roads, grass, creek beds and so on. The driver was instructed to drive the vehicle in his normal manner and to take no special precautions to limit speed or to avoid obstacles which he would normally negotiate.

In the case of the M113, the primary interest was position location and the systems ability to survive in that vehicle's environment. In the case of the M109, the interest was threefold; determine gun tube azimuth upon arrival at a firing point, and determine the ability to survive in an M109 environment including firing shocks.

After installation and alignment, operation of the system was performed by a randomly selected Specialist Forth Class. His training consisted of approximately 15 minutes of instruction after which he was able to operate the system on his own by reference to a very simply written operator's manual.

A typical mission consisted of the following. From a cold start, the system was turned on and allowed to run while the vehicle was driven to a checkpoint. This permitted sufficient time for the system to warm up and stabilize. Upon arrival at the checkpoint, the system was placed in the "Align" mode and was allowed to gyrocompass, an operation which takes 20 minutes. During this period, the operator enters latitude, scale factor, grid covergence, easting and northing of present position and resets distance travelled to zero. At the end of 20 minutes, a "Wait" indicator light extinguishes and the mode switch is moved to the "Nav" position at which time the driver was notified to progress to the next checkpoint. Upon arrival at subsequent checkpoints, the vehicle was stopped long enough to take data or for discussion and analysis of results if such was warranted. At the end of a mission (up to 7 checkpoints and as long as 43 km), coordinates were updated and distance travelled was reset at zero. In some cases, heading was also updated through a regyro-compassing cycle. Data collected from each of the six missions conducted is presented in Appendix A.

Accuracy of lay of the gun tube was determined by the process of reciprocal laying. A Wilde T16 theodolite was oriented by reference to a known distant aiming point. The theodolite in conjunction with the weapons panoramic telescope was then used to determine the azimuth of the gun tube by way of the following equation:

$$A_G = R_T - R_P$$

Where

A_G is the azimuth of the gun tube (+/- 6400 if required).

R_T is the theodolite reading. This is the angle measured from the distant aiming point to the line of sight of the gunner's panoramic telescope.

R_p is the reading on the upper counter on the gunner's panoramic telescope. This is the angle measured from the axis of the gun tube to the line of sight of the theodolite.

It was assumed that when the gun tube is in the travel lock, it is parallel to the vehicles fore/aft axis. Consequently, the heading of the chassis as indicated by the navigator is also the direction in which the gun tube is pointing. Before making azimuth measurements, a scribed line on the cab was alined with the edge of a gear tooth on the cab ring gear. By so doing, a constant relationship between the cab and hull is maintained. Under these conditions, it was assumed that any actual misalinement between the gun tube and fore/aft axis would be constant and would show up as a bias in the data which could be subtracted out. Realizing the accuracy limitations of this measurement technique, the approach was selected because it was the quickest and easiest to accomplish in consideration of the total allocated test interval of 1 week.

RESULTS

General

All test data obtained on both the M113 and the M109A1 are contained in Charts 1 through 6 of appendix A. The following is an explanation of the column headings from left to right:

Checkpoint - self explanatory.

True position - actual UTM easting and northing of a checkpoint as previously determined by survey.

True tube azimuth - actual tube azimuth of M109A1 as determined by theodolite.

Terrain character - self-explanatory.

Navigator position - UTM easting and northing of a checkpoint as indicated by the navigation system.

Distance travelled - distance travelled

between successive checkpoints as determined by the navigator.

Cumulative Distance Travelled - total distance travelled from mission start point to current position as indicated by the navigator.

Time - self explanatory.

Navigator Tube Azimuth - tube azimuth of M109A1 as determined by the navigator.

UTM Error - difference between (2) and (5).

Radial Error - radial error based on (10).

Accuracy - % error based on (11) and (7).

Tube Pointing Error - difference between (9) and (3).

Throughout the test, it was assumed that the capability of the system to navigate was unquestioned. That is, the test was run from an applications standpoint rather than from an engineering systems evaluation standpoint. In this respect, all data taken, be it good or bad, are presented in the following charts. There were several instances when, for no apparent reason, a larger than anticipated increase in the navigation error would occur at one checkpoint only to disappear at the next. In keeping with the above ground rule, that data are included on the charts even though it is believed that time permitting, the source of the error could have been resolved and quite possibly could have been attributed to something other than the navigator.

In those cases where a blank appears in a particular column, it is because data was accidently not recorded. This is particularly true for data gathered on the M109 on the 18th of July listed in Chart 4. That particular day was plagued with a continuous downpour for which both civilian personnel and navigator electronics were ill-equipped to cope.

M113 Results

Three missions were run on the M113 ranging in time up to 1 hour and 44 minutes and in distance up to 33.5 km. Not shown on the charts is that prior to the start of mission number 2, the known coordinates of the start-point were entered into the navigator but the system was not regyrocompassed. Consequently, missions number 1 and 2 can be thought of as a continuous mission during which a known checkpoint was encountered thereby allowing for the reduction of the position error to zero midway through the mission. This is a realistic mode of operation and that which would be recommended in a tactical situation. On this basis, mission time can be considered to have been 2 hours and 42 minutes.

Since of prmary interest to the artilleryman is the absolute error upon arrival at a point, the most meaningful data is presented in columns 10 - "UTM ERROR" and 11 - "RADIAL ERROR". Table 1 summarizes the Circular Error Probable (CEP) for each mission conducted. When referencing these numbers, it is important to associate them with the cumulative distance travelled in order to put the error in perspective. In addition, appendix B contains a map of the Fort Sill test course indicating terrain features. Individual mission courses are also presented on the subsequent pages of the appendix. In referring to these columns, it is important to associate them with column 7 - "CUMULATIVE DISTANCE TRAVELLED" in order to put the errors in perspective.

The last two checkpoints in mission number one indicate an extremely small percentage of error. This is because they represent a return to prior checkpoints on the same mission (#2 and #4). The nature of the navigator is such that many of the errors induced in proceeding to a checkpoint are removed upon returning while the total distance travelled has increased. Thus, on a percentage of distance travelled basis, the effect is to reduce the overall error.

In summation, considering the hasty installation, the lack of any attempt to optimize alignment and scale factors, and the distances and durations of missions, the results are extremely encouraging. The results obtained clearly indicate the potential of this technology for application to the Army Forward Observer Vehcile (FOV) Program. Of particular interest is the inherent heading capability of the system which is not available with the radio based systems presently being pursued.

Table 1. Circular error probable (CEP)[a] for Ft. Sill test of LNS-2000

COURSE	CEP IN METERS	CUMULATIVE DISTANCE TRAVELLED IN METERS
17 July 1979 Course No. 1	11.5	29,143[b]
17 July 1979 Course No. 2	31.3	17,164[b]
17 July 1979 Course No. 3	25.2	33,528
18 July 1979 Course No. 4	40.2	-------[c]
19 July 1979 Course No. 4	33.4	42,999
19 July 1979 Course No. 5	7.7	15,161

a. $$CEP = 0.589 \left[\sqrt{\frac{\sum_{N=1}^{n} E_N^2}{n}} + \sqrt{\frac{\sum_{N=1}^{n} N_N^2}{n}} \right]$$

b. Continuous Mission

c. See appendix A, Course #4, Mission #1.

It should also be mentioned that these results are not the result of a stroke of good luck. The system has been successfully evaluated in an M113 by MASSTER (Fort Hood) in June/July '74, by Pakistan in Jan '78, by Israel in June '75 and by USAETL in 1979. In all cases, results obtained were on the order of 0.5% of distance travelled or less.

