X-802-70-217
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NASA TM X-63959

AT SEA EVALUATION OF THE AN/SRN-9 NAVIGATION SATELLITE SYSTEM ABOARD THE USNS VANGUARD

JOHN J. McKENNA

MAY 1970

GSFC — GODDARD SPACE FLIGHT CENTER —
GREENBELT, MARYLAND

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INTRODUCTION

The purpose of this report is to evaluate the accuracy of the AN/SRN-9, Navigation Satellite System. The data for this evaluation was taken under at-sea environmental conditions on the USNS VANGUARD during the period 26 through 29 September 1969 while conducting navigation tests within the LORAC B network in the vicinity of Grand Bahama Island. The data that was collected consisted of GEOS B/C Band radar, AN/SRN-9, SINS position, and LORAC position fixes.

The LORAC position fixes were used for position reference, with which to compare the AN/SRN-9 position fixes. The accuracy of the ship's position determined by using LORAC is assumed to be $\pm$ 0.01 nautical miles. All data for both LORAC and the AN/SRN-9 (APL Datum) were referenced to the Fisher ellipsoid.

The AN/SRN-9 is a radio receiving system designed to receive and to decode transmissions from orbiting satellites that comprise the NAVY Navigation Satellite System (NNSS). This system is capable of providing accurate position fixes at frequent intervals (approximately every hour and a half) without regard to the ship's geographic position on the earth's surface or to environmental conditions.

BACKGROUND MATERIAL

The AN/SRN-9 equipment is manufactured by ITT in San Fernando, California. It consists of four primary components viz. an antenna, a receiver, a frequency standard, and a thermal printer. Transmissions from Navy Navigation Satellites are detected by the receiver and then are processed by a UNIVAC 1230 to obtain a geographic position fix for resetting the (SINS MK 3 MOD 5) inertial navigator. The output data from the AN/SRN-9 to be

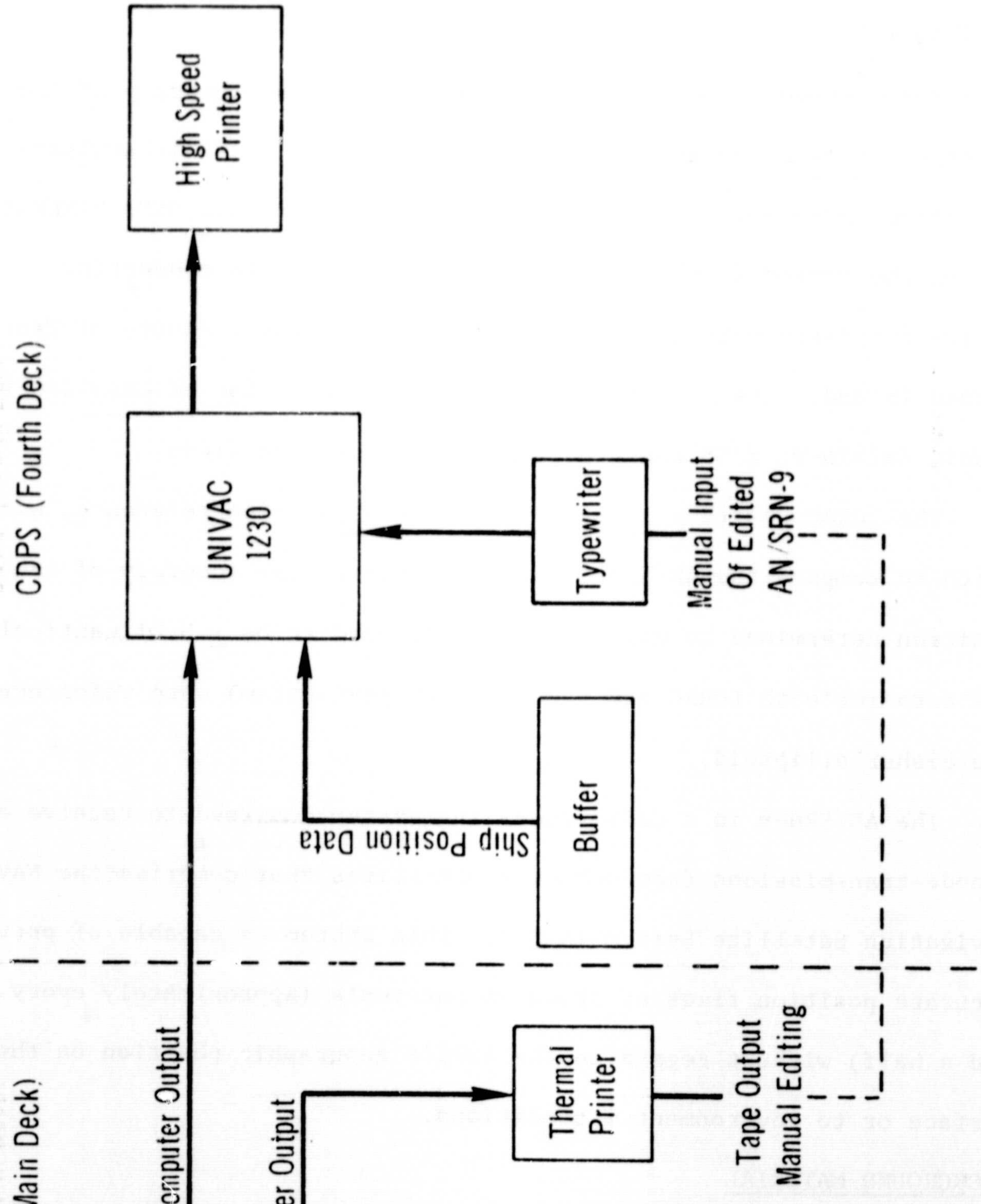
NAVIGATION (Main Deck)
AN/SRN-9
Computer Output
Printer Output
Thermal Printer
Tape Output
Manual Editing
CDPS (Fourth Deck)
UNIVAC
1230
High Speed Printer
Ship Position Data
Buffer
Typewriter
Manual Input
Of Edited
AN/SRN-9

