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FIELD EVALUATION OF THE LR80 LAND NAVIGATION SYSTEM.(U)
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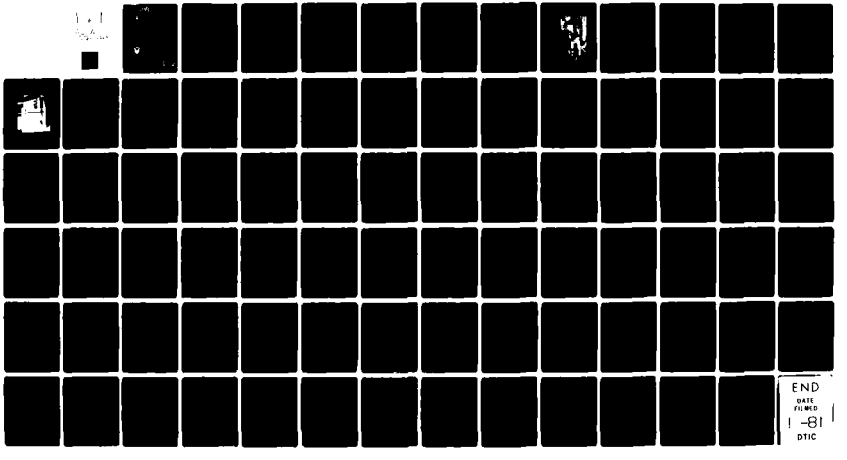

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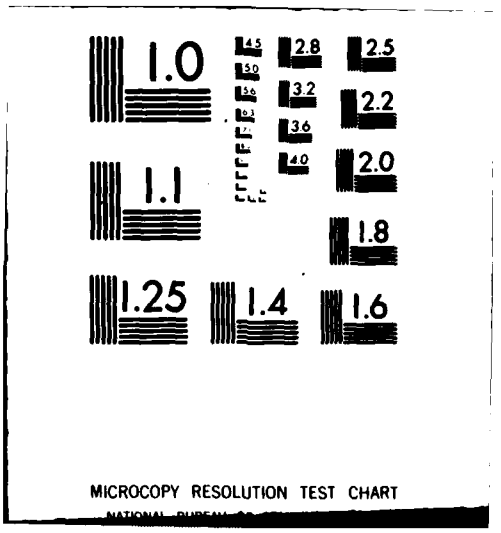
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LEVEL III (4)

AD A091885

TECHNICAL REPORT RG-80-22

FIELD EVALUATION OF THE LR80 LAND NAVIGATION SYSTEM

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Guidance and Control Directorate
US Army Missile Laboratory

April 1980

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

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

This report contains the results of a field evaluation of the Litton Industries LR80 Land Navigation System conducted by the Guidance and Control Directorate at Redstone Arsenal, Alabama.

The evaluation was performed by Messrs L. Jack Little and Newman Oldham of the Inertial Systems Development Branch with the support of Litton Field Engineer Bill Evans.

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20. (Continued)

The overall performance of the system established a north alignment with .021°, a position accuracy of .33 percent of the distance traveled and the elevation variation was so great that an accuracy value was not considered.

CONTENTS

TABLES

I. INTRODUCTION

A Litton Industries LR80 Land Navigation System was subjected to a field evaluation by the Inertial Systems Development Branch of the US Army Missile Command (MICOM), Guidance and Control Directorate. Test directors Messrs. Newman Oldham and Jack Little of MICOM were supported by Litton Industries Field Engineer W. Evans.

The system was evaluated only in the field for position accuracy, heading accuracy, and repeatability. The two courses employed in the evaluation were 82 kilometers and 47.64 kilometers in length which required approximately 2.0 hours and 1.5 hours respectively to traverse the courses.

A. System Description

The LR80 main frame is a strapdown system currently used by Litton for three different applications. The initial application was for the Advanced Attack Helicopter (AAH) Heading Attitude Reference System (HARS) with a subsequent version configured as a Land Navigator. The last application, known as the LN82, will provide the navigation function for intermediate range ballistic missiles. The fundamental difference between these three systems are based on software.

The Land Navigator version employs two, two degree of freedom G-7 tuned rotor gyros and three single axis A-4 accelerometer to provide inertial sensing. An odometer that is coupled into the vehicle, a GMC van (see Figure 1) final drive provides smoothing to the longitudinal accelerometer. The Z axis, or vertical channel for the system, enables determining elevation changes with the system.

The odometer employed in the LR80 system is a Rotaswitch Model 702 that is input to the system at 64 cycles per second. The computer, inertial sensor electronics, and strapdown inertial cluster is mounted in a common package that is aligned to the longitudinal axis of the parent vehicle. Also, a porro prism is mounted approximately 90 degrees off the longitudinal axis of the instrument cluster in order to monitor the system alignment accuracy and repeatability by optical means.

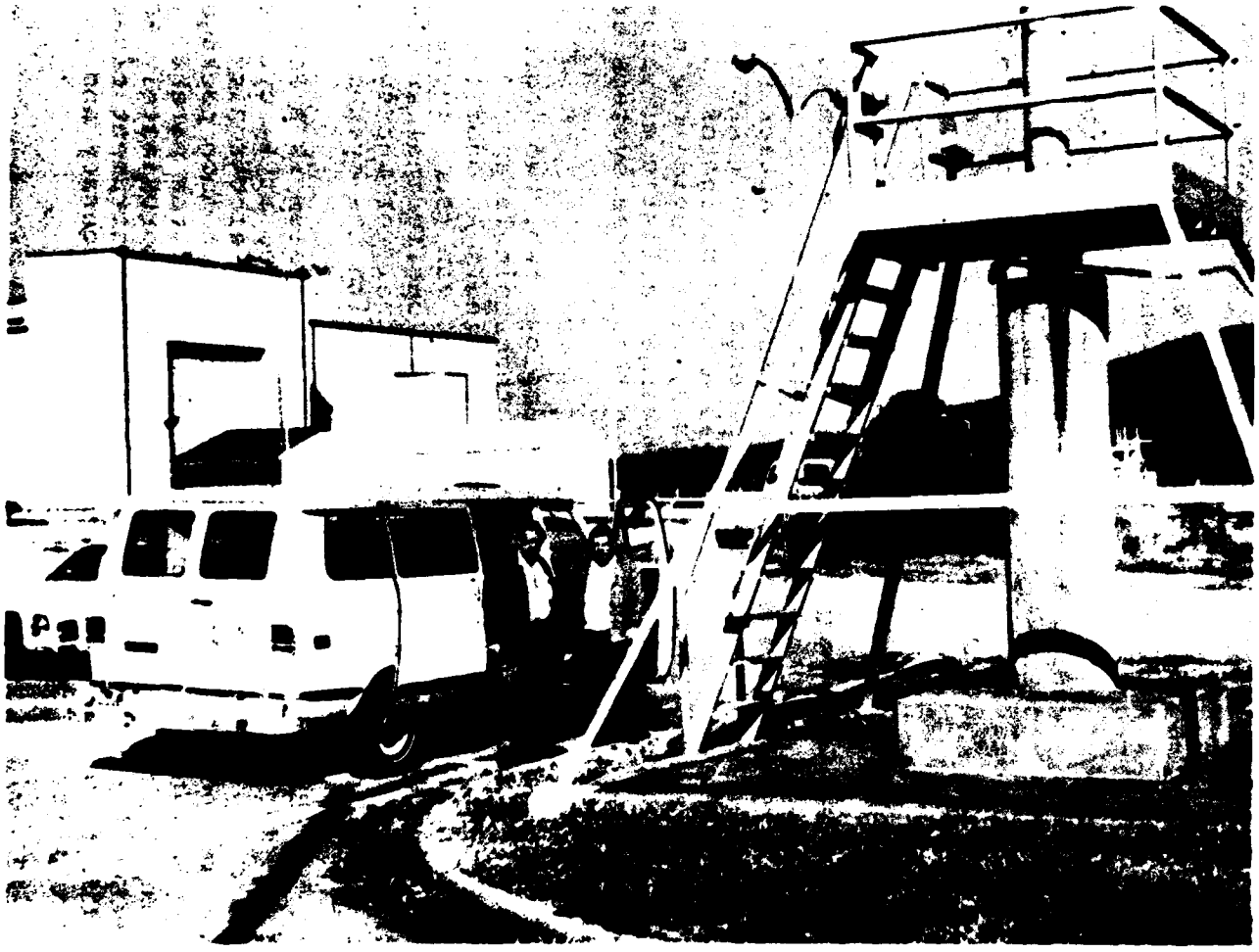

Figure 1. GMC van test bed and 5400 Astro monument.

B. Operation Description

This system uses a gyrocompassing routine, a common technique used by the Litton Company, that employs two positions, 180 degrees apart, to sense a positive and negative value of earth rate by the sensitive axis of a gyro oriented in the horizontal plane. The two positions and associated computations require approximately 300 seconds to complete the alignment routine, establish a true north alignment, and enter the navigation mode.

1. Control/Display

The LN80 system evaluated was preprototype and used the AAH/HARS control panel for data entry and system operation while the data output was printed on a Texas Instrument line printer. The initial alignment included entering:

(a) Grid convergence angle

(b) Azimuth or sight angle

(c) Elevation boresight angle

(d) Odometer scale factor deviation

(e) True latitude

just prior to entering the gyrocompassing routine.