M109 Results

Three missions were run in an M109A1. Mission number one was run on 18 July 1979. The entire day was marked by continuous and heavy rain which in turn created extremely muddy conditions and with it, excessive track slippage and heading errors. This being the first day in the M109, it was essential to establish HRU alignment and scale factor correction data. This is accomplished by driving the vehicle between two known points. By comparing known versus indicated checkpoint data, upon arrival at the second point, along track and cross track errors can be determined. From this data heading and scale factor errors are computed which in turn are used to calibrate the system. This is a "one time" procedure which is required when the system is initially installed in a new vehicle. With the environmental conditions that existed, difficulty was encountered in establishing consistent results. After two such attempts, it was decided to proceed with the test fully realizing that larger than normal navigation errors would result. In keeping with the ground rule to present all data, information obtained on this run is included in the charts. The chart for this mission, Chart 4, also indicates a considerable amount of unrecorded data. This is related to a disruption in the data taking process caused by the extremely adverse weather. The lack of tube azimuth data was due to the inability to see the distant aiming points due to low visibility.

By early afternoon of the first day, difficulty was encountered with the operation of the navigator and further field exercises for the day were terminated. After investigation, it was found that the problem was caused by rain water which had gotten into the electrical connectors. It should be pointed out that this is not a deficiency in the hardware design. The system as tested is not militarized and is packaged in accordance with commercial practices. Its location under the gun shield was such that it sat under a virtual waterfall throughout the day. Under the environmental conditions that existed, it was reasonable to expect the problem that eventually occurred.

After drying out over night, the system was found to operate properly. Due to the previous days difficulties, on the second day it was decided to make a totally new start. Consequently, new HRU alignment and scale factor data was determined before making runs number 2 and 3. From the charts it can be seen that results obtained on these two missions are in line with those obtained on the M113. The missions' range in time up to 3 hours and 25 minutes and in distance up to 35 km. Between missions, the known coordinates of the new start point were entered and the system was regyrocompassed. It should be noted that heading as indicated by the navigator was observed both before and after regyrocompassing and was found to have drifted between zero and 1 mil. This condition was also typical of performance on the M113. From this it is concluded that missions of considerably longer duration could be run without regyrocompassing. However, to maintain accuracy, known points would have to be periodically encountered along the way which would be used to reset the UTM position error to zero.

Again, the data have been left in tabular form so that the absolute errors are readily apparent. In referring to the absolute error, it is important to associate it with the cumulative distance travelled. The data indicates that for the first 6 km of mission No. 2 and all 15 km of mission No. 3, the generally accepted position requirement for artillery of ±20 meters was never exceeded. Both of these distances are far in excess of the typical moves that artillery is projected to have to make to survive on future battlefields.

It should also be noted that on mission No. 2, after traveling a distance of 43 km, the error was only 64 meters and this was accomplished without ever updating coordinates or regyrocompassing. This is a vast improvement over the 300+ meters that can be expected with map spotting techniques.

Also shown on the charts is data related to tube pointing accuracy. As was stated previously under conduct of the test, it was fully expected that due to the measurement technique selected, a constant bias would be introduced in the measurement. The data support this expectation, in all cases the tube was actually to the left of the indicated azimuth. With respect to checkpoint No. 6 of mission No. 3, an additional error of up to 3 mils was introduced due to the neglect to align the turret before making the measurement. If that data point is disregarded or if the 3 mils was substracted from it, the spread of data for the overall mission is 8.6 to 12 mils. Further, if the first two checkpoints of mission number 2 are disregarded on the basis that they were the first two measurements made and are questionable due to a lack of experience with the measurement technique, the spread of data on this mission was from 9 to 13 mils. This is a fairly good assumption based on the difficulty experienced in making these two measurements. Under these circumstances, the overall spread for the two missions is from 8.6 to 13 mils or 4.4 mils. This spread is attributed to a combination of measurement technique and navigator heading error. No attempt was made to isolate the individual errors.

In establishing the validity of disregarding some of the above data points, the following must be considered. In order to determine the heading drift that occurred during a mission, heading was checked both before and after regyrocompassing at the end of each mission. Invariably, it was found to be within 1 mil for both the M109 and M113. Assuming the turret has a fixed relationship to the hull, tube accuracy of lay should be as accurate as the navigator heading accuracy. It should therefore be possible to lay the weapon within 1 mil over the duration of the mission's run which is in fairly good agreement with the 4.4 mils indicated above. Using the data in the charts with the exception of the 3 points already discussed, the mean is 10.6 mils and the standard deviation is 1.7 mils. From this, it is deduced that the offset between the gun tube and carriage is 10.6 mils and that the gun can be layed within ± 1.7 mils, 1σ.

In order to evaluate the ability of the system to withstand firing shocks, the following test was conducted. The cooperation of a battalion which was conducting a regularly scheduled training exercise was enlisted. One of its howitzers was pulled out of position for installation of the system. Since it was only necessary to demonstrate repeatability in order to determine survivability, no attempt was made to align the HRU. Following installation, the weapon was driven from the battery position to a known checkpoint. The northing and easting as indicated by the navigator were recorded and the weapon was returned to the battery position where it was emplaced for a fire mission. The fire mission consisted of a 10 round registration, charge 4 green bag fired at a relatively fixed deflection and quadrant elevation. Heading, Easting and Northing as indicated by the navigator were recorded both before and after firing. No change was observed. After firing, the weapon was again pulled out of position and driven to the known checkpoint. The difference in northing and easting as compared to that before firing was -20m and +1m respectively. Navigator readings before and after firing are presented in table 2. From this it is concluded that the system can survive firing shocks.

One additional point is worthy of discussion. On three occasions, the true value of the navigator was more than amply demonstrated and purely by accident in each case. On two occasions errors of 700 meters and 40 meters respectively were avoided while on the the third occasion an error of 200 mils in tube azimuth was avoided. The source of the error was as follows. In the 700 meter case, the weapon was driven to the wrong checkpoint. In the 40 meter case, the weapon was at the right checkpoint but was parked over the wrong marker. In the 200 mil case, in reciprocally laying the weapon, digits were accidentally transposed. The point to be made is that in each case, it was only because of a conflict with the navigator results that the positions and azimuth were checked and in each case, the conflict was resolved in favor of the navigator. Thus, there were three errors that had been avoided because the weapon was equipped with a navigator.

CONCLUSIONS

Conclusions reached based on the 1 week test are:

1. It has been demonstrated that gimbal stabilized gyro technology is capable of supporting artillery requirements for position location and determination of heading under actual field conditions.

2. A system has been demonstrated which is totally self-contained, has no external signature, and requires no external stimulus.

3. A continuous output of position and head-

Table 2. Firing test (20 July 1979) M109, 10 rds, ch 4 green bag, fixed def. and QE

	Start Checkpoint	Battery Position		Finish Checkpoint	Difference
		Before Firing	After Firing		
Easting	45190	44605	44605	45191	+ 1
Northing	32990	33146	33146	32970	-20
Heading	-----	79	79	-----	---

ing is available thereby providing the capability for rapid emplacement, frequent moves, terrain emplacement, and dispersed weapons.

4. Performance in an M113 demonstrated the system's potential for use in a forward observer vehicle. With the addition of appropriate sensors and software a further capability to provide Azimuth-To-Target can be provided.

5. The system demonstrated an ability to position the gun tube on the M109 within ± 2 mils; a considerable improvement over the existing technique.

6. By the simple addition of the navigator, the capability to shoot and move is immediately available. The capability to determine guntube azimuth was demonstrated. Once this is known, the pantel, aiming posts, and collimator can be used in the conventional manner.

7. By the addition of appropriate sensors and software, the gun tube can be layed in azimuth and elevation without any external references.

8. For moves up to 6 km, raw data indicates the ability to determine the weapons true position well within 20 meters. For distance greater than 6 km (up to 43 km) the data indicates an ability to determine position within 0.25 % of distance travelled.