Figure 1

processed by the UNIVAC 1230 is obtained either from the thermal printer or by a direct connection to the UNIVAC 1230 computer in the Central Data Processing (CDP) room.

Data reduction of the AN/SRN-9 output data is accomplished by the CDP installed aboard the Apollo ship either by use of a "Stand Alone" computer program or by a routine in the Apollo Ship's 'STANDBY' mode of computer operation. The 'Stand Alone' computer program has a more sophisticated data editing routine than does the program in the STANDBY mode, however, it can only be used when the ship's operational computer programs are not in use.

As explained previously, the AN/SRN-9 has two data outputs viz. a thermal printer and a direct cable connection to the UNIVAC 1230 computer. Figure 1 illustrates these two methods for handling the AN/SRN-9 data. Both the direct computer connection and the printer output tape provide identical data and can be used independently. The two methods are differentiated by the method for entry of the data into the computer and by the manner in which the redundant data received during the satellite pass is edited. With the computer link, both the data editing and entry of data are accomplished as functions of the data reduction process for the AN/SRN-9. Both of these functions are manual when the data is reduced by using the output tape from the AN/SRN-9 thermal printer. In addition, velocity information derived from either ship's course and speed or position at two minute increments must be synthesized with the edited thermal printer data.

DATA REQUIREMENTS FOR A POSITION FIX

Twenty-seven data words for each even two-minute increment must flow between the AN/SRN-9 receiver and the computer.* This data consists of fixed and variable orbit parameters for the satellite and counts by the receiver's data processing unit (DPU) for doppler cycles and refraction

* SEE APPENDIX

cycles. A minimum of three sets of this data is required. In addition, provision must be made to account during the satellite pass for the movement of the ship from its estimated position. Aboard the Apollo ship, this velocity is obtained either from the inertial navigator or the MK 19/EM Log combination. The foregoing data is then processed by the computer to calculate for the geographic position of the ship.

ERROR SOURCES IN THE ANALYSIS OF AN/SRN-9 DATA

Errors considered when evaluating the data were:

1. Error in the LORAC reference positions. (assumed to be ±0.01 nautical mile)

2. Error due to the distance between the LORAC antenna and the AN/SRN-9 antenna. (approximately 60 feet or 0.01 nautical mile)

3. Navy Navigation Satellite System errors.

4. Errors related to ship's velocity.

5. Data handling errors.

6. Error caused by equipment malfunctions.

Of the error sources enumerated above, the first two were not considered in the evaluation because of their small magnitude. Navy Navigation Satellite System error cannot be controlled from aboard ship. It results from changes in the satellite orbit from that predicted at the time of injection of the orbital parameters into the satellite's memory. It is estimated that this error can reach a magnitude of 0.05 nautical miles. This error also is not considered in this evaluation.