2. Navigation Mode

Upon completion of the alignment, velocity damping and level control gains are utilized to provide a north reference, local level mechanization for the LR80. The system performs the navigation problem in the Universal Transverse Mecator (UTM) grid system and the system parameters are output every 20 seconds in a table format. However the data, presented in UTM coordinates, are relative to the origin which is initialized at zero.

C. Data Summary

The proposed accuracy for the system was specified to be 0.3 percent of the distance traveled and altitude. The actual measured system performance is:

Gyrocompassing accuracy: .021° of true North
Absolute position accuracy
and percent of distance traveled: .33%
Nominal repeatability accuracy: .07%

D. Evaluation

1. Description and Results

(a) The field evaluation was partitioned into three tests: (1) Gyrocompassing accuracy, (2) repeatability over the long road course, and (3) point to point accuracy over the accurate short road course.

Prior to each test, the system was powered up and allowed to stabilize thermally. During the warm up and stabilization time, data was collected to insure that the proper initialization parameters were inserted into the computer memory.

While traversing the road courses, a full stop was made at each check point to allow system settling and record the position data.

II. LONG COURSE REPEATABILITY

The long course, 90 kilometer distance, has two approximately true north legs and one west-southwest leg that runs very straight, such that cross track errors can be scrutinized more easily.

Table 1 contains the list of check points used in this test. Two types of check points were used in this course; those with known positions values and those established by the LR80. Those points established by the LR80, were developed by calculating the mean of $\bar{X}$ of the easting and the northing for a number of measurements contained in Tables 2 through 5, made at the same point along the course. As each point was established, precise reference marks were made such that the vehicle could be repositioned over the point within 10 centimeters. Upon labeling the check points for the course, variations in each subsequent data point were analyzed and presented as one-sigma radial error and percentage of the distance traveled error. The radial errors represent the one-sigma value calculated from the square root of the sum of the squares of the easting and northing of each check point.

The summary of the data from the 90 kilometer course is contained in Table 6. The radial one-sigma value for each check point is determined by calculating the root sum square for each data set measured for each check point:

$$r_i = \sqrt{(\text{northing})^2 + (\text{easting})^2}$$

The sigma value is determined from the $r_i \mid_{i=1}^{i=n}$ which is representative of the repeatability for a given check point. The percentage error of the distance traveled is calculated from the radial one-sigma error and the total distance traveled from the reference origin.

The data indicates a worst case of .29 percent of the distance traveled which occurs when the system turns north at the Mooresville check point (MOR). However, this .29 percent error remained constant for the duration of the nominal north leg of the course. The four sets of data for MOR and FMC check points were resolved into northing and easting vectors that have a mean of:

$\bar{X}_n$ = 15329.3 meters

$\bar{X}_e$ = 237.5 meters

The actual distance traveled was 15,262 meters which is in error 69 meters when compared to the root sum square of $\bar{X}_n$ and $\bar{X}_e$. The dispersion of the easting data for this leg of the course is approximately two times that for the north error. The cross track error indicates a heading error which is further substantiated by the decrease in error as the loop begins to close.

Also included in the data is a value reflecting closure error or the error in returning to the starting origin. The closure error was .02 percent of the distance traveled.

A. Gyrocompassing Accuracy

1. Test Description

A series of measurements were designed to evaluate the accuracy, repeatability and accuracy as a function of system heading. In order to perform these measurements, the vehicle was positioned nominally on 45 degree increment between 0 and 360 degrees. While positioned on the specified headings, the LR80 was initialized to gyrocompass with and without the engine operating. Three sets of

gyrocompassing heading angles were recorded along with the theodolite readings between true north and the system case mounted porro prism (see Figure 2).

The north reference line established between the reference monument and the porro prism was established to be accurate within 30 seconds of arc and the porro prism was aligned to 90.425 degrees with respect to the longitudinal axis of the LN80 system.

B. Data Analysis

Table 7 presents the data collected for the gyrocompassing accuracy test. Data point 21 illustrates the worst case error of .277 degrees. However, the mean of the error data $\bar{X}_{\epsilon 1}$ indicates a .021 degree misalignment error in performing a north alignment when the entire data is analyzed. However, when the mean $\bar{X}_{\epsilon 2}$ for error data is calculated, without the vehicle engine running, the value of the mean increases by 21 percent. Similarly, the one-sigma value decreases by 18 percent with the engine off. The base motion of the system does degrade the repeatability of the system alignment but improves the misalignment error.

Upon completing this series of measurements, navigation problems having a 1.9 and 1.3 hour duration were performed over the 90 kilometer course. During the alignment mode, in preparation for the navigation problem, the theodolite was used to accurately measure the vehicle heading. Upon completion of the navigation problem, the vehicle was oriented in approximately the same position as the initial alignment position. Again, the theodolite was used to verify vehicle heading in contrast to the displayed vehicle heading without a gyrocompass update. Table 7 summary presents a worst case of .064 degrees/hour drift for the gyro and heading indication. This data exhibits gyro performance for drift and vibration influence in a field environment.

III. 48 KILOMETER COURSE

The 48 kilometer course includes three first order survey stakes with an elevation change of 304.8 meters. In addition to these precision reference points, six other check points were established with the navigation system to aid in improving the estimate of the system repeatability.

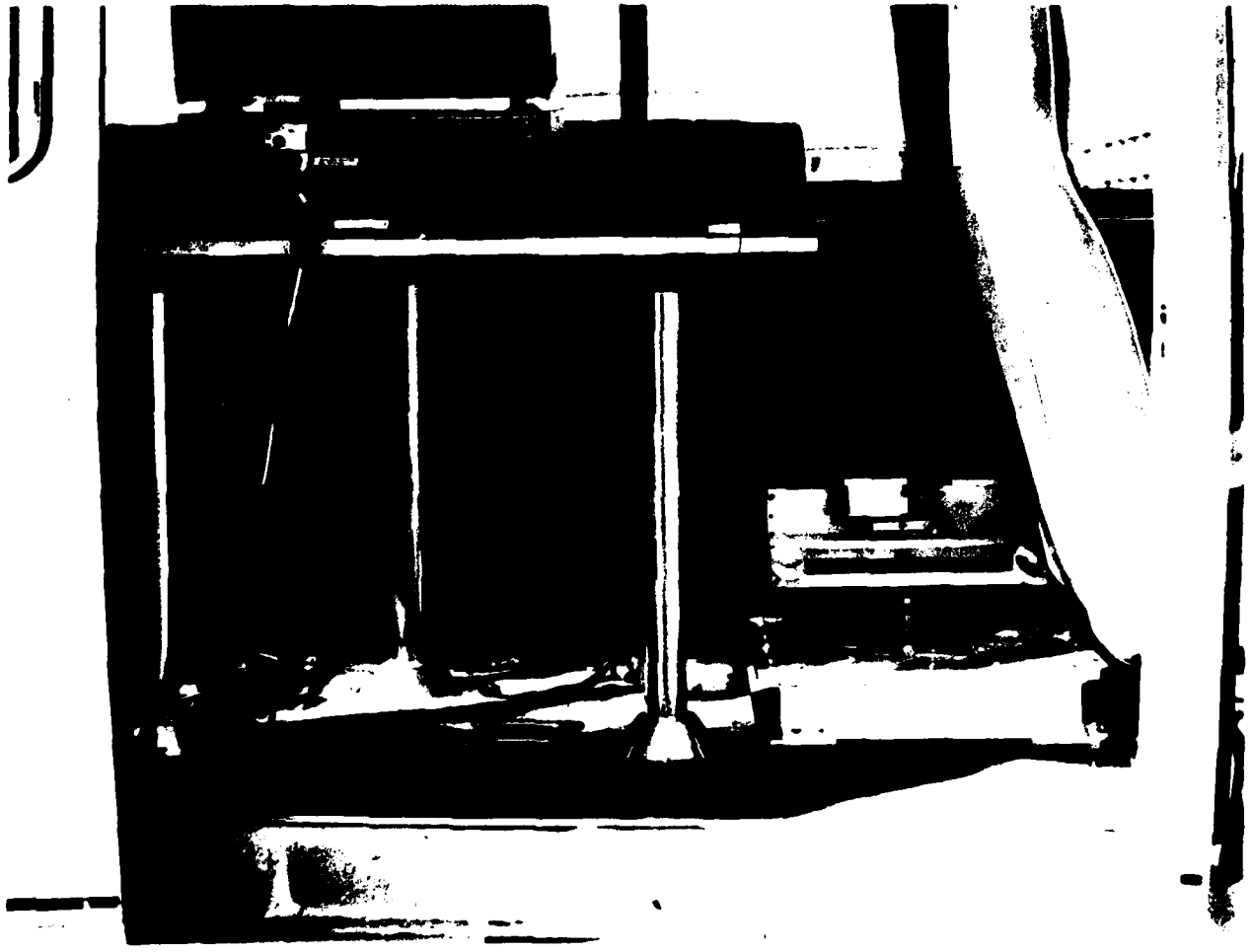

Figure 2. Test mounting of the navigator.

The course was traversed in the same direction for each data set and a gyrocompass was performed prior to each run or data set. The raw data, with the zero reference at the 5400 Astro monument, was converted to the UTM coordinate frame to facilitate data comparison with other land navigation systems.

The converted data, including altitude, is recorded in Tables 8 through 18. The precision survey data points are summarized in Table 19, and the composite data were analyzed and summarized by check point in Tables 20 through 27. The mean, root sum square of the northing and easting and one-sigma was calculated from the multiple values recorded for each check point (see Table 28). In the case where the check point was established by the system, the values N and E are the means calculated as opposed to the precise survey point where the value is absolute within first order survey accuracies. Also, elevation data recorded is analyzed although the absolute value and repeatability of the information is rather excessive.