9. The system provides heading information not available with radio or satellite based systems. For artillery, this is a requirement every bit as important as position.

10. Operation of the system is simple and straight forward and can be accomplished by inexperienced and unskilled personnel with a minimum of instruction.

11. Although it was not demonstrated, there are very obvious advantages of such a system for night operations.

12. There is an increasing need for a dynamic azimuth reference capability in artillery systems. The device which serves this function can also provide the

heading reference for a navigator; the most critical and expensive component of such a system. Thus, for a modest increase in cost for additional hardware and software, a position location capability can be added to systems requiring a heading capability.

13. The ability to shoot and move was indirectly demonstrated when after firing ten rounds, the weapon was moved approximately 640 meters to a checkpoint. The system demonstrated sufficient accuracy upon arrival (20 m) that it could have been fired.

14. Although the technology has been adequately demonstrated, additional data must be obtained to statistically characterize system accuracy.

15. The system is interchangeable from one vehicle to another without any considerations other than alinement and scale factor.

RECOMMENDATIONS

The following recommendations are made based on the 1-week test:

1. An in-depth series of field experiments should be pursued to further evaluate the practicality and advantages of such a capabiltiy. Two of the systems tested are available. A two gun battery could be devised to evaluate terrain emplacement frequent moves, etc.

2. The encouraging test results and the potential benefits available with artillery use of a gyro-based land navigator, warrant immediate attention and further development.

APPENDIX A.

MISSION DATA

DATE: 17 JULY 1979
VEHICLE: M113 APC
WEATHER: CLOUDY

COURSE: NO.1
MISSION: NO.1
START COORDINATE

1	2		3	4	5		6
CHECKPOINT	TRUE POSITION		TRUE TUBE AZIMUTH	TERRAIN CHARACTER	NAVIGATOR POSITION		D T
	E	N			E	N	
1	KIOWA 58641	37686	NA	GRAVEL ROAD	58651	37685	1 E
2	BCA4 58562	39315	NA	GRAVEL ROAD	58556	39309	3
3	STA37 57664	40681	NA	GRAVEL ROAD	57659	40668	2
4	FLAGG 59426	41845	NA	GRAVEL ROAD	59414	41839	2
5	FRISCO 60472	47039	NA	CROSS COUNTRY, CREEK BEDS	60448	47035	6
6	FLAGG 59426	41845	NA	GRAVEL ROAD	59413	41842	6
7	BCA4 58562	39315	NA	GRAVEL ROAD	58573	39321	[illegible]

NOTES:

URSE : NO.1
SSION : NO.1
ART COORDINATES: E - 57457 N - 36918

	5		6	7	8		9	10
	NAVIGATOR POSITION		DISTANCE TRAVELED	CUMULATIVE DISTANCE TRAVELED	TIME		NAVIGATOR TUBE AZIMUTH	UTM E
R	E	N			ARRIVE	DEPART		E
	58651	37685	1799 ESTIMATED	1799 ESTIMATED	0909	0923	NA	10
	58556	39309	3,220	5,019	0930	0938	NA	-6
	57659	40668	2,657	7,676	0943	0946	NA	-15
	59414	41839	2,488	10,164	0951	0956	NA	-12
	60448	47035	6,878	17,042	1009	1013	NA	-24
	59413	41842	6,810	25,700	1025	--	NA	-13
	58573	39321	3,443	29,143	1033	--	NA	11

	9	10			12	13
ART	NAVIGATOR TUBE AZIMUTH	UTM ERROR E	UTM ERROR N	RADIAL ERROR	ACCURACY	TUBE POINTING ERROR
3	NA	10	-1	10	0.56%	NA
3	NA	-6	-6	8	0.16%	NA
6	NA	-15	+13	14	0.18%	NA
6	NA	-12	-6	13	0.13%	NA
3	NA	-24	-4	24	0.14%	NA
	NA	-13	-3	13	0.05%	NA
	NA	11	6	13	0.04%	NA

DATE: 17 JULY 1979
VEHICLE: M113 APC
WEATHER: CLOUDY

COURSE: NO.2
MISSION: NO.2
START COORDINATES:

1	2		3	4	5		
CHECKPOINT	TRUE POSITION		TRUE TUBE AZIMUTH	TERRAIN CHARACTER	NAVIGATOR POSITION		DIS TRA
	E	N			E	N	
1	BCA4 58641	37686	NA		58652	37683	1,786
2	SAA2 58608	34701	NA		58640	34709	4,084
3	ADAMS 59756	33868	NA		59791	33885	1,554
4	ARBUCKLE 61952	33418	NA		61995	33451	3,079
5	8 BOOM 56692	34680	NA		56737	34669	6,66
6							
7							

NOTES:

ORDINATES: E- 58562 N- 39315

5	6	7	8		9	10		
GATOR ITION	DISTANCE TRAVELED	CUMULATIVE DISTANCE TRAVELED	TIME		NAVIGATOR TUBE AZIMUTH	UTM ERROR		RA ER
N			ARRIVE	DEPART		E	N	
37683	1,786	1,786	1051	1056	NA	11	-3	1
34709	4,084	5,870	1103	1117	NA	32	8	3
33885	1,554	7,424	1121	1131	NA	35	17	3
33451	3,079	10,503	1140	1145	NA	43	33	[illegible]
34669	6,661	17,164	1153	1156	NA	45	-11	[illegible]

9	10		11	12	13
NAVIGATOR TUBE AZIMUTH	UTM ERROR		RADIAL ERROR	ACCURACY	TUBE POINTING ERROR
	E	N			
NA	11	-3	11	0.62%	NA
NA	32	8	33	0.56%	NA
NA	35	17	39	0.53%	NA
NA	43	33	54	0.51%	NA
NA	45	-11	46	0.27%	NA

DATE: 17 JULY 1979 COURSE: NO.3

VEHICLE: M113 APC MISSION: NO.3

WEATHER: CLOUDY START COORDINATES:

1	2		3	4	5		6
CHECKPOINT	TRUE POSITION		TRUE TUBE AZIMUTH	TERRAIN CHARACTER	NAVIGATOR POSITION		DIST TRAV
	E	N			E	N	
1	ROCKY 40753	41499	NA	VERY ROUGH	40716	41505	3,499
2	GRASS 40743	40681	NA	VERY ROUGH	40727	40668	2,785
3	METRO 39174	40324	NA	VERY ROUGH	39157	40314	2,658
4	SOLID 41088	38903	NA	VERY ROUGH	41080	38898	2,885
5	FP180 42678	32941	NA	PAVED ROAD	42691	32954	7,877
6	BAR 50591	33168	NA	MUD	50606	33209	8,360
7	ART 51998	37507	NA	PAVED ROAD	52008	37544	5,464

NOTES:

NO.3

NO.3

OORDINATES: E - 43552 N - 41787

5		6	7	8		9	10	
AVIGATOR POSITION		DISTANCE TRAVELED	CUMULATIVE DISTANCE TRAVELED	TIME		NAVIGATOR TUBE AZIMUTH	UTM ERROR	
	N			ARRIVE	DEPART		E	N
	41505	3,499	3,499	1429	1441	NA	-37	6
	40668	2,785	6,284	1447	1450	NA	-16	-13
7	40314	2,658	8,942	1459	1502	NA	-17	-10
0	38898	2,885	11,827	1512	1515	NA	-8	-5
1	32954	7,877	19,704	1530	1534	NA	13	13
6	33209	8,360	28,064	1551	1554	NA	15	41
8	37544	5,464	33,528	1603	1605	NA	20	37