The most significant of the errors is due to ship's velocity. It is also, an error that is difficult to measure and thus to provide compensation. The magnitude of any velocity error has a direct effect on the position fix calculated by the computer that reduces the AN/SRN-9 data. Figure 2 is a chart produced by John Hopkins University showing Longitude error due to velocity North error in relation to the geometry of the satellite pass. Figure 3 is a similar chart but showing Latitude error due to velocity EAST error in relation to the geometry of the satellite pass. From examination of these two figures it can be stated that velocity North error is the most significant error.

Data handling errors are generally correctable and can be defined as those errors made:

1. in editing the thermal printer tape
2. in transcribing data on forms
3. in typing the data into the computer
4. by using incorrect computer loading procedures
5. by incorrect setting of the computers' sense switch options
6. by incorrect analysis of the AN/SRN-9 data calculated by the computer

Each of the foregoing errors can be significantly reduced either by training or automating the data handling functions.

Equipment malfunction errors are defined as:

1. Incorrect data handling by the computer and
2. Errors made by the AN/SRN-9 equipment.

This type of error is more difficult to locate but both the computer and the AN/SRN-9 have diagnostic procedures which serve to locate malfunctions of this nature.

Figure 4 is a tabulation of the foregoing error sources.

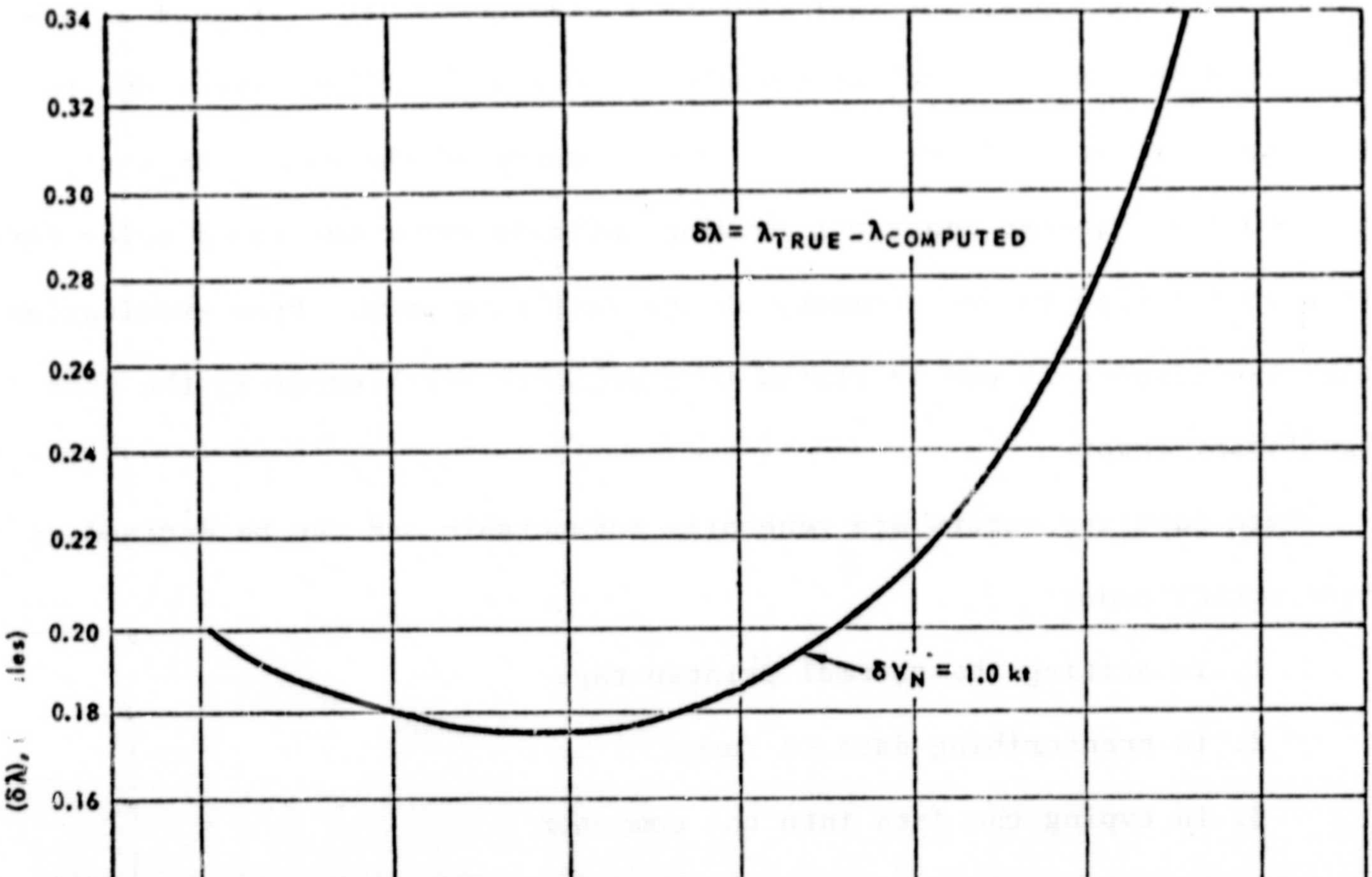

Figure 2 LONGITUDE ERROR DUE TO VELOCITY NORTH ERROR

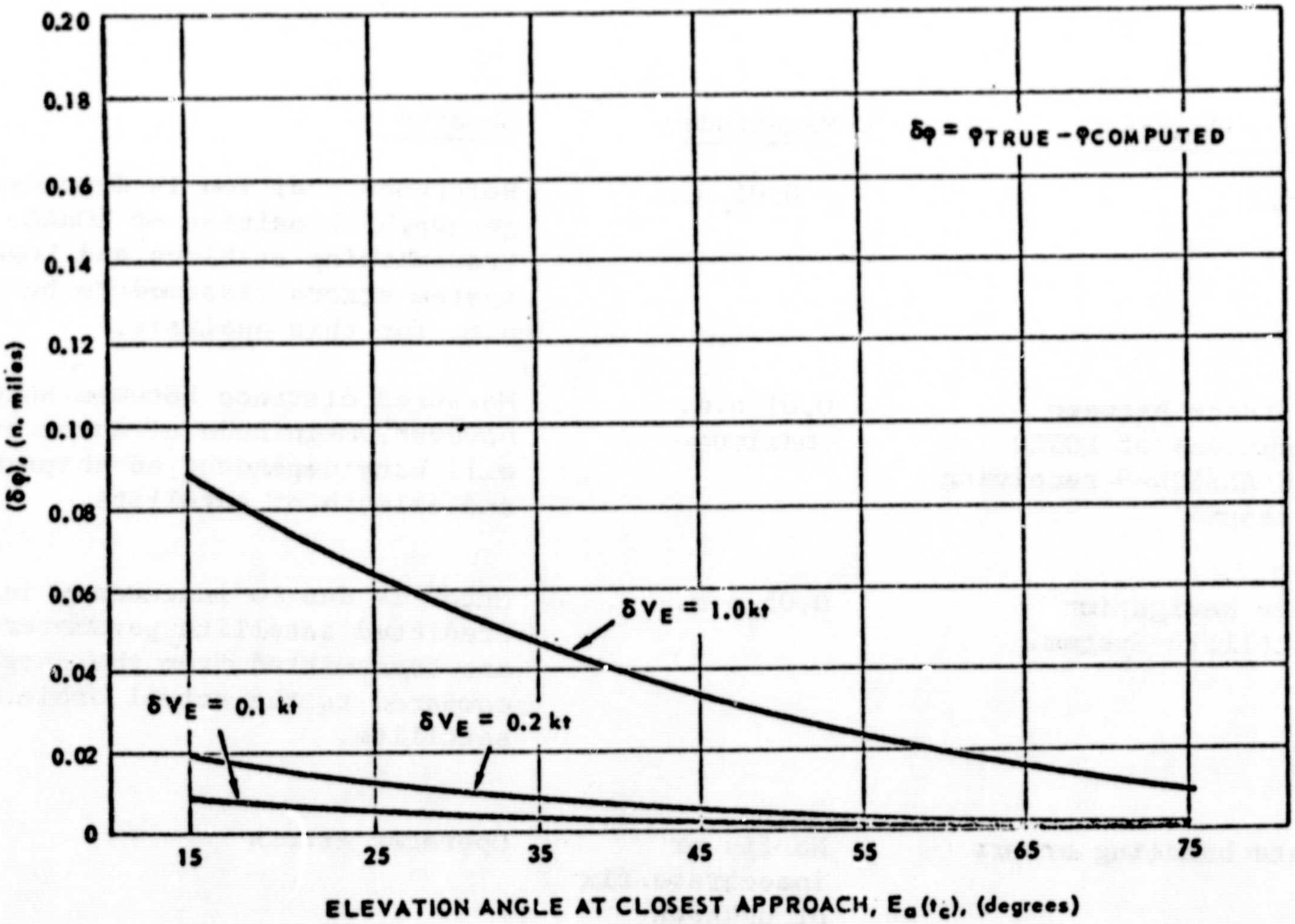

Figure 3 LATITUDE ERROR DUE TO VELOCITY EAST ERROR

Error sources considered in the analysis of AN/SRN-9 data
Nominal accuracy (1 Sigma) of AN/SRN-9 under at sea conditions is assumed to be between 0.1 to 0.2 nautical miles