The altitude value of the check point is obtained from the contour lines of a 1:24000 map. The elevation in feet is converted to meters and the reference marker elevation, 5400 Astro monument, is subtracted to reference all check points to the 5400 datum plane.

The error analysis reflecting worst case errors are calculated two ways: (1) Where a check point is established by the system, the percent error is a repeatability, and (2) where the check point is absolute, then the percentage error is in absolute position.

The repeatability value of error is calculated by use of the difference between the mean value of the check point and the data point having the greatest error:

$$\% \text{ error} = \left(\frac{\bar{X} - R_i}{X}\right) \times 100\%$$

$\bar{X}$ = mean of a check point in meters

R_i = greatest error data point in northing or easting in meters.

The percentage error of the distance traveled is evaluated with the one-sigma spread of the root sum square

of the easting and northing data in conjunction with the distance traveled extracted from the 1:24000 map:

$$\% \text{ of distance traveled} = \left(\frac{\sigma_R}{d}\right) \times 100\%$$

σ_R = one-sigma of all root sum square values calculated from northing and easting data points (meters).

d = total distance traveled from origin or reference point (meters).

The altitude data was evaluated to establish the mean and one-sigma of the data points recorded. These mean and reference altitudes were compared to show a general error; the errors in general were so great that little can be said for the data being useful. There were some rationalizations for the poor performance in the vertical channel but these issues must be resolved at the proper time.

The data generated in calculating the mean value for a check point was used in the calculation of the percentage of the distance traveled error for each data point. This data is listed in Tables 8 through 18.

Th errors associated with the established points are characteristically insignificant. Table 19 reveals that the absolute error of .54 percent is the worst case with .3 to .4 percent of the distance traveled being more characteristic of the system performance.

The much smaller errors associated with the closure at the 5400 monument are indicative that system errors tend to average out when returning to the start point. Greater emphasis must be placed on the repeatability and absolute position errors as a function of distance along the course. In reviewing the easting and northing values, 404.5 meters in northing one-sigma for GD/JL is the greatest error. A more nominal value is 40 meters error. These values are not necessarily verified in the root sum square values or radial errors of the check point because the greatest radial error is 84.2 meters.

IV. CONCLUSIONS

The overall systems performance is excellent in defining position in the horizontal plane. However, the erratic performance of the elevation channel is very unsatisfactory. A pitch misalignment coefficient, a major factor in the elevation channel error, must be entered during the initialization mode for various load distribution within the parent vehicle. This effect should not be evident in a triad of accelerometers because coordinate transformations within the system software should resolve the cross coupling due to vehicle pitch change.

This undesirable feature of the pitch channel should be resolved in the LR80 system prototype before this system should be considered for applications requiring accurate elevation data.

The demonstrated positional accuracy of the system would fill navigational requirements for a number of missile launchers, radars, indirect fire weapons, and vehicles in the Army inventory. However, this system was a prototype system and operational features could not be evaluated. The performance was outstanding. The repeatability of .07 percent for the system reflects an inherent capability of the system to improve on the .33 percent obsolete navigational accuracy of the system.

Also, this is an innovative application of the strapdown inertial technology which uses the triad of accelerometers for leveling and smoothing of the displacement information from the odometer. This system, once configured into a production prototype, should be subjected to a more rigorous evaluation in a MIL Specification environment coupled with performance attributes.

TABLE 1. 90 KILOMETER NAVIGATION COURSE

SURVEY STAKE IDENT	UTM COORDINATES	
	NORTHING	EASTING
5400	33310	33200
BW/JL	41051	34152
BW/20	41074	31776
RASS	40445	29825
RSAB	38636	26016
MCLR	35439	19499
GBR	33079	14316
MOR	31526	10999
BMR	34518	11046
H20	32420	11085
SC	39685	11166
PC	42900	11214
FMC	46800	11242
RRB	44882	19648
SR	45723	26148
72/JL	42679	34096
5400	33310	33200

TABLE 2. 90 KILOMETER NAVIGATION COURSE, 25 OCTOBER

TIME: Start 0934; END

DATE: 25 October 1979

SURVEY STAKE IDENT	UTM COORDINATES		ALT METERS
	NORTHING METERS	EASTING METERS	
5400	33311	33204	0
BW/JL	41113	34129	69.4
BW/2O	41083	31592	89.0
RASS	40395	29617	110.1
RSAB	38609	25940	133.1
MCLR	35396	19444	182.6
GBR	32968	14216	194.9
MOR	31468	10907	214.2
BMR	34428	10949	242.2
H20	36341	10974	249.1
SC	39628	11020	271.9
PC	42860	11048	304.2
FMC	46785	11048	348.0
RRB	44903	19443	431.7
SR	45810	26029	479.2
72/JL	43583	33953	506.6
5400	33382	33200	549.2

Data correct from raw system data to UTM coordinates based on 5400 monument zero reference.

TABLE 3. 90 KILOMETER NAVIGATION COURSE, 26 OCTOBER

TIME: Start 0900; END 1100

DATE: 26 October 1979 GYRO: Start 6302.2: End 6296.5

SURVEY STAKE IDENT	UTM COORDINATES		ALT METERS
	NORTHING METERS	EASTING METERS	
5400	33311	33204	0
BW/JL			
BW/20	41074	37599	54.6
RASS	40388	29626	68.3
RSAB	38606	25952	77.3
MCLR	35399	19463	100.8
GBR	32976	14235	98.0
MOR	31478	10929	106.4
BMR	34432	10971	122.3
H20	36342	10996	124.5
SC	39626	11042	138.3
PC	42854	11072	157.3
FMC	46778	11072	189.1
RRB	44895	19454	251.5
SR	45800	26030	277.1
72/JL	43573	33990	274.2
5400	33378	33216	269.3

Data correct from raw system data to UTM coordinates based on 5400 monument zero reference.

TABLE 4. 90 KILOMETER NAVIGATION COURSE, 29 OCTOBER

TIME: Start PM; END

DATE: 29 October 1979

SURVEY STAKE IDENT	UTM COORDINATES		ALT
	NORTHING METERS	EASTING METERS	METERS
5400	33311	33204	0
BW/JL	41082	34213	33.4
BW/20	41079	31618	40.9
RASS	40413	29704	52.9
RSAB	38673	26016	56.1
MCLR	35548	19494	72.0
GBR	33191	14241	62.7
MOR	31741	10915	69.1
BMR	34691	10994	81.8
H20	36601	11073	82.5
SC	39882	11162	92.3
PC	43108	11232	109.1
FMC	47030	11283	137.6
RRB	45034	19637	180.6
SR	45845	26228	200.1
72/JL	43504	34158	190.5
5400	33322	33211	176.5

Data correct from raw system data to UTM coordinates based on 5400 monument zero reference.

TABLE 5. 90 KILOMETER NAVIGATION COURSE, 13 NOVEMBER

TIME: Start ; END

DATE: 13 November 1979

SURVEY STAKE IDENT	UTM COORDINATES NORTHING METERS	UTM COORDINATES EASTING METERS	ALT METERS
5400	33311	33204	0
BW/JL			
BW/20	41166	31656	15
RASS	40492	29661	19.5
RSAB	38731	25939	15.6
MCLR	35556	19352	18.7
GBR	33160	14042	3.7
MOR	31678	10687	-0.3
BMR	34652	10757	8.0
H20	36576	10804	4.7
SC	39884	10884	10.0
PC	43133	10945	18.2
FMC	47089	10985	31.9
RRB	45092	19429	54.4
SR	45936	26082	58.4
72/JL	43600	34093	41.8
5400	33362	33180	13.3

Data correct from raw system data to UTM coordinates based on 5400 monument zero reference.

TABLE 6. 90 KILOMETER COURSE DATA SUMMARY

SURVEY	10-25-79		10-26-79		10-29-79		11-13-79		RADIAL ERROR	% DIST TRADE
STAKE	NORTHING	EASTING	NORTHING	EASTING	NORTHING	EASTING	NORTHING	EASTING	R = 1σ	
BW/JL	41113	34129			41082	34213			15	.15
BW/20	41083	31592	41074	31599	41079	31618	41166	31656	44.4	.35
RASS	40395	29617	40388	29626	40413	29704	40492	29661	44.7	.30
RSAB	38609	25940	38606	25952	38673	26016	38731	25939	48.1	.25
MCLR	35396	19444	35399	19463	35548	19494	35556	19352	64.3	.25
GBR	32968	14216	32976	14235	33191	14241	33160	14042	185.9	.27
MOR	31468	10907	31478	10929	31741	10915	31678	10687	104.2	.29
BMR	34428	10949	34432	10971	34691	10994	34652	10757	109.4	.29
H20	36341	10974	36342	10996	36601	11073	36576	10804	117.3	.29
SC	39628	11020	39626	11042	39882	11162	39884	10884	125.0	.29
PC	42860	11048	42854	11072	43108	11232	43133	10945	132.3	.28
PMC	46785	11048	46778	11072	47030	11283	47089	10985	143.9	.28
RRB	44903	19443	44895	19454	45034	19637	45092	19429	92.7	.16
SR	45810	26029	45800	26030	45845	26228	45936	26082	68.3	.10
72/J1	43583	33953	43573	33990	43504	34158	43600	34093	39.6	.05
5400	33382	33200	33378	33216	33322	33211	33362	33180	18.3	.02