	9	10		11	12	13
PART	NAVIGATOR TUBE AZIMUTH	UTM ERROR E	UTM ERROR N	RADIAL ERROR	ACCURACY	TUBE POINTING ERROR
41	NA	-37	6	37	1.06%	NA
50	NA	-16	-13	21	0.33%	NA
02	NA	-17	-10	20	0.22%	NA
15	NA	-8	-5	9	0.08%	NA
34	NA	13	13	18	0.09%	NA
54	NA	15	41	44	0.16%	NA
05	NA	20	37	38	0.11%	NA

DATE: 18 JULY 1979 | COURSE: NO.4
VEHICLE: M109, HOWITZER | MISSION: NO.1
WEATHER: RAINY (SEE NOTE BELOW) | START COORDINATES:

1	2		3	4	5		6
CHECKPOINT	TRUE POSITION		TRUE TUBE AZIMUTH	TERRAIN CHARACTER	NAVIGATOR POSITION		DIST. TRAV
	E	N			E	N	
1	FP181 42166	33467	NOTE 2	NOTE 1	42139	33495	
2	BBA1 40558	33011	NOTE 2	NOTE 1	40526	33047	
3	METRO 39174	40324	NOTE 2	NOTE 1	39163	40388	9,253
4	GRASS 40743	40681	NOTE 2	NOTE 1	40741	40731	
5							
6							
7							

NOTES:

(1) EXTREMELY HEAVY RAIN ALMOST CONTINUOUSLY. VERY MUDDY COURSE IN MOST CASES

(2) NO TUBE LAYING INFORMATION RECORDED DUE TO LOSS OF VISIBILITY TO DISTANT A
TO A THOROUGH SOAKING BY RAIN WATER. AFTER DRYING OUT, THE SYSTEM AGAIN FUNCT
ITS PRESENT CONFIGURATION).

RSE : NO.4

SION : NO.1

RT COORDINATES: E - 42678 N - 32941

5		6	7	8		9	10	
NAVIGATOR POSITION		DISTANCE TRAVELED	CUMULATIVE DISTANCE TRAVELED	TIME		NAVIGATOR TUBE AZIMUTH	UTM ER	
E	N			ARRIVE	DEPART		E	
42139	33495					NOTE 2	-27	2
40526	33047		3,413			NOTE 2	-32	3
39163	40388	9,253	12,666	1224		NOTE 2	-11	6
40741	40731					NOTE 2	-2	5

. VERY MUDDY COURSE IN MOST CASES WHICH WAS CAUSING CONSIDERABLE TRACK SLIPPAGE.

TO LOSS OF VISIBILITY TO DISTANT AIMING POINTS. SYSTEM EVENTUALLY MALFUNCTIONED DUE
DRYING OUT, THE SYSTEM AGAIN FUNCTIONED PROPERLY. (ELECTRONICS IS NOT MILITARIZED IN

8		9	10		11	12	13
IME		NAVIGATOR TUBE AZIMUTH	UTM ERROR		RADIAL ERROR	ACCURACY	TUBE POINTING ERROR
	DEPART		E	N			
		NOTE 2	-27	28	39		NOTE 2
		NOTE 2	-32	36	48	1.41%	NOTE 2
		NOTE 2	-11	64	65	0.51%	NOTE 2
		NOTE 2	-2	50	50		NOTE 2

ACK SLIPPAGE.

ALFUNCTIONED DUE
OT MILITARIZED IN

DATE: 19 JULY 1979

VEHICLE: M109, HOWITZER

WEATHER: CLOUDY

COURSE: NO.4

MISSION: NO.2

START COORDINATES:

1	2		3	4	5		6
CHECKPOINT	TRUE POSITION		TRUE TUBE AZIMUTH	TERRAIN CHARACTER	NAVIGATOR POSITION		DIS.T TRAV
	E	N			E	N	
1	FP189 45193	32990	141.2	SOME MUD, TANK TRAIL	45193	32999	3,514
2	FP180 42678	32941	3967.3	MUDDY TANK TRAIL	42666	32943	2,649
3	FP181 42166	33467	5238	TANK TRAIL	42131	33488	921
4	SOLID 41088	38903	3721	½ MUD TANK TRAIL ½ PAVED ROAD	41053	38921	7,742
5	METRO 39174	40324	5347	CROSS COUNTRY, MOSTLY ROCKS	39143	40355	5,504
6	ROCKEY 40753	41499	3997	CROSS COUNTRY, VERY ROUGH TERRAIN	40717	41532	2,76
7	ARA1 51341	37332	NO DAP		51282	37356	15,5

NOTES:

: NO.4

: NO.2

COORDINATES: E- 48301 N- 32881

5		6	7	8		9	10	
NAVIGATOR POSITION		DISTANCE TRAVELED	CUMULATIVE DISTANCE TRAVELED	TIME		NAVIGATOR TUBE AZIMUTH	UTM ERROR	
E	N			ARRIVE	DEPART		E	N
93	32999	3,514	3,514	0954		146	0	9
66	32943	2,649	6,163	1012		3970	-12	2
31	33488	921	7,084	1029		5247	-35	21
53	38921	7,742	14,826	1107		3734	-35	18
43	40355	5,504	20,330	1140		5360	-31	31
717	41532	2,765	23,095	1203		4008	-36	33
282	37356	15,543	42,999	1319		6019	-59	24

	9	10		11	12	13
E	NAVIGATOR TUBE AZIMUTH	UTM ERROR		RADIAL ERROR	ACCURACY	TUBE POINTING ERROR
PART		E	N			
	146	0	9	9	0.26%	+4.8
	3970	-12	2	12	0.19%	+2.7
	5247	-35	21	41	0.58%	+9
	3734	-35	18	39	0.26%	+13
	5360	-31	31	44	0.22%	+13
	4008	-36	33	49	0.21%	+11
	6019	-59	24	64	0.15%	

DATE: 19 JULY 1979

VEHICLE: M109, HOWITZER

WEATHER: CLOUDY

COURSE: NO.5

MISSION: NO.3

START COORDINATES:

1	2		3	4	5		6
CHECKPOINT	TRUE POSITION		TRUE TUBE AZIMUTH	TERRAIN CHARACTER	NAVIGATOR POSITION		DIST TRAV
	E	N			E	N	
1	ART 51998	37507	4806.9	MOSTLY PAVED AND GRAVEL ROAD	51993	37508	851
2	JRA3 50678	39516	NO DAP	MOSTLY PAVED AND GRAVEL ROAD SOME MUD	50684	39509	2,921
3	STA29 53078	39852	4128.6	MUDDY TANK TRAIL	53083	39847	5,30
4	STA30 52228	41121	5862.9	PAVED ROAD	52238	41124	1,54
5	STA33E 54440	40798	3148.9	CROSS COUNTRY GRASS	54435	40803	2,28
6	STA28 53884	39974	4577.2	MOSTLY CROSS COUNTRY ON GRASS	53872	39979	1,1
7	MISSION 54307	39201	3481.0	CROSS COUNTRY NOT VERY ROUGH	54294	39200	1,0

NOTES:

* TURRET NOT REALIGNED RESULTING IN ZERO TO +3 MIL ERROR.