Error Source	Magnitude	Remarks
LORAC	$\pm$ 0.01 n.m.	Reference position is dependent on geographic position of LORAC transmitting stations and LORAC system errors. Assumed to be $\pm$ 0.01 n.m. for this analysis.
Distance between locations of LORAC and AN/SRN-9 receiving antenna	0.01 n.m. maximum	Measured distance between antennae, however, magnitude of error effect will vary dependent on ships heading and azimuth of satellite.
Navy Navigation Satellite System	0.05 n.m.	Error is due to inaccuracy in the predicted satellite parameters that are transmitted from the satellite compared to the actual orbit of the satellite.
Data handling errors	No fix or inaccurate fix of unknown magnitude	Operator errors
Equipment malfunction	No fix or inaccurate fix of unknown magnitude	Equipment problem

Figure 4

AN/SRN-9 Shipboard Position Fixes

Satellite Pass			LORAC Position		CDPS Position				Printer CDPS Position			
Day	Time	Number	Lat	Long	Lat	Long	Δ Lat	Δ Long	Lat	Long	ΔLat	Δ Long
269	1434	30140	27° 8.48	76° 25.17	27° 8.56	76° 24.79	+0.08	+0.38	27° 8.65	76° 26.29	+0.17	-1.12
269	1758	30130	27° 6.78	76° 20.38	27° 6.71	76° 21.73	-0.07	-1.35	27° 6.25	76° 20.03	-0.43	+0.35
269	1946	30130	27° 7.98	76° 22.33	27° 7.95	76° 21.92	-0.03	+0.41	27° 7.58	76° 22.30	-0.40	+0.03
269	2212	30180	27° 5.67	76° 25.90	Did not reduce to fix				27° 5.50	76° 26.08	-0.17	-0.18
270	0000	30180	27° 8.33	76° 20.26	27° 7.72	76° 20.28	-0.61	-0.02	Did not reduce to fix			
270	0748	30140	27° 4.64	76° 28.16	27° 4.55	76° 35.20	-0.09	-7.04	27° 4.60	76° 29.53	-0.04	-1.37
270	0336	30140	27° 9.74	76° 22.28	Did not reduce to fix				27° 11.70	76° 19.75	+1.96	+2.53
270	0454	30120	27° 6.94	76° 22.13	Not Attempted				27° 7.10	76° 22.15	+0.16	-0.02
270	0736	30130	27° 7.74	76° 24.07	27° 7.82	76° 23.45	+0.08	+0.62	Not Attempted			
270	1120	30180	27° 8.24	76° 33.34	Did not reduce to fix							
270	1304	30180	27° 6.68	76° 22.88	Not Attempted				27° 9.15	76° 21.90	+2.47	+0.98
270	1340	30140	27° 6.78	76° 18.04	27° 6.72	76° 18.42	-0.06	-0.38	Did not reduce to fix			
270	1424	30120	27° 6.29	76° 11.99	Incorrect Estimated Position				27° 6.28	76° 12.47	-0.01	-0.48
270	1528	30140	27° 7.26	76° 15.76	Did not reduce to fix				Did not reduce to fix			
270	1606	30120	27° 7.09	76° 20.56	Did not reduce to fix				Did not reduce to fix			
270	2044	30130	27° 5.63	76° 27.80	See 270/2046				27° 5.68	76° 29.70	+0.05	-1.90
270	2046		27° 5.64	76° 27.98	27° 5.12	76° 29.62	-0.52	-1.64	See 270/2044			
270	2310	30180	27° 5.60	76° 43.27	27° 5.60	76° 43.07	0.00	+0.20	Did not reduce to fix			
270	1856	30130	27° 8.08	76° 21.42	Not Attempted				Not attempted			
271	0058	30140	27° 6.41	76° 48.39	See 271/0100				27° 5.84	76° 49.11	-0.57	-0.72
271	0100		27° 6.42	76° 48.28	27° 6.44	76° 48.36	+0.02	-0.08	See 271/0058			
271	0208	30120	27° 6.86	76° 43.07	27° 6.75	76° 43.54	-0.11	-0.47	27° 7.67	76° 41.05	+0.81	+2.02
271	0244	30140	27° 6.94	76° 38.42	27° 6.72	76° 38.66	-0.24	-0.20	27° 7.91	76° 37.59	+0.97	+0.83
271	0350	30120	27° 7.18	76° 30.40	27° 7.29	76° 30.43	+0.11	-0.03	Not Attempted			
271	0650	30130	27° 7.13	76° 18.38	Did not reduce to fix				Not Attempted			
271	0836	30130			Not Attempted				Not Attempted			
271	0838				Not Attempted				Not Attempted			
271	1028	30180	27° 7.62	76° 18.61	27° 40.84	77° 19.81	+33.22	-61.10	27° 7.65	76° 18.41	+0.03	+0.20
271	1220	30180			Not Attempted				Not Attempted			
271	1252	30140	27° 9.00	76° 25.87	27° 8.90	76° 26.13	-0.10	-0.26	Not Attempted			
271	1326				Not Attempted				Not Attempted			
271	1516	30120			Not Attempted				Not Attempted			
271	1810	30130	27° 8.60	76° 18.44	27° 7.89	76° 18.54	-0.71	-0.10	Did not reduce to fix			
271	1958	30130	27° 9.28	76° 23.79	Not Attempted				Did not reduce to fix			
271	2222	30180	27° 7.42	76° 21.88	Not Attempted				Did not reduce to fix			
272	0942		28° 41.45	78° 56.26	Not Attempted				27° 26.02	76° 25.90	75.43	97.61
272	2054	30130	28° 15.28	79° 59.90	Not Attempted				Not Attempted			
272	1720	30130	28° 0.61	78° 59.83	Not Attempted				Not Attempted			
272	1606	30120	27° 55.61	76° 40.04	Not Attempted				Not Attempted			
272	0306	30120	27° 6.03	76° 20.81	Not Attempted				27° 6.01	76° 19.28	-0.02	+1.53