TABLE 7. COMPASS ROSE GYROCOMPASS TEST

COMPASS ROSE GC TEST 90° 15' 15" = 90.254

RUN #	MTR	THEO DEGREES	THEO + MIRROR DEGREES	VAN DEGREES	ERROR DEGREES
1	On	180.300	270.554	270.471	-.083
2	On	180.2944	270.5481	270.466	-.082
3	Off	180.29171	270.546	270.466	-.080
AVG			270.549	270.468	-.081
7	On	225.1539	315.4081	315.587	.179
8	Off	225.1547	315.4089	315.268	-.141
9	On	225.1547	315.4089	315.420	.011
AVG			315.4086	315.425	.016
11	On	270.5203	360.7745	360.709	-.065
12	Off	270.5203	360.7745	360.755	-.019
13	On	270.5233	360.7775	360.651	-.126
AVG			360.7755	360.705	-.070
15	On	313.8731	44.1273	43.994	-.133
16	Off	313.8700	44.1242	44.251	.127
17	Off	313.8700	44.1242	44.250	.126
AVG			44.1252	44.165	.040
19	Off	359.4917	89.7459	89.773	.027
20	Off	359.4917	89.7459	89.790	.044
21	On	359.8367	90.0909	89.814	.277
AVG			89.8609	89.793	-.069
23	Off	44.8635	135.1177	135.029	-.089

TABLE 7. (Continued)

COMPASS ROSE GC TEST 90° 15' 15" = 90.254

RUN #	MTR	THEO DEGREES	THEO + MIRROR DEGREES	VAN DEGREES	ERROR DEGREES
24	Off	44.8635	135.1177	135.051	-.067
25	On	44.8683	135.1225	135.254	.131
AVG			135.1193		-.008
27	Off	88.7339	178.988	179.002	.014
28	Off	88.7339	178.988	179.095	.107
29	On	88.7339	178.988	179.035	.047
AVG			178.988	179.044	.056
35	Off	135.4508	224.705	224.834	.129
32	Off	134.4492	224.704	224.796	.092
33	On	134.4492	224.703	224.553	-.150
AVG			224.7037	224.7277	.024
35	Off	181.0964	271.3506	271.305	.045
36	Off	181.0964	271.3506	271.277	.074
37	On	181.0989	271.3531	271.317	.036
AVG			271.3514	271.2997	.052

13 November 1979 SUMMARY

THEO	MIRROR	DEGREES	TIME	VAN	
181.2317°	90.2542	271.485	0 Start	271.416	-.069
181.8131	90.2542	272.067	1.9 hrs End	271.987	-.080

$$\text{Drift} = \frac{(-.080+.069)^{\circ}}{1.9 \text{ hrs}} = \frac{.005^{\circ}}{\text{hr}}$$

TABLE 7. (CONCLUDED)

THEO	MIRROR	DEGREES	TIME	VAN	
180.9986	90.2542	271.253	0 Start	271.144	-.109
179.8992	90.2542	270.153	1.3 hrs End	269.961	-.192

$$\text{Total Drift} = \frac{(-.109 + .192)^\circ}{1.3 \text{ hrs}} = \frac{.064^\circ}{\text{hr}}$$

Total error angle data

$\sigma_\varepsilon = .106$ degrees

$\bar{X}_{\varepsilon_1} = .021$

Error angle data with engine off

$\sigma_\varepsilon = .084$ degrees

$\bar{X}_{\varepsilon_2} = .026$ degrees

TABLE 8. 48 KILOMETER COURSE, 26 October

DATE: 26 October 1979 TIME START: 003 Min

DIST END: END: 098 Min

HEADING START: 6377.2 END: 6350.2

STATION	NORTHING $\tilde{N}$ METERS	EASTING $\tilde{E}$ METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310.0	3320.0	0.0	-
BW/J	41085.0	34255.3	13.7	.20
GD/JL MEA	41836.0	34247.7	15.6	.23
GD/CA MEA	41782.0	39101.6	14.6	.03
GD/MS MEA	40914.5	42657.9	223.0	.15
MS MEA	44654.5	42698.1	397.1	.25
RP MEA	44963.3	43189.4	307.7	.09
PC MEA	43025.2	38271.6	20.2	.32
BW/J MEA	41086.3	34250.3	14.1	.08
5400 MEA	33329.2	33188.8	-10.6	.01

$$d = \sqrt{\tilde{N}^2 + \tilde{E}^2}$$

$\bar{X}_r$ = Mean of all station meas

d = Actual distance traveled

$$\% \text{ distance traveled} = \left(\frac{\tilde{d} - \bar{X}_r}{d}\right) \times 100$$

TABLE 9. 48 KILOMETER COURSE, 29 October

DATE: 29 October 1979 TIME START: 3.6 Min

DIST END: END: 92.9 Min

HEADING START: 6334.5 END: 6302.5

STATION	NORTHING METERS	EASTING METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310	33200	0.0	-
BW/J	41104.2	34215.4	11.0	.09
GD/JL MEA	41857.6	34204.4	12.3	.13
GD/CA MEA	41828.6	39073.4	9.7	.06
GD/MS MEA	40981.2	42642.3	222.9	.02
MS MEA	44731.0	42663.2	378.9	.38
RP MEA	45043.9	43154.8	258.4	.04
PC MEA	43071.6	38230.7	-14.1	.34
GD/JL MEA	41856.7	34203.6	-21.4	.03
BW/J	41102.6	34211.7	-31.3	.015
5400 MEA	33326.3	33200.9	-53.8	.025

TABLE 10. 48 KILOMETER COURSE, 29 October

DATE: 29 October 1979 PM TIME START:

DIST END: END:

HEADING START: END:

STATION	NORTHING METERS	EASTING METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310.0	33200.0	0.0	-
BW/J	41091.4	34209.5	23.1	.04
GD/JL MEA	41843.5	34197.5	25.7	.016
GD/CA MEA	41818.0	39054.8	33.7	.07
GD/MS MEA	40972.4	42616.5	251.2	.10
MS MEA	44716.3	42636.5	418.3	.26
RP MEA	45027.9	43125.9	329.9	.08
PC MEA	43061.2	38215.9	48.0	.29
GD/JL MEA	41853.2	34196.2	53.9	.02
BW/JL	41100.6	34203.7	47.7	.002
5400 MEA	33337.8	33185.0	43.9	.02

TABLE 11. 48 KILOMETER COURSE, 14 November

DATE: 14 November 1979 TIME START: 0 Min

DIST END: END: 31.9 Min

HEADING START: 0 END: 5811.6

STATION	NORTHING METERS	EASTING METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310	33200	0.0	-
GD/JL MEA				
GD/CA MEA	41853.5	39041.4	-29.3	.04
GD/MS MEA	41016.1	42617.5	132.4	.06
MS MEA	44770.6	42622.6	243.4	.38
RP MEA				
PC MEA				
GD/JL MEA				
5400 MEA				

TABLE 12. 48 KILOMETER COURSE, 15 November

DATE: 15 November 1979 A.M. TIME START: 7.2 Min

DIST END: END: 87.9

HEADING START: END: 6376.3

STATION	NORTHING METERS	EASTING METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310	33200	0.0	-
GD/JL MEA	41826.3	34164.1	28.4	.32
GD/CA MEA	41815.3	39013.5	38.7	.26
GD/MS MEA	40982.5	42574.1	219.6	.22
MS MEA	44719.1	42577.0	350.0	.10
RP MEA	45033.1	43063.4	271.0	.23
PC MEA	43052.0	38171	67.0	.18
GD/JL MEA	41824.2	34166.5	80.1	.09
5400 MEA	33333.4	33200.8	81.6	.03

TABLE 13. 48 KILOMETER COURSE, 16 November

DATE: 16 November 1979 A.M. TIME START:

DIST END: END:

HEADING START: 3308.3 END: 3304.9

STATION	NORTHING METERS	EASTING METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310	33200	0.0	-
GD/JL MEA	41851.2	34166.2	25.6	.13
GD/CA MEA	41842.5	39031.2	32.6	.06
GD/MS MEA	41013.0	42605.4	210.9	.002
MS MEA	44764.7	42606.9	339.3	.32
RP MEA	45080.7	43095.4	259.0	.01
PC MEA	43079.1	38181.2	50.4	.26
GD/JL MEA	41845.7	34160.6	59.3	.06
5400 MEA	33315.6	33196.3	57.9	.004

TABLE 14. 48 KILOMETER COURSE, 16 November

DATE: 16 November 1979 P.M. TIME START:

DIST END: END:

HEADING START: END:

STATION	NORTHING METERS	EASTING METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310	33200	0.0	-
GD/JL MEA	41860.6	34183.9	48.3	.04
GD/CA MEA	41842.6	39046.5	63.8	.01
GD/MS MEA	41003.5	42623.1	250.7	.03
MS MEA	44757.2	42632.6	388.0	.37
RP MEA	45071.8	43121.2	310.0	.03
PC MEA	43089.8	38207.9	113.0	.34
GD/JL MEA	41866.8	34182.7	131.6	.02
5400 MEA	33286.9	33200.9	145.6	.03

TABLE 15. 48 KILOMETER COURSE, 19 November

DATE: 19 November 1979 A.M. TIME START:

DIST END: END:

HEADING START: END:

STATION	NORTHING METERS	EASTING METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310	33200	0.0	-
GD/JL MEA	41888.9	34179.5	23.5	.21
GD/CA MEA	41872.2	39060.9	28.3	.21
GD/MS MEA	41029.4	42647.7	205.4	.21
MS MEA	44793.7	42654.7	331.3	.54
RP MEA	45108.9	43145.4	249.3	.20
PC MEA	43116.0	38215.0	34.9	.42
GD/JL MEA	41887.7	34180.7	39.5	.06
5400 MEA	33324.4	33198.1	28.9	.02

TABLE 16. 48 KILOMETER COURSE, 19 November

DATE: 19 November 1979 P.M. TIME START: 3.6 Min

DIST END: END: 72.5

HEADING START: 6334.5 END: 6336.3

STATION	NORTHING METERS	EASTING METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310	33200	0.0	-
GD/JL MEA	41850.1	34213.2	15.9	.13
GD/CA MEA	41811.5	39076.5	16.5	.004
GD/MS MEA	40958.6	42649.9	190.2	.03
MS MEA	44710.1	42674.9	312.7	.35
RP MEA	45022.2	43164.9	229.9	.01
PC MEA	43060.8	38247.4	10.6	.36
5400 MEA	33320.0	33191.7	-8.6	.003

TABLE 17. 48 KILOMETER COURSE, 20 November

DATE: 20 November 1979 A.M. TIME START:

DIST END: END:

HEADING START: 6327.3 END: 6330.6

STATION	NORTHING METERS	EASTING METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310.0	33200	0.0	-
GD/JL MEA	41878.0	34140.7	9.9	.09
GD/CA MEA	41886.6	39018.2	9.8	.09
GD/MS MEA	41059.3	42606.5	185.4	.17
MS MEA	44819.7	42598.3	309.3	.46
RP MEA	45135.9	43085.9	226.5	.12
PC MEA	43131.8	38178.7	8.2	.38
GD/JL MEA	41890.4	34155.8	8.2	.02
5400 MEA	33415.2	33209.3	9.4	.17

TABLE 18. 48 KILOMETER COURSE

DATE: TIME START:

DIST END: END:

HEADING START: END:

STATION	NORTHING METERS	EASTING METERS	ALTITUDE METERS	% OF DIST TRAVELED
5400 MEA	33310	33200	0.0	-
GD/JL MEA	41837	34169.6	-27.4	.22
GD/CA MEA				
GD/MS MEA				
MS MEA				
RP MEA				
PC MEA				
GD/JL MEA				
5400 MEA	33346.0	33202.1	-55.3	.12

Post Cal: Theodolite 270.153°

System (No GC) 269.961°

Finial Δ = $-.192^{\circ}$

Initial Δ = $-.108$

DRIFT = $-.084^{\circ}$

TABLE 19. SURVEY STAKE DATA

RUN NO	PERCENT OF DISTANCE TRAVEL ERROR		
	MONTE SANO	PRES CHURCH	5400 CLOSURE
1	.25	.32	.01
2	.38	.34	.025
3	.26	.29	.02
4	.38	-	-
5	.10	.18	.03
6	.32	.26	.004
7	.37	.34	.03
8	.54	.42	.02
9	.35	.36	.003
10	.46	.38	.17

TABLE 20.

SURVEY STAKE - BOB WALLACE/JORDAN LANE

(N) NORTHING: 41095.6 ALT: 198 M/12 M

(E) EASTING: 34211.0

NORTHING METERS	EASTING METERS	ROOT SUM SQUARE (METERS)	ELEV METERS
41113.0	34129.0	53432.8	69.4
41082.0	34213.0	53462.7	33.4
41085.0	34255.3	53492.1	13.7
41086.3	34250.3	53489.9	14.1
41104.2	34215.4	53481.3	11.0
41102.6	34211.7	53477.7	-31.3
41091.4	34209.5	53467.7	23.1
41100.6	34203.7	53471.0	47.7

$\bar{X}_a$ = 22.6M

$1\sigma_a$ = 27.7M

$\bar{X}_n$ = 41095.6 $\bar{X}_E$ = 34211.0 $\bar{X}_R$ = 53471.9

$1\sigma_n$ = 10.3 $1\sigma_E$ = 35.9 $1\sigma_R$ = 17.6

Worst case repeatibility error = .07% $\frac{\bar{X} - R_i}{\bar{X}}$

Worst case elevation error = 1.8 X

% of Distance Traveled = $\frac{\sigma_R}{d} = \frac{17.6}{998.1} = .18\%$

TABLE 21.

SURVEY STAKE - GOVERNORS DR/JORDAN LANE G/J

(N) NORTHING: 41758.1 ALTITUDE: 198M/12M

(E) EASTING: 34183.6

NORTHING METERS	EASTING METERS	ROOT SUM SQUARE (METERS)	ELEVATION METERS
41836.0	34247.7	54066.2	15.6
41857.6	34204.4	54055.5	12.3
41856.7	34203.6	54054.3	-21.4
41843.5	34197.5	54040.2	25.7
41853.2	34196.2	54046.9	53.9
41826.3	34164.1	54005.8	28.4
41824.2	34166.5	54005.7	80.1
41851.2	34166.2	54026.4	25.6
41845.7	34160.6	54018.6	59.3
41860.6	34183.9	54044.9	48.3
41866.8	34182.7	54048.9	131.6
41888.9	34179.5	54064.0	23.5
41887.7	34180.7	54063.8	39.5
41850.1	34213.2	54055.3	15.9
41878.0	34140.7	54031.0	9.9
41890.4	34155.8	54050.2	8.2
41837.0	34169.6	54017.5	-27.4

$\overline{X}_a = \underline{29.9}$

$1\sigma_a = \underline{35.5}$

TABLE 21. (CONCLUDED)

$\overline{X}_n$ = 41758.1 $\overline{X}_e$ = 34183.6 $\overline{X}_R$ = 54040.9

$1\sigma_n$ = 404.5 $1\sigma_e$ = 24.2 $1\sigma_R$ = 19.3

Worst case repeatability error = 0.06%

Worst case elevation error = 2.5 X

% of Distance Traveled = $\frac{19.3}{10741}$ = .18%

TABLE 22.

SURVEY STAKE - GOVERNORS DR/CALIFORNIA ST

(N) NORTHING: 41835.3 ALTITUDE: 208M/22

(E) EASTING: 39051.8

NORTHING METERS	EASTING METERS	ROOT SUM SQUARE (METERS)	ELEVATION METERS
41782.0	39101.6	57224.7	14.6
41828.6	39073.4	57239.5	9.7
41818.0	39054.8	57219.1	33.7
41853.5	39041.4	57235.9	-29.3
41815.3	39013.5	57188.9	38.7
41842.5	39031.2	57220.9	32.6
41842.6	39046.5	57231.4	63.8
41872.2	39060.9	57262.8	28.3
41811.5	39076.5	57229.1	16.5
41886.6	39018.2	57244.3	9.8

$\bar{X}_a$ = 21.8M

σ_a = 23.1M

$\bar{X}_n$ = 41835.3 $\bar{X}_e$ = 39051.8 $\bar{X}_R$ = 57229.7

$1\sigma_n$ = 29.3 $1\sigma_e$ = 26.1 $1\sigma_R$ = 18.2

Worst case repeatability error = .07%
Elevation error = .9%

% of Distance Traveled = $\frac{18.2}{15711}$ = .11%

TABLE 23.

SURVEY STAKE - GOVERNORS DR/MONTE SANO BLVD

(N) NORTHING: 40993.0 ALTITUDE: 372M/186M

(E) EASTING: 42624.1

NORTHING METERS	EASTING METERS	ROOT SUM SQUARE (METERS)	ELEVATION METERS
40914.5	42657.9	59107.5	223.0
40981.2	42642.3	59142.4	222.9
40972.4	42616.5	59117.7	251.2
41016.1	42617.5	59148.7	132.4
40982.5	42574.1	59094.2	219.6
41013.0	42605.4	59137.9	210.9
41003.5	42623.1	59144.0	250.7
41029.4	42647.7	59179.7	205.4
40958.6	42649.9	59132.2	190.4
41059.3	42606.5	59170.8	185.4

$\bar{X}_a$ = 209.2M

σ_a = 32.9M

$\bar{X}_n$ = 40993.0 M $\bar{X}_e$ = 42624.1 M $\bar{X}_R$ = 59137.5 M

$1\sigma_n$ = 38.4 M $1\sigma_e$ = 24.4 M $1\sigma_R$ = 25.1 M

Worst case repeatability error = .07%

Worst case elevation error = 12%

% of Distance Traveled = $\frac{25.1}{19719}$ = .12%

TABLE 24.

SURVEY STAKE - MONTE SANO

(N) NORTHING: 44704 ALTITUDE: 484.2/298.2

(E) EASTING: 42558

NORTHING METERS	EASTING METERS	ROOT SUM SQUARE (METERS)	ELEVATION METERS
44654.5	42698.1	61783.1	397.1
44731.0	42263.2	61538.9	378.9
44716.3	42636.5	61785.3	418.3
44770.6	42622.6	61815.0	243.4
44719.1	42577.0	61746.2	350.0
44764.7	42606.9	61799.9	339.3
44757.2	42632.6	61812.2	388.0
44793.7	42654.7	61853.8	331.3
44710.1	42674.9	61807.3	312.7
44819.7	42598.3	61833.8	309.3

$\bar{X}_a$ = 346.8M

σ_a = 48.9M

$\bar{X}_n$ = 44743.7 $\bar{X}_e$ = 42596.5 $\bar{X}_R$ = 61777.5M

$1\sigma_n$ = 45.0 $1\sigma_e$ = 116.2 $1\sigma_R$ = 84.2M

$$\Delta_n = \frac{N - \bar{X}_n}{N} \times 100 \qquad \Delta_n = .09\%$$

$$\Delta_e = \frac{E - X_E}{N} \times 100 \qquad \Delta_e = .09\%$$

TABLE 24. (CONCLUDED)

Worst case absolute error = .30%

Worst case elevation error = 16% $\frac{\bar{X} - A}{A}$

% of Distance Traveled = $\frac{84.2}{24175}$ = .35%

TABLE 25.