.5

0.3

ORDINATES: E- 51341 N- 37332

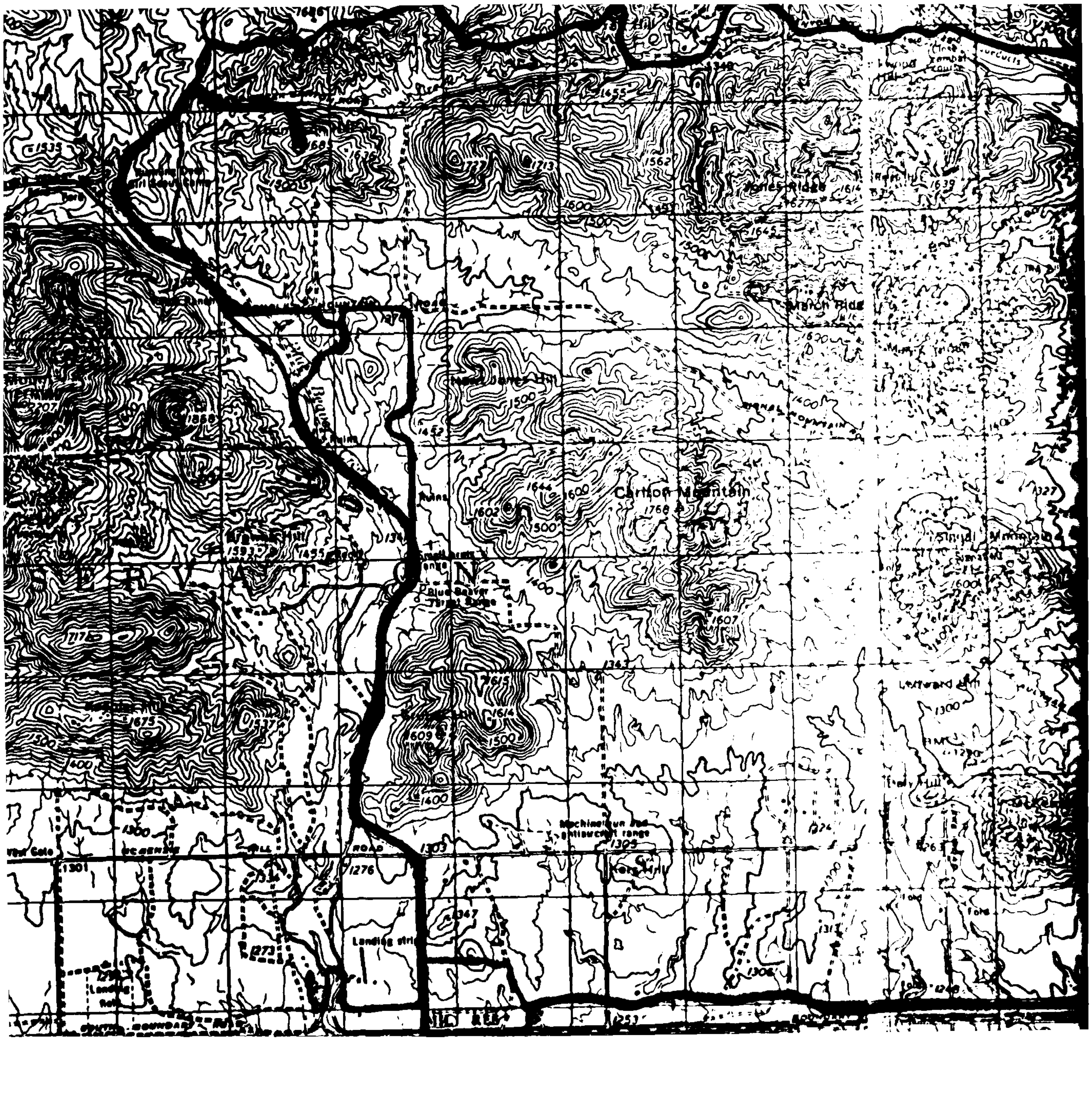
5		6	7	8		9	10	
IGATOR SITION		DISTANCE TRAVELED	CUMULATIVE DISTANCE TRAVELED	TIME		NAVIGATOR TUBE AZIMUTH	UTM ERROR	
	N			ARRIVE	DEPART		E	N
	37508	851	851	1319		4815.5	-5	1
	39509	2,921	3,772	1450		5248.0	6	-7
	39847	5,308	9,080	1500		4137.5	5	-5
	41124	1,545	10,625	1513		5872.5	10	3
	40803	2,288	12,913	1525		3159.0	5	5
	39979	1,179	14,092	1540		4592.0	+12	5
	39200	1,069	15,161	1600		3493.0	-13	-1

...ART	9 NAVIGATOR TUBE AZIMUTH	10 UTM ERROR		11 RADIAL ERROR	12 ACCURACY	13 TUBE POINTING ERROR
		E	N			
	4815.5	-5	1	5	0.6%	+8.6
	5248.0	6	-7	9	0.24%	--
	4137.5	5	-5	7	0.08%	+8.9
	5872.5	10	3	10	0.09%	+9.6
	3159.0	5	5	7	0.05%	+10.1
	4592.0	+12	5	13	0.09%	+14.8*
	3493.0	-13	-1	13	0.[illegible]	+12

APPENDIX B.