Figure 5 Shipboard Data Reductions.

FINDINGS - SHIPBOARD RESULTS

At times, other navigation tests had priority over the data collection for the AN/SRN-9 evaluation with the result that some data could not be taken. This loss of data did not have a significant effect on the evaluation of the AN/SRN-9.

The data received by the AN/SRN-9 was reduced by two methods while at sea viz.

1. By utilizing the AN/SRN-9 computer output that connects directly to the UNIVAC 1230 computer and

2. By editing the data output from the thermal printer and then manually inputing this edited data into the UNIVAC 1230 for data reduction.

Velocity input for all satellite passes reduced aboard ship consisted of a single course and speed inserted by the computer operator. Comparison of the position fixes obtained by each of the foregoing data reduction methods were then compared to the reference position obtained from the LORAC B network. Figure 5 is a tabulation of these comparisons. The first two columns are the Day Number and time (GMT) of the satellite position fix. Column three identifies the particular (NNSS) satellite on which the fix is based. Columns four and five are the LORAC reference position in Latitude and Longitude. Columns six through nine are Latitude, Longitude, and the differences in Latitude and Longitude in minutes referenced to the LORAC position for the data reduction method that utilizes the direct link between the AN/SRN-9 receiver and the UNIVAC 1230. Column ten through thirteen provide the same data as columns six through nine except that the comparisons are for the data reduction method which utilizes the AN/SRN-9 thermal printer with a manual input into the UNIVAC 1230 computer.

ANALYSIS SHIPBOARD DATA REDUCTIONS

Seven of the satellite passes that were attempted utilizing the direct link between the AN/SRN-9 and the UNIVAC 1230 did not reduce to a fix. Examination of the data revealed that this failure to reduce to a position fix can be attributed to:

1. operator error in setting up the computer to receive the AN/SRN-9 data

2. a deficient program in which the computer operator was required to guess correctly the exact number of two minute increments that would be received during the satellite pass.

3. an equipment malfunction as in satellite pass 271/1028 (reference to a particular satellite pass will be indicated by the day/time of the fix) where there were five discrepancies in data printed out on the high-speed-printer when compared to the data that was printed by the thermal printer. Compensation for the foregoing program deficiency was accomplished by assuming that only three two minute intervals of data would be received. This, however, does reduce the accuracy of the fix. The equipment malfunction that caused the discrepancy in the data was not discovered. The thermal printer tape data was assumed to be correct because it is repeated at two minute intervals throughout the satellite pass.

The tabulation for the data reduced using data from the thermal printer tape and manual insertion of the data into the UNIVAC 1230 also contains satellite passes that did not reduce to a fix. This can be attributed to either data editing errors or errors made by the operator in typing the data into computer.

Calculated three sigma deviations in nautical miles of the satellite data reductions for Latitude and Longitude are shown in figure 6.