SURVEY STAKE - ROCKY POINT

(N) NORTHING: 45054.2

(E) EASTING: 43127.3

NORTHING METERS	EASTING METERS	ROOT SUM SQUARE (METERS)	ELEVATION METERS
44963.3	43189.4	62346.0	307.7
45043.9	43154.8	62380.2	258.4
45027.9	43125.9	62348.7	329.9
45033.1	43063.4	62309.2	271.0
45080.7	43095.4	62365.7	259.0
45071.8	43121.2	62377.1	310.0
45108.9	43145.4	62420.6	249.3
45022.2	43164.9	62371.5	229.9
45135.9	43085.9	62399.1	226.5

$\overline{X}_a$ = 271.3

σ_a = 34.6

$\overline{X}_n$ = 45054.2 $\overline{X}_e$ = 43127.3 $\overline{X}_R$ = 62368.7 M

$1\sigma_n$ = 48.5 $1\sigma_e$ = 38.3 $1\sigma_R$ = 30.4

Worst case repeatability error = .08%

% Distance Traveled = $\frac{30.4}{25717}$ = 0.1%

TABLE 26.

SURVEY STAKE - PRESBYTERIAN CHURCH

(N) NORTHING: 43007.0 ALTITUDE: 195.6/9.6

(E) EASTING: 38133.9

NORTHING METERS	EASTING METERS	ROOT SUM SQUARE (METERS)	ELEVATION METERS
43025.2	38271.6	59583.7	20.2
43071.6	38230.7	57591.2	-14.1
43061.2	38215.9	57573.6	48.0
43052.0	38171.0	57536.9	67.0
43079.1	38181.2	57564.0	50.4
43089.8	38207.9	57589.7	113.0
43116.0	38215.0	57614.0	34.9
43060.8	38247.4	57594.2	10.6
43131.8	38178.7	57601.8	8.2

$\bar{X}_a$ = 37.6 M

σ_a = 35.6

$\bar{X}_n$ = 43076.4 M $\bar{X}_e$ = 38213.3 M $\bar{X}_R$ = 57583.2

$1\sigma_n$ = 30.8 M $1\sigma_e$ = 31.5 M $1\sigma_R$ = 21.4

$$\Delta_n = \frac{N - \bar{X}_n}{N} \times 100 \qquad \Delta_n = .16\%$$

$$\Delta_e = \frac{E - \bar{X}_e}{N} \times 100 \qquad \Delta_E = .21\%$$

TABLE 26. (CONCLUDED)

Worst case absolute error = .18%

Worst case elevation error = 3.9X

% of Distance Traveled = $\frac{21.4}{32421}$ = .07%

TABLE 27.

SURVEY STAKE - BUILDING 5400

(N) NORTHING: 33310 ALTITUDE: 86M/0 M

(E) EASTING: 33200

NORTHING METERS	EASTING METERS	ROOT SUM SQUARE (METERS)	ELEVATION METERS
33329.2	33188.8	47035.4	-10.6
33326.3	33200.9	47041.9	-53.8
33337.8	33185.0	47038.8	43.9
33333.4	33200.8	47046.9	81.6
33315.6	33196.3	47031.1	57.9
33286.9	33200.9	47014.0	145.6
33324.4	33198.1	47038.6	28.9
33320.0	33191.7	47031.0	-8.6
33415.2	33209,3	47110.9	9.4
33346.0	33202.1	47060.2	-55.3

$\overline{X}_a$ = 23.9 M

σ_a = 58

$\overline{X}_n$ = 33333.5 $\overline{X}_e$ = 33197.9 $\overline{X}_R$ = 47044.9 M

$1\sigma_n$ = 31.1 $1\sigma_e$ = 7.3 $1\sigma_R$ = 24.7 M

$\Delta_n = \frac{N - \overline{X}_n}{N} \times 100$ Δ_n = .07%

$\Delta_E = \frac{E - \overline{X}_E}{N} \times 100$ Δ_E = .006%

TABLE 27. (CONCLUDED)

Worst case repeatability error = .03%

% of Distance Traveled $= \frac{24.7}{48369} = .05\%$

TABLE 28. SUMMARY OF CHECK POINT MEAN VALVE AND ONE - SIGMA

CHECK POINT	NORTHING MEAN	(METERS) ONE-SIGMA	EASTING MEAN	(METERS) ONE-SIGMA	ROOT SUM SQUARE (METERS) MEAN	ONE-SIGMA
	$\bar{X}_n$	$1\sigma_n$	$\bar{X}_e$	$1\sigma_e$	$\bar{X}_R$	$1\sigma_R$
BW/JL	41095.6	10.3	34211.0	35.9	53471.9	17.6
GD/JL	41758.1	404.5	34183.6	24.2	54040.9	19.3
GD/CA	41835.3	29.3	39051.8	26.1	57229.7	18.2
GD/MS	40993.0	38.4	42624.1	24.4	59137.5	25.1
MS	44743.7	45.0	42596.5	116.2	61777.5	84.2
RP	45054.2	48.5	43127.3	38.3	62368.7	30.4
PC	43076.4	30.8	38213.3	31.5	57583.2	21.4
5400	33333.5	31.1	33197.9	7.3	47044.9	24.7

APPENDIX A.

90 KILOMETER COURSE DATA

LONG COURSE DATA 25 October 1979

DEPART 0934 HEADING 359.6°

	EASTING METERS	NORTHING METERS	ALT METERS
5400 MONUMENT	0	0	0
BOB WALLACE/JORDAN	924.5	7802.3	69.4
BOB WALLACE/HWY 20	-1612.4	7771.9	89.0
RASS Redstone Sub Sta.	-3587.4	7083.8	110.1
RSAB Redstone Arsenal Boundry	-7263.9	5297.9	133.1
Madison County Line MCLR	-13760.0	2085.4	182.6
Greenbrier Road GBR	-18987.8	-343.0	194.9
Mooresville MOR	-22297	-1843.3	214.2
Belle Mina Railroad BMR	-22255.0	1117.0	242.2
Old Highway 20 H20	-22230.3	3030.1	249.1
Salem Corner SC	-22184.1	6316.7	271.9
Peets Corner PC	-22155.7	9548.9	304.2
French Mill Corner FMC	-22155.6	13474.2	348.0
Railroad Bed Road RRB	-13761.5	11592.3	431.7
Slaughter Road SR	-7175.3	12499.5	479.2

	EASTING METERS	NORTHING METERS	ACT METERS
Jordan - Hwy 72 J72	749.0	10272.2	506.6
Bob Wallace - Jordan	902.3	7848.2	510.8
5400 Monument	-4.0	70.6	549.2

LONG COURSE DATA IN UTM 25 October 1979

STATION	NORTHING	EASTING
5400	33311	33204
BW/JL	41113	34129
BW/20	41083	31592
RASS	40395	29617
RSAB	38609	25940
MCLR	35396	19444
GBR	32968	14216
MOR	31468	10907
BMR	34428	10949
H20	36341	10974
SC	39628	11020
PC	42860	11048
FMC	46785	11048
RRB	44903	19443
SR	45810	26029
72/JL	43583	33953
5400	33382	33200

TEST RUN: AM/PM, COURSE: BELLE MINA

DATE: 26 October 1979

CHECK POINT	TIME MIN	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
LAB	-	0	0	-	-
BW/20		-1605.1	7763.5	54.6	
RASS		-3578.2	77076.6	68.3	
RASB		-7252	5295.3	77.3	
MCLR		-1374.1	2088.0	100.8	
GBR		-18968.8	-335.3	98.0	
MOR		-22275.5	-1832.9	106.4	
BMR		-22233.1	1120.8	122.3	
H20		-22207.9	3031.4	124.5	
SC		-22161.6	6315.2	138.3	
PC		-22131.7	9542.8	157.3	
FMC		-22131.6	13466.7	189.1	
RRB		-13750.5	11583.9	251.5	
SR		-7174.3	12489.2	277.1	
J72		785.8	10262.5	274.2	
LAB		12.2	67.5	269.3	
		Final heading Gyro compass heading		6296.5 6302.2 } Δ	= 5.7 MILS
		Time 7211 sec			

LONG COURSE DATA IN UTM 26 October

STATION	NORTHING	EASTING
5400	33311	33204
BW/20	41074	31599
RASS	40388	29626
RASB	38606	25952
MCLR	35399	19463
GBR	32976	14235
MOR	31478	10929
BMR	34432	10971
H20	36342	10996
SC	39626	11042
PC	42854	11072
FMC	46778	11072
RRB	44895	19454
SR	45800	26030
J72	43573	33990
LAB	33378	33216