TERRAIN CHARACTER AND

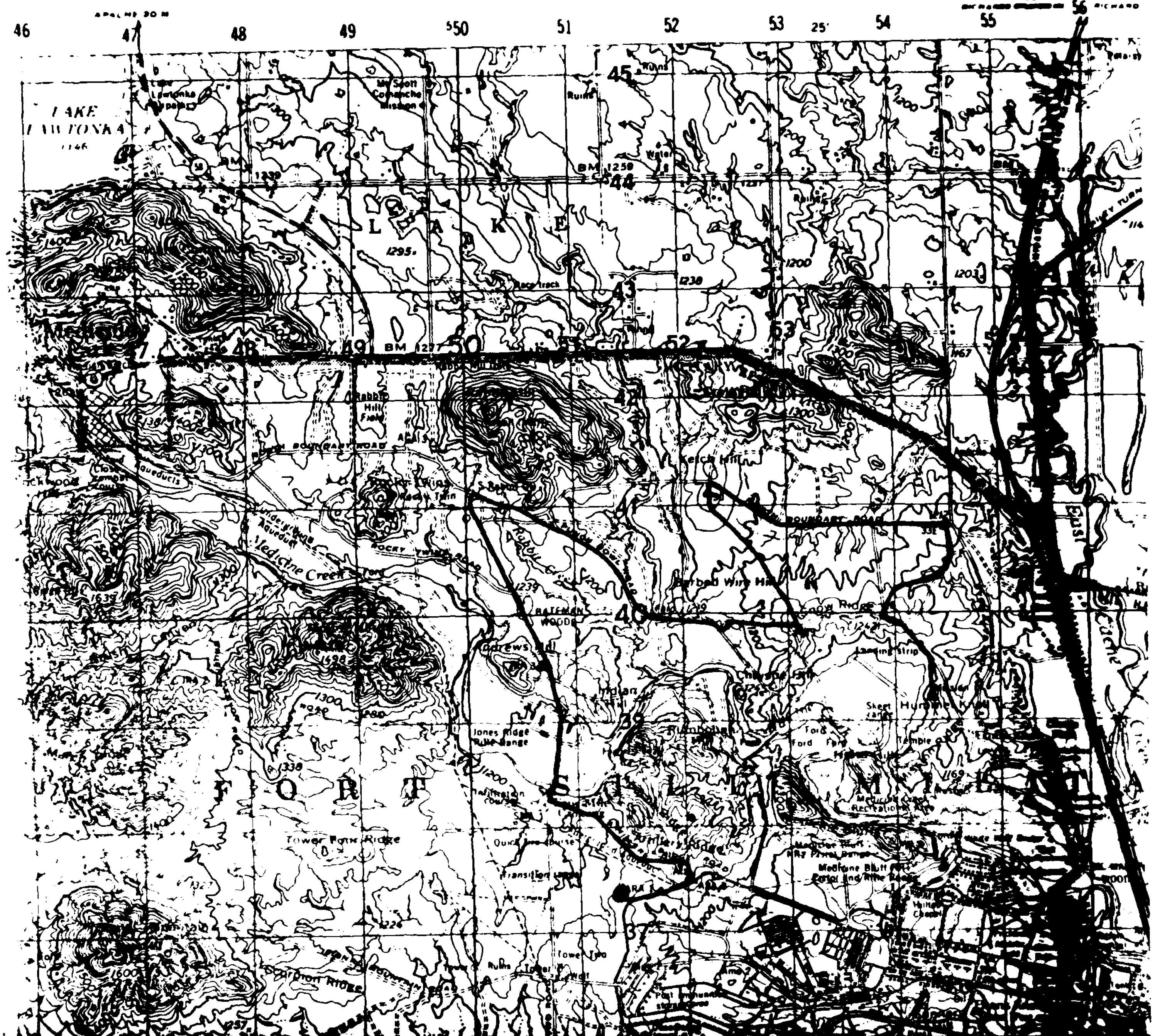
TEST COURSES

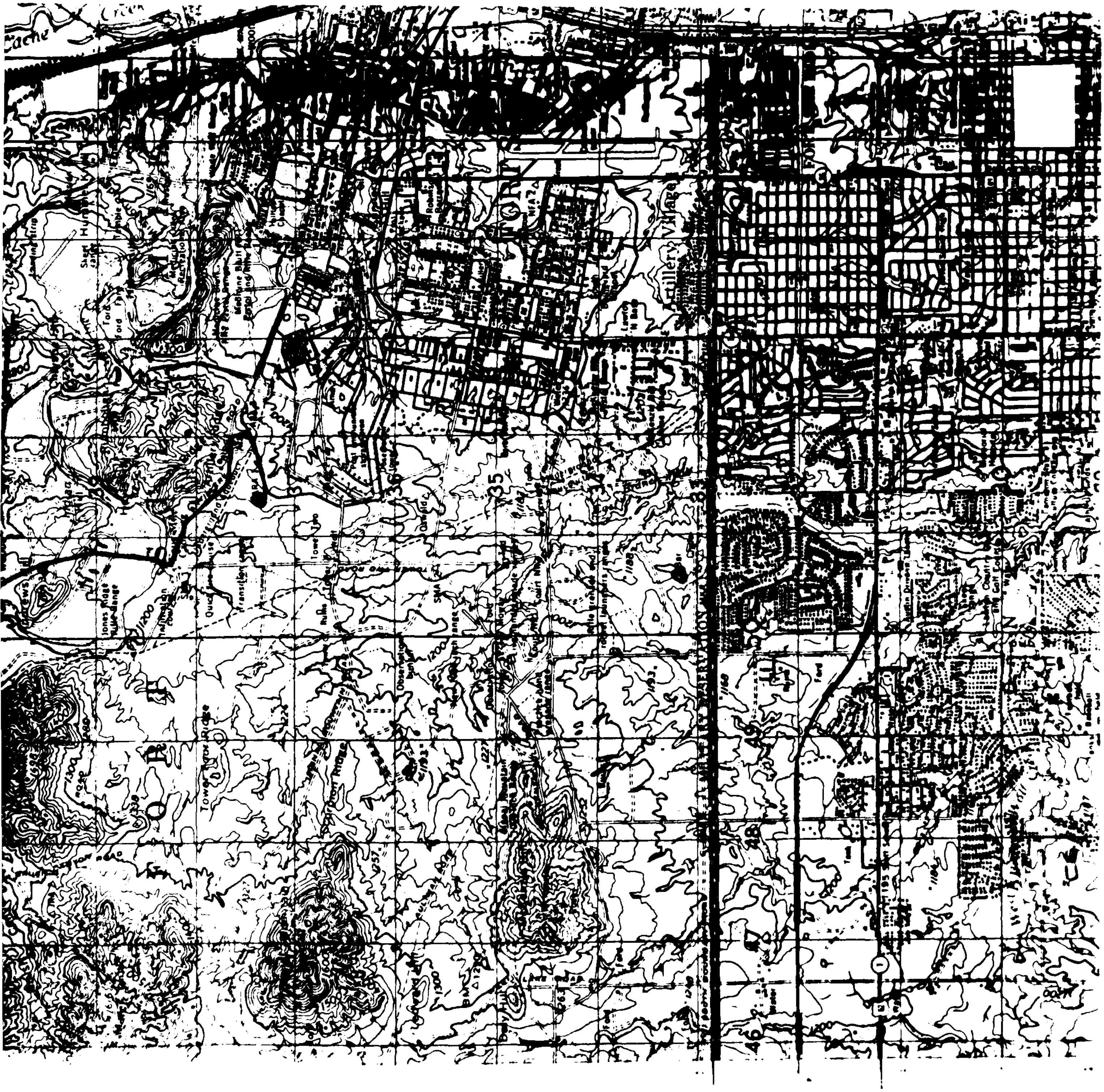


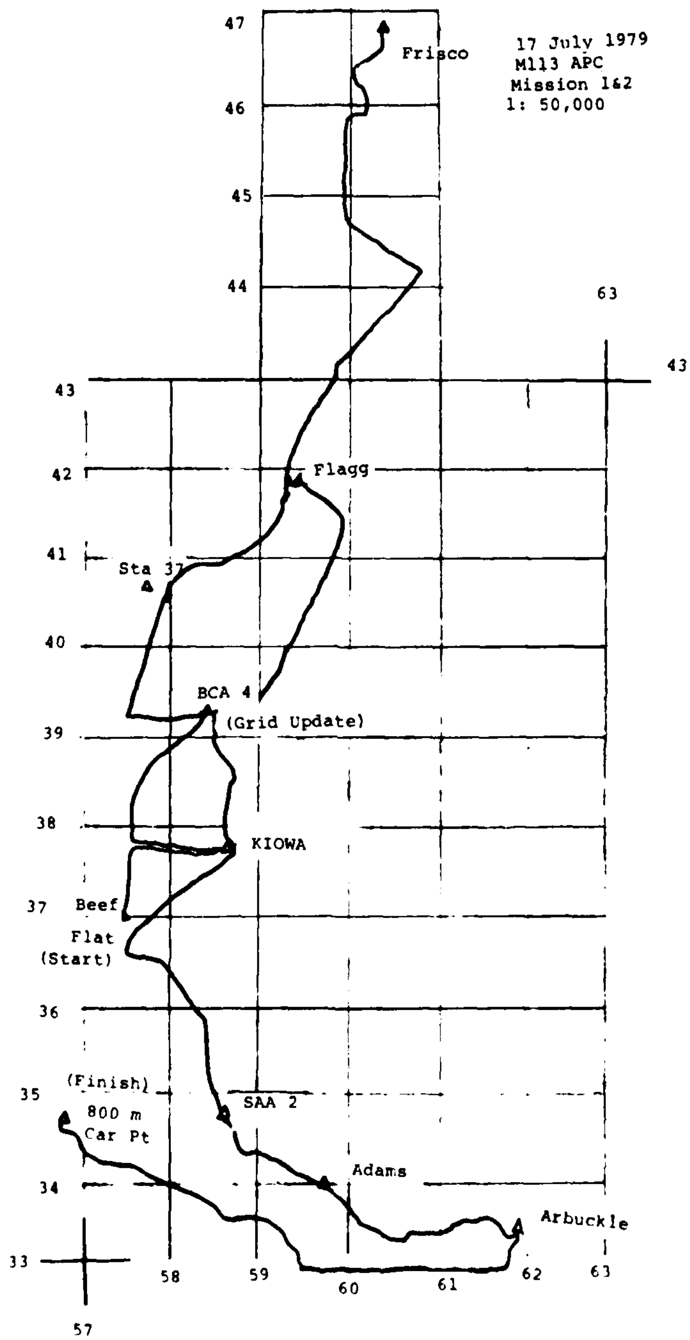
Carlson Mountain
Jones Ridge
Landing strip