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	Lat.	Long.
CDPS Link	0.87	4.81
Thermal Printer tape	2.52	3.24

FIGURE 6

FINDINGS - POST MISSION DATA REDUCTIONS

Following the at sea data reductions, the thermal printer tapes for all satellite passes taken were edited. The data was :

1. corrected for obvious errors in the data such as refraction counts with large changes between successive two minute counts and

2. SINS or LORAC positions at two minute intervals were synthesized into the data.

Then the edited data was reduced by the latest version of DBA Systems 'Stand Alone' computer program both with and without data editing of the residuals. Figure 6 is a tabulation of this data. Columns one through five are the same as described for figure 5. Column six is the source of the two minute position inputs (velocity) for insertion into the computer program. Column seven is the maximum elevation of the satellite as calculated by the AN/SRN-9 data reduction program. Columns eight through eleven are the Latitude and Longitude without automatic editing of the residuals of the AN/SRN-9, fix, and delta latitude; and delta longitude referenced to the LORAC position fix. Columns twelve through fifteen are the Latitude and Longitude with automatic editing of the residuals of the AN/SRN-9 fix; and delta latitude; and delta longitude referenced to the LORAC position fix.

AN/SRN-9 Analyzed Data 2 Minute Velocity Input

Satellite Pass Day	Time	Number		LORAC Position Lat	Long	Position Input	Elevation	POSITION – NO EDIT Lat	Long	Δ Lat	Δ Long	POSITION – AUTO EDIT Lat	Long	Δ Lat	Δ Long	
269	1434	30140		27° 8.48	76° 25.17	SINS	46.2	27° 8.65	76° 24.71	+ 0.17	+0.46	27° 8.53	76° 25.08	+0.05	+0.09	
269	1758	30130		27° 6.78	76° 20.38	SINS	21.4	27° 6.85	76° 20.58	+ 0.07	-0.20	27° 6.85	76° 20.58	+0.07	-0.20	
269	1946	30130		27° 7.98	76° 22.33	SINS	44.6	27° 7.90	27° 22.38	- 0.08	-0.05	27° 7.90	76° 22.38	-0.08	-0.05	(2)
269	2212	30180		27° 5.67	76° 25.90	SINS	21.6	27° 5.35	76° 26.05	- 0.32	-0.15	27° 5.64	76° 25.99	-0.03	-0.09	
270	0000	30180						Did not Reduce to fix								(1)
270	0148	30140		27° 4.64	76° 28.16	SINS	81.6	27° 4.73	76° 27.61	+ 0.09	+0.55	27° 4.55	76° 27.96	-0.09	+0.20	
270	0336	30140		27° 9.74	76° 22.28	SINS	9.7	27° 9.75	76° 21.86	+ 0.01	+0.42	27° 10.20	76° 22.30	+0.46	-0.02	(2)
270	0454	30120		27° 6.94	76° 22.13	LORAC	6.7	27° 6.95	76° 22.20	+ 0.01	-0.07	27° 6.95	76° 22.20	+0.01	-0.07	
270	0736	30130		27° 7.74	76° 24.07	SINS	52.3	27° 7.67	76° 23.97	- 0.07	+0.10	27° 7.65	76° 24.03	-0.09	+0.04	
270	1120	30180		27° 8.24	76° 33.34	SINS	72.4	27° 8.09	76° 33.91	- 0.15	-0.57	27° 8.07	76° 33.64	-0.17	-0.30	
270	1304	30180		27° 6.68	76° 22.88	LORAC	9.6	27° 8.72	76° 22.18	+ 2.04	+0.70	27° 8.72	76° 22.18	+2.04	+0.70	(5)
270	1340	30140		27° 6.78	76° 18.04	SINS	70.8	27° 6.75	76° 18.01	- 0.03	+0.03	27° 6.75	76° 18.01	-0.03	+0.03	