TEST RUN: AM/PM, COURSE: BELLE MINA

DATE: 29 October 1979

CHECK POINT	TIME SEC	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
LAB		0.0	0.0	0.0	6354.9
BW/J	776	1008.7	7771.5	33.4	6259.0
BW/20	1055	-1521.9	7768.0	40.9	4354.4
RASS	1235	-3500.4	7101.8	52.9	4433.3
RASB	1475	-7187.9	5362.4	56.1	4261.1
MCLR	1835	-13709.6	2237.4	72.0	4372.4
GBR	2136	-18962.6	-119.9	62.7	4214.1
MOR	2356	-22288.7	-1570.0	69.1	4550.9
BMR	2575	-22209.8	1380.0	81.8	35.6
H20	2895	-22160.3	3290.5	82.5	6266.6
S	3116	-22071.5	6571.2	92.3	4.9
PC	3316	-22000.9	9797.2	109.1	6378.7
FMC	3555	-21949.6	13719.4	137.6	3.4
RRB	4055	-13596.0	11723.1	180.6	1607.7
SR	4416	-7004.9	12533.7	200.1	1865.9
J72	4855	924.7	10193.1	190.5	2356.0
LAB	5735	-21.7	11.1	176.5	6270.5

29 October 1979

STATION	NORTHING	EASTING
5400	33311	33204
BW/J	41082	34213
BW/20	41079	31618
RASS	40413	29704
RASB	38673	26016
MCLR	35548	19494
GBR	33191	14241
MOR	31741	10915
BMR	34691	10994
H20	36601	11073
SC	39882	11162
PC	43108	11232
FMC	47030	11283
RRB	45034	19637
SR	45845	26228
J72	43504	34158
5400	33322	33211

TEST RUN: AM/PM, COURSE: BELLE MINA

DATE: 13 November 1979

CHECK POINT	TIME MIN	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
BW/20	2274	-1547.8	7854.5	15.0	4361.5
RASS	2414	-3543.0	7181.4	19.5	4468.2
RASB	2634	-7264.7	5420.0	15.6	4335.9
MCLR	2995	-13851.6	2244.8	18.7	4413.2
GBR	3294	-19161.7	-151.4	3.7	4350.2
MOR	3495	-22516.8	-1632.6	-0.3	4568.5
BMR	3774	-22446.9	+1341.3	8.0	23.0
H20	4154	-22400.0	3264.9	4.7	49.1
SC	4374	-22320.0	6573.0	10.0	45.1
PC	4574	-22258.9	9822.2	18.2	17.0
FMC	4794	-22219.0	13777.5	31.9	6386.8
RRB	5215	-13774.8	11781.1	54.4	1637.2
SR	5574	-7122.1	12624.8	58.4	1929.0
J72	5994	888.8	10288.9	41.8	2502.9
LAB	7175	-24.4	50.7	13.3	3215.5
					4831.5 MILS
					271.984°

Post Theodolite Cal

Theodolite + Bias = 272.0673
System = 271.984

$\Delta \angle$ = -.0833

APPENDIX B.

48 KILOMETER COURSE DATA

TEST RUN: AM/PM, COURSE: SHORT

DATE: 26 October 1979

CHECK POINT	TIME SEC	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
LAB	227.	0.0	0.0	0.0	6377.2
BW/J	1367	1055.3	7775.0	13.7	6340.6
G/J	1488	1047.7	8526.7	15.6	1358.6
C/G	1987	5901.6	8472.7	14.6	1702.3
GMS	2287	9457.9	7605.2	223.0	1730.8
MS	2747	9498.1	11345.2	397.1	5751.2
RP	3127	9989.4	11654.0	307.7	5754.8
CHURCH	3728	5071.6	9715.9	20.2	2607.8
BW/J	4587	1050.3	7777.0	14.1	3122.1
LAB	5888	-11.2	19.9	-10.6	6350.2

TEST RUN: AM/PM, COURSE: MONTE SANO

DATE: 29 October 1979

CHECK POINT	TIME SEC	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
LAB	219	0.0	0.0	0.0	6334.5
BW/J	894	1015.4	7794.2	11.0	6316.9
G/J	1015	1004.4	8547.6	12.3	1291.1
CG	1594	5873.4	8518.6	9.7	1598.6
GMS	1915	9442.3	7671.2	222.9	1707.7
MS	2875	9463.2	11421.0	378.8	5739.3
RP	3234	9954.8	11733.9	285.4	5928.7
CHURCH	3914	5030.7	9761.6	-14.1	2603.8
G/J	4634	1003.6	8546.7	-21.4	4543.3
BW/J	4834	1011.7	7792.6	-31.3	3076.2
LAB	5574	0.9	16.3	-53.8	6302.5

TEST RUN: AM/PM, COURSE: MONTE SANO

DATE: 29 October 1979 SECOND AFTERNOON RUN

CHECK POINT	TIME MIN	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
LAB		0.0	0.0	0.0	0
BW/J	1175	1009.5	7781.4	23.1	6304.2
GJ	1295	997.5	8533.5	25.7	1283.2
CG	1876	5854.8	8508.0	33.7	1590.6
GMS	2256	9416.5	7662.4	251.2	1694.3
MS	2715	9436.5	11406.3	418.3	5779.6
RP	3015	9925.9	11717.9	329.9	5930.1
CHURCH	3615	5015.9	9751.2	48.0	2612.1
GJ	4196	996.2	8543.2	53.9	4567.5
BW/J	4375	1003.7	7790.6	47.7	3032.3
LAB	5015	-15.0	27.8	43.9	6356.6

TEST RUN: AM/PM, COURSE: MONTE SANO

DATE: 14 November 1979

CHECK POINT	TIME MIN	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
LAB	0	0.0	0.0	0.0	0
CG	1217	5841.4	8543.5	-29.3	1630.2
GMS	1516	9417.5	7706.1	132.4	1709.0
MS	1916	9422.6	11460.6	243.4	5811.6

TEST RUN: AM/PM, COURSE: SHORT (MONTE SANO)

DATE: 15 November 1979 AM

CHECK POINT	TIME MIN	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
LAB		0.0	0.0	0.0	-
GJ	1695	964.1	8516.3	28.4	1290.4
CG	2175	5813.5	8505.3	38.7	1670.9
GMS	2476	9374.1	7672.5	219.6	1724.2
MS	2935	9377.0	11409.1	350.0	5806.0
RP	3215	9863.4	11723.1	271.0	5962.3
CHURCH	3815	4971.0	9742.0	67.9	2615.6
GJ	4495	966.5	8514.2	80.1	4597.1
LAB	5275	0.8	23.4	81.6	6376.3

LITTON LAND NAV SURVEY TEST DATE: 16 November 1979 AM

CK PT NAV TIME LAB	EAST OOO	NORTH OOO	ALT OOO	.3% DT METERS
GJ	983.9	8544.9	18.1	
OBS	966.2	8541.2	25.6	
DELTA	17.7	3.7	-7.5	±25.8
CG	5847.8	8525.3	16.4	
OBS	5831.2	8532.5	32.6	
DELTA	15.6	- 7.2	-16.2	±39.2
GMS	9411.2	7686.2	181.9	
OBS	9405.4	7703.0	210.9	
DELTA	5.8	- 16.8	-29.0	±50.2
MONTE SANO	9421.6	11432.7	302.5	
OBS	9406.9	11454.7	339.3	
DELTA	14.7	- 22.0	-36.8	±61.5
R. P	9918.7	11739.5	224.7	
OBS	9895.4	11770.7	259.0	
	23.3	- 31.2	-34.3	±63.3
CHURCH	5010.8	9766.2	6.7	
OBS	4981.2	9769.1	50.4	
DELTA	29.6	- 2.9	-43.7	±79.1
GJ	983.9	8544.9	18.1	
OBS	960.6	8535.7	59.3	
DELTA	23.3	9.2	41.2	±91.3
LAB	000	000	000	
OBS	- 3.7	5.6	57.9	
DELTA	3.7	-5.6		±117.1

TOTAL DISTANCE TRAVELED 39021 METERS/24.25 MILES
CLOSING RADIAL ERROR 6.7 METERS
PERCENT OF DISTANCE TRAVELED 0.0172%
FINAL HEADING 3304.9
RG GYRO COMPASS 3308.3

LITTON LAND NAV SURVEY TEST DATE: 16 November 1979 PM

CK PT NAV TIME LAB	EAST OOO	NORTH OOO	ALT OOO	.3% DT METERS
GJ	983.9	8544.9	18.1	
OBS	983.9	8550.6	48.3	
DELTA	0	6.3		±25.8
CG	5847.8	8525.3	16.4	
OBS	5846.5	8532.0	63.8	
DELTA	1.3	- 6.7		±39.2
GMS	9411.2	7686.2	181.9	
OBS	9423.1	7692.9	250.7	
DELTA	- 11.9	- 6.7		±50.2
MONTE SANO	9421.6	11432.7	302.5	
OBS	9432.6	11446.6	388.0	
DELTA	- 11.0	- 13.9		±61.5
R. P	9918.7	11739.5	224.7	
OBS	9921.2	11761.2	310.0	
	- 2.5	- 21.7		±63.3
CHURCH	5010.8	9766.2	6.7	
OBS	5007.9	9779.2	113.0	
DELTA	2.9	- 13.0		±79.1
GJ	983.9	8544.9	18.1	
OBS	982.7	8556.2	131.6	
DELTA	1.2	- 11.3		±91.3
LAB	000	000	000	
OBS	0.9	-23.7	145.6	
DELTA	-.9	-23.7		±117.1

TOTAL DISTANCE TRAVELED 39021 METERS/24.25 MILES
CLOSING RADIAL ERROR _____
PERCENT OF DISTANCE TRAVELED _____
FINAL HEADING 6360.1
RG GYRO COMPASS 6361.6