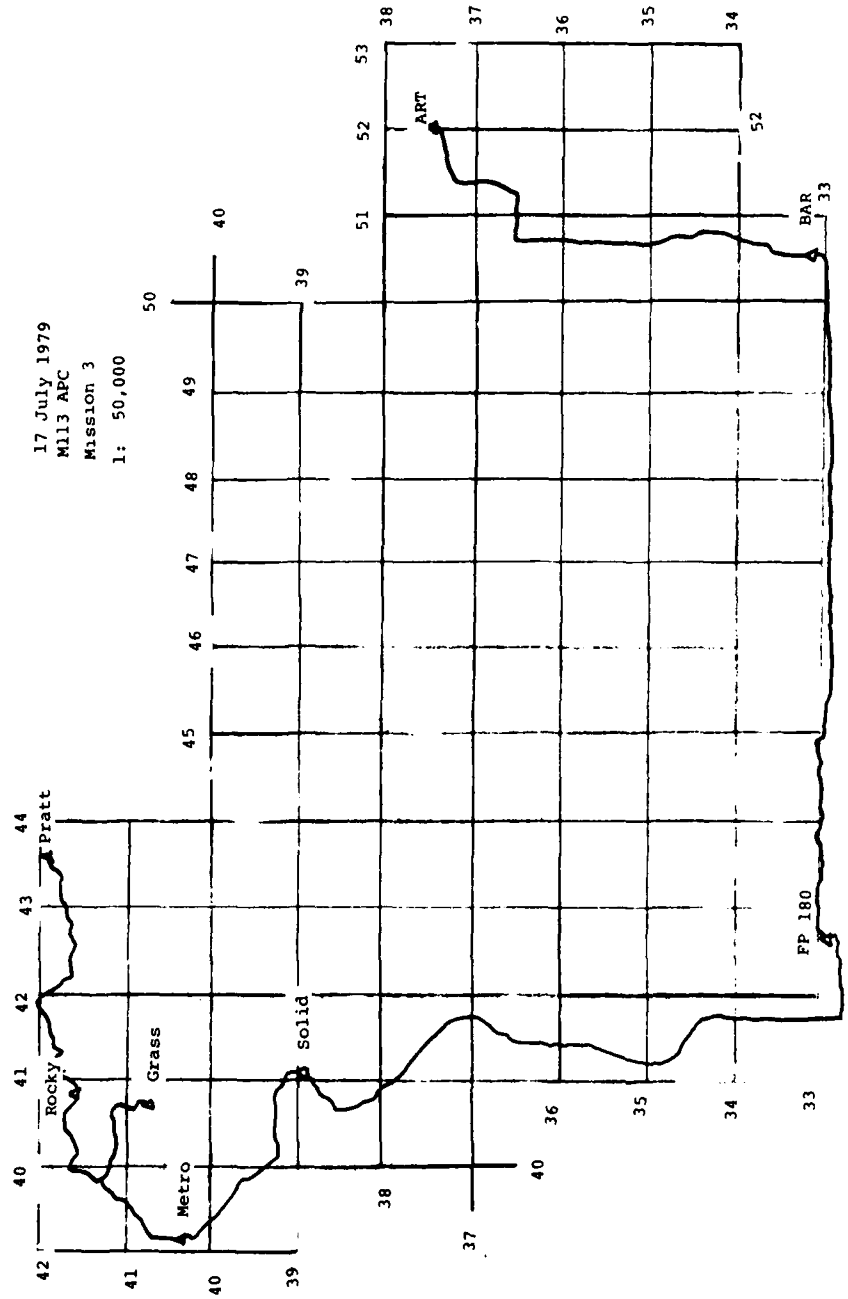

Medicine Creek
Tower Rock Ridge
Leeward Hill
Daly Hill
Artillery Village
F O R T

ƆKLAHOMA 1:50,000

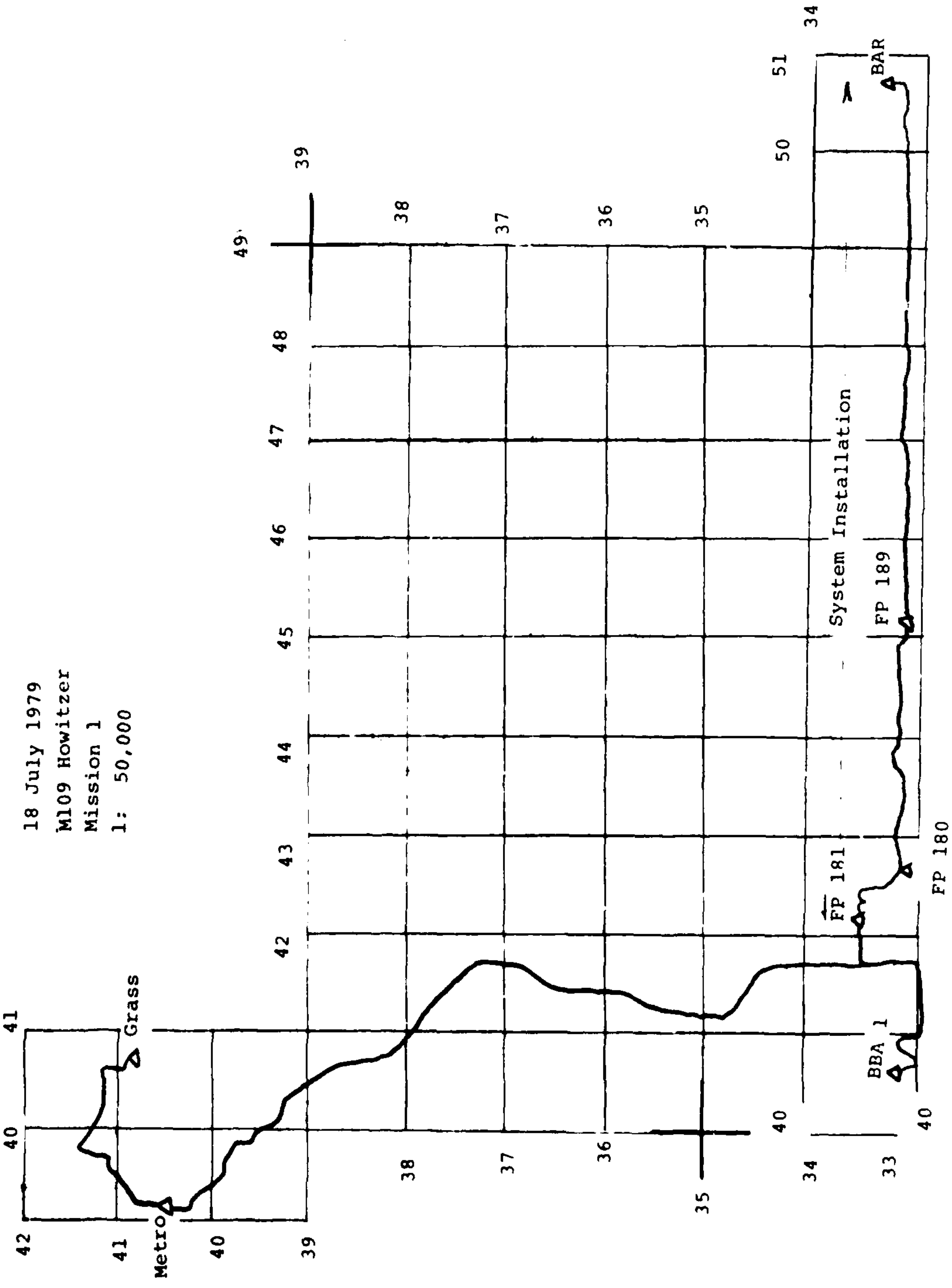


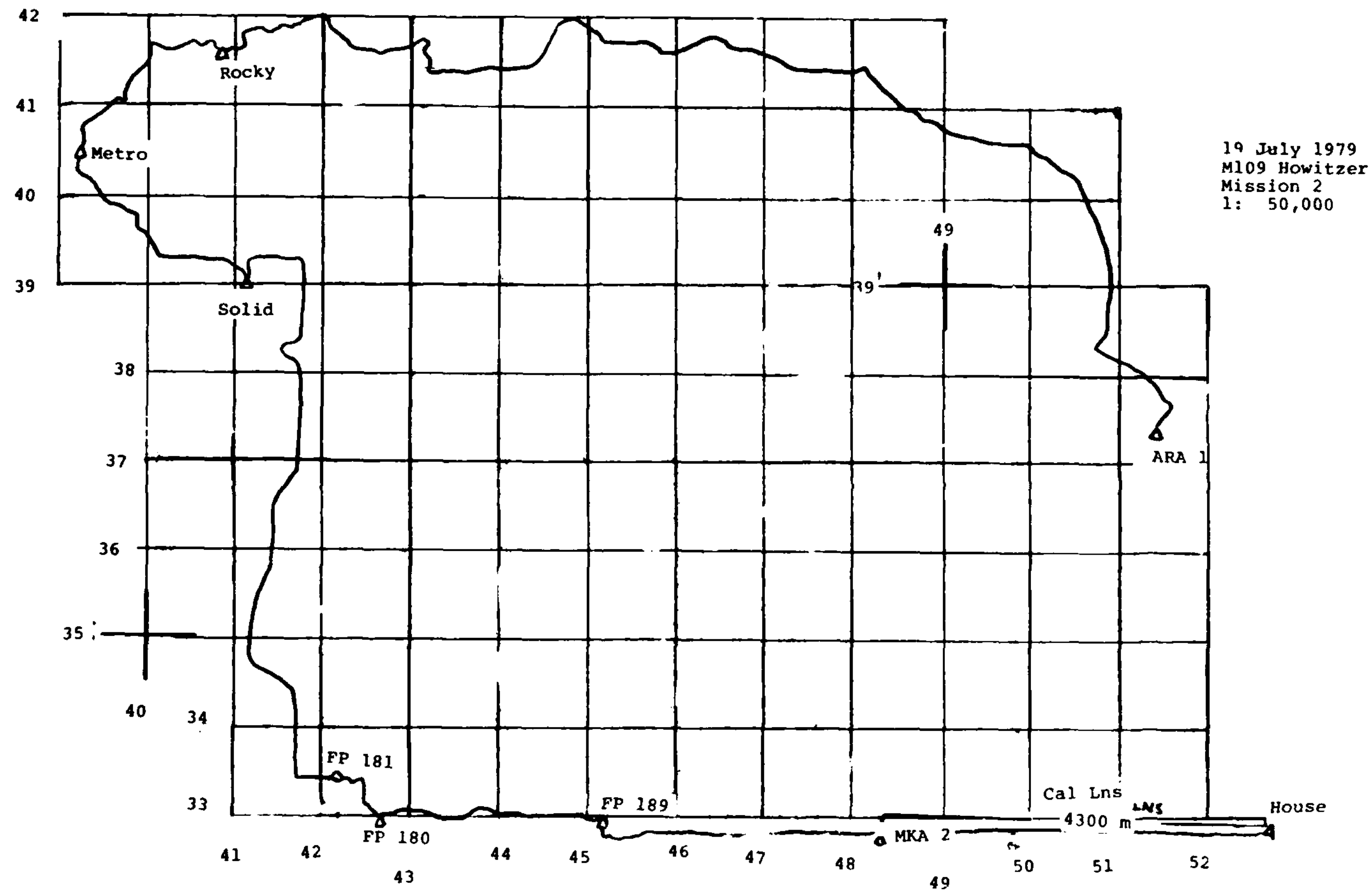



17 July 1979
M113 APC
Mission 1&2
1: 50,000
Frisco
Flagg
Sta 37
BCA 4
(Grid Update)
KIOWA
Beef
Flat
(Start)
(Finish)
800 m
Car Pt
SAA 2
Adams
Arbuckle
47
46
45
44
43
42
41
40
39
38
37
36
35
34
33
57
58
59
60
61
62
63

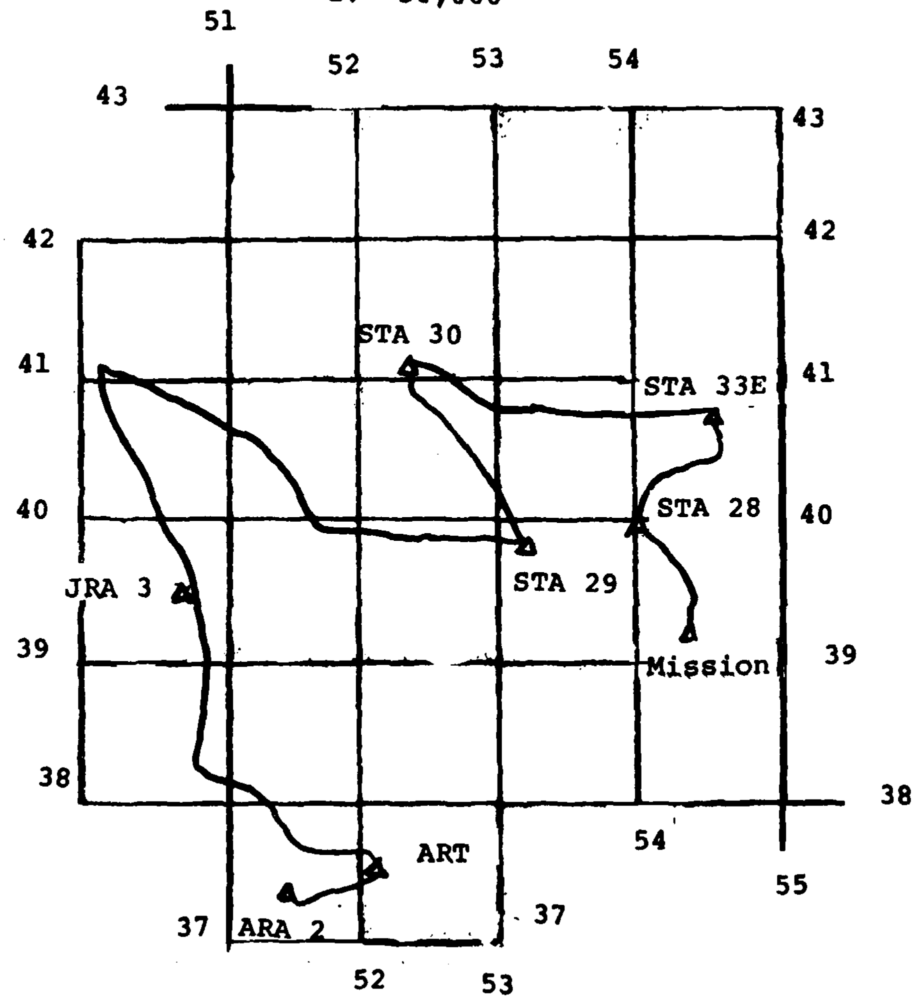


17 July 1979
M113 APC
Mission 3
1: 50,000
ART
BAR
FP 180
Pratt
Rocky
Grass
Metro
Solid


18 July 1979
M109 Howitzer
Mission 1
1: 50,000
Grass
Metro
BBA 1
FP 181
FP 180
FP 189
System Installation
BAR


19 July 1979
M109 Howitzer
Mission 2
1: 50,000
Rocky
Metro
Solid
ARA 1
FP 181
FP 180
FP 189
MKA 2
Cal Lns
4300 m
House
42
41
40
39
38
37
36
35
34
33
40
41
42
43
44
45
46
47
48
49
50
51
52

19 July 1979
M109 Howitzer
Mission 3
1: 50,000



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