TEST RUN: AM/PM, COURSE: MONTE SANO

DATE: 19 November 1979

CHECK POINT	TIME MIN	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
LAB	-	0	0	0	6336.8
GJ	788	979.5	8578.9	23.5	1359.1
CG	1307	5860.9	8562.2	28.3	1660.1
GMS	1667	9447.7	7719.4	205.4	1697.7
MS	2108	9454.7	11483.7	331.3	5779.6
RP	2407	9945.4	11798.9	249.3	5948.8
CHURCH	2988	5015.0	9806.0	34.9	2613.1
GJ	3567	980.7	8577.7	39.5	4518.0
LAB	4327	-1.9	14.4	28.9	6357.2

TEST RUN: AM/PM, COURSE: MONTE SANO

DATE: 19 November 1979

CHECK POINT	TIME MIN	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
LAB	219	0.0	0.0	0.0	6334.5
G/J	815	1013.2	8540.1	15.9	1296.3
CG	1315	5876.5	8501.5	16.5	1669.0
GMS	1675	9449.9	7648.6	190.2	1737.7
MS	2095	9474.9	11400.1	312.7	5788.2
RP	2356	9964.9	11712.2	229.9	5974.2
CHURCH	3035	5047.4	9750.8	10.6	2634.6
GJ	3796	991.2	6782.1	0.6	3226.9
LAB	4355	-8.3	10.0	-8.6	6336.3

LITTON LAND NAV SURVEY TEST DATE: 20 November 1979

CK PT NAV TIME AB	EAST OOO	NORTH OOO	ALT OOO	.3% DT METERS
GJ	983.9	8544.9	18.1	
OBS	940.7	8568.0	9.9	
DELTA	43.2	23.1		±25.8
CG	5847.8	8525.3	16.4	
OBS	5818.2	8576.6	9.8	
DELTA	39.6	51.3	6.6	±39.2
GMS	9411.2	7686.2	181.9	
OBS	9406.5	7749.3	185.4	
DELTA	5.7	63.1	3.5	±50.2
MONTE SANO	9421.6	11432.7	302.5	
OBS	9398.3	11509.7	309.3	
DELTA	23.3	77.0		±61.5
RP	9918.7	11739.5	224.7	
OBS	9885.9	11825.9	226.5	±63.3
CHURCH	5010.8	9766.2	6.7	
OBS	4978.7	9821.8	8.2	
DELTA	32.1	55.6		±79.1
GJ	983.9	8544.9	18.1	
OBS	955.8	8580.4	8.2	
DELTA	28.1	35.5		±91.3
LAB	000	000	000	
OBS	9.3	29.2	9.4	
DELTA				±117.1

TOTAL DISTANCE TRAVELED 39021 METERS/24.25 MILES
CLOSING RADIAL ERROR 32 METERS
PERCENT OF DISTANCE TRAVELED .0344%
FINAL HEADING 6327.3
RG GYRO COMPASS 6330.6

CHECK POINT	TIME SEC	EASTING METERS	NORTHING METERS	ELEVATION METERS	HEADING MILS
LAB		0.0	0.0	0.0	
GJ	4095	969.6	8527.0	-27.4	4595.4
LAB	4795	2.1	24.6	-55.3	3201.9
					269.962
	Post Cal				
	Theodolite		270.153°		
	System (No GC)		269.961°		
		Δ =	-.192°		
	Before run Δ =		-.108		
	Drift		-.084		

APPENDIX C.

SURVEY POINT ANALYSIS

48 KILOMETER COURSE DATA

LN 80 ROAD TEST DATA

CHECK POINT BOB WALLACE/JORDAN LANE

EASTING METERS	NORTHING METERS	ELEVATION METERS	
1055.3	7775.0	13.7	26-10-79 AM
1050.3	7777.0	14.1	
1015.4	7794.2	11.0	29-10-79 AM
1011.7	7792.6	-31.3	
1009.5	7781.4	23.1	24-10-79 PM
1003.7	7790.6	47.7	
1008.7	7771.5	33.4	29-10-79 PM
1024.5	7802.3	69.4	25-10-79
902.3	7848.2	510.8	

LN 80 ROAD TEST DATA

CHECK POINT GOVERNORS/JORDAN (G/J)

EASTING METERS	NORTHING METERS	ELEVATION METERS	
1047.7	8526.7	15.6	26-10-79 AM
1050.3	7777.0	14.1	26-10-79 PM
1004.4	8547.6	12.3	29-10-79 AM
1003.6	8546.7	-21.4	
997.5	8533.5	25.7	29-10-79 PM
996.2	8545.2	53.9	
964.1	8516.3	28.4	15-11-79 AM
966.5	8514.2	80.1	
966.2	8541.2	25.6	16-11-79 AM
960.6	8535.7	59.3	
983.9	8550.6	48.3	16-11-79 PM
982.7	8556.2	131.6	
979.5	8578.9	23.5	
980.7	8577.7	39.5	
979.5	8578.9	23.5	19-11-79 AM
977.7	8576.9	39.5	
1013.2	8540.1	15.9	19-11-79 PM
1016.3	8546.3	10.6	
940.7	8568.0	9.9	20-11-79 AM
955.8	8580.4	8.2	

LN 80 ROAD TEST DATA

CHECK POINT CALIFORNIA/GOVERNORS (CG)

EASTING METERS	NORTHING METERS	ELEVATION METERS		
5901.6	8472.7	14.6	26-10-79	
5073.4	8518.6	9.7	29-10-79	
5854.8	8508.0	33.7	29-10-79	PM
5841.4	8543.5	-29.3	14-11-79	
5813.5	8505.3	38.7	15-11-79	AM
5831.2	8532.5	32.6	16-11-79	AM
5846.5	8532.0	63.8	16-11-79	PM
5860.9	8562.2	28.3	19-11-79	AM
5876.5	8501.5	16.5	19-11-79	PM
5818.2	8576.6	9.8	20-11-79	AM

LN 80 ROAD TEST DATA

CHECK POINT GOVERNORS/MONTE SANO (GMS)

EASTING METERS	NORTHING METERS	ELEVATION METERS		
9457.9	7605.2	223.0	26-10-79	
9442.3	7671.2	222.9	29-10-79	AM
9416.5	7662.4	251.2	29-10-79	PM
9417.5	7706.1	132.4	14-11-79	
9374.1	7672.5	219.6	15-11-79	AM
9405.4	7703.0	210.9	16-11-79	AM
9423.1	7692.9	250.7	16-11-79	PM
9447.7	7719.4	205.4	19-11-79	AM
9449.9	7648.6	190.2	19-11-79	PM
9406.5	7749.3	185.4	20-11-79	AM

LN 80 ROAD TEST DATA

CHECK POINT MONTE SANO (MS) FIRST ORDER SURVEY

EASTING METERS	NORTHING METERS	ELEVATION METERS		
9498.1	11345.2	397.1	26-10-79	
9463.2	11421.0	378.8	29-10-79	AM
9436.5	11406.3	418.3	29-10-79	PM
9422.6	11460.6	243.4	14-11-79	
9377.0	11409.1	350.0	15-11-79	AM
9406.9	11454.7	339.3	16-11-79	AM
9432.6	11446.6	388.0	16-11-79	PM
9454.7	11483.7	331.3	19-11-79	AM
9474.9	11400.1	312.7	19-11-79	PM
9398.3	11509.7	309.3	20-11-79	AM

LN 80 ROAD TEST DATA

CHECK POINT ROCKY POINT (RP)

EASTING METERS	NORTHING METERS	ELEVATION METERS	
9989.4	11654.0	307.7	26-10-79
9954.8	11733.9	285.4	29-10-79 AM
9925.9	11717.9	329.9	29-10-79 PM
9863.4	11723.1	271.0	15-11-79 AM
9895.4	11770.7	259.0	16-11-79 AM
9921.2	11761.2	310.0	16-11-79 PM
9945.4	11798.9	249.3	19-11-79 AM
9964.9	11712.2	229.9	19-11-79 PM
9885.9	11825.9	226.5	20-11-79 AM

LN 80 ROAD TEST DATA

CHECK POINT CHURCH (FIRST ORDER SURVEY)

EASTING METERS	NORTHING METERS	ELEVATION METERS	
5071.6	9715.9	20.2	26-10-79
5030.7	9761.6	-14.1	29-10-79 AM
5015.9	9751.2	48.0	29-10-79 PM
4971.0	9742.0	67.9	15-11-79 AM
4981.2	9769.1	50.4	16-11-79 AM
5007.9	9779.2	113.0	16-11-79 PM
5015.0	9806.0	34.9	19-11-79 AM
5047.4	9750.8	10.6	19-11-79 PM
4978.7	9821.8	8.2	20-11-79 AM

LN 80 ROAD TEST DATA

CHECK POINT MONUMENT 5400 CLOSURE

EASTING METERS	NORTHING METERS	ELEVATION METERS		
-11.2	19.9	-10.6	26-10-79	
.9	16.3	-53.8	29-10-79	AM
-15.0	27.8	43.9	29-10-79	PM
0.8	23.4	81.6	15-11-79	AM
-3.7	5.6	57.9	16-11-79	AM
0.9	-23.7	145.6	16-11-79	PM
-1.9	14.4	28.9	19-11-79	AM
-8.3	10.0	-8.6	19-11-79	PM
9.3	29.2	-9.4	20-11-79	

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