270	1424	30120		27° 6.29	76° 11.99	SINS	42.7	27° 6.51	76° 10.65	+ 0.22	+1.34	27° 6.24	76° 11.88	-0.05	+0.11	
270	1528	30140		27° 7.26	76° 15.76	SINS	13.0	27° 7.12	76° 16.05	- 0.14	-0.29	27° 7.12	76° 16.05	-0.14	-0.29	(3)
270	1606	30120		27° 7.09	76 2056	LORAC	22.5	27° 7.75	76° 19.47	+ 0.66	+1.09	27° 7.75	76° 19.47	+0.66	+1.09	(2,3)
270	2044	30130		27° 5.63	76° 27.80	SINS	11.8	27° 6.11	76° 27.85	+ 0.48	-0.05	27 5.73	76° 27.74	+0.10	+0.06	
270	2310	30180		27° 5.60	76 43.27	SINS	67.9	27 5.45	76° 42.88	- 0.15	+0.39	27° 5.57	76° 43.03	-0.03	+0.24	
271	1856	30130		27° 8.08	76 21.42	LORAC	76.2	26 29.53	76° 30.30	-38.55	-8.88	27° 7.98	76° 21.54	-0.10	-0.12	
271	0058	30140		27° 6.41	76 48.39	LORAC	31.9	27° 6.36	76° 48.42	- 0.05	-0.03	27° 6.34	76° 48.42	-0.07	-0.03	
270	0208	30120		27° 6.86	76 43.07	LORAC	34.3	27° 6.92	76° 43.15	+ 0.06	-0.08	27° 6.92	76° 43.15	+0.06	-0.08	
271	0244	30140		27 6.94	76 38.42	LORAC	29.3	27 6.92	76° 38.45	- 0.02	-0.03	27° 6.92	76° 38.45	-0.02	-0.03	
271	0356	30120		27 7.18	76° 30.40	LORAC	24.6	27° 7.20	76° 30.43	+ 0.02	-0.03	27 7.20	76° 30.43	+0.02	-0.03	
271	0650	30130	BI	27° 7.13	76° 18.38	LORAC	66.3	27° 7.06	76° 18.29	- 0.07	+0.09	27° 7.12	76° 18.38	-0.01	0.00	
271	0836	30130	AI	27° 7.37	76 21.18	LORAC	14.0	27° 6.55	76 20.55	- 0.82	+0.63	27 7.30	76° 21.27	-0.07	-0.09	(4)
271	0838	30130		27° 7.36	76 21.35	LORAC	14.0	27 7.03	76° 20.77	- 0.33	+0.58	27° 7.37	76° 21.45	+0.01	-0.10	
271	1028	30180		27 7.62	76 18.61	SINS	37.7	27° 7.54	76 18.38	- 0.08	-0.23	27° [illegible].59	76° 18.48	-0.03	+0.13	
271	1220	30180		27 10.07	76 22.76	LORAC	26.9	27° 9.81	76 21.87	- 0.26	+0.89	27° 9.81	76° 21.87	-0.26	+0.87	
271	1252	30140		27° 9.00	76 25.87	LORAC	27.4	27° 8.81	76° 25.88	- 0.19	-0.01	27° 9.00	76° 25.87	-0.19	-0.[illegible]	
271	1326							Did not Reduce to fix								(1)
271	1516	30120		27 5.35	76° 20.39	LORAC	63.5	27° 5.27	76° 20.26	- 0.08	+0.13	27° 5.23	76° 20.15	-0.12	+0.24	
271	1810	30130		27° 8.60	76° 18.44	SINS	31.2	27° 8.47	76° 18.45	- 0.13	-0.01	27° 8.46	76° 18.51	-0.14	-0.07	(2)
271	1958	30130		27 9.28	76° 23.79	SINS	31.2	27 9.46	76° 23.87	+ 0.18	-0.08	27° 9.46	76° 23.87	+0.18	-0.08	
271	2222	30180		27° 7.42	76 21.88	LORAC	31.1	27 7.43	76° 21.92	+ 0.01	-0.04	27° 7.43	76° 21.92	+0.01	-0.04	
272	0942			28° 41.45	78° 56.26			Did not Reduce to fix								(1)
272	2054	30130		28° 15.28	79° 59.90	LORAC	11.0	28° 15.41	80 00.00	+ 0.13	-0.10	28° 15.41	80° 00.00	+0.13	-0.10	
272	1720	30130		28° 0.61	78° 59.83	LORAC	8.4	28° 0.03	79° 0.38	+ 0.53	-0.55	28° 0.03	73° 0.38	+0.58	0.55	(3)
272	1606	30120		27° 55.61	78° 40.04	LORAC	25.1	27° 55.74	78° 40.22	+ 0.73	-0.18	27° 55.74	78° 40.22	+0.13	-0.18	(2)
272	0306	30120		27° 6.03	76° 20.81	LORAC	67.0	27° 6.05	76° 20.90	+ 0.02	-0.09	27° 5.99	76° 20.93	-0.04	+0.12	

Notes

(1) Did not reduce to a position fix

(2) Ship in turn during pass

(3) Loss of data at mid-pass

(4) Before injection results for 271/0838

(5) RMS of residuals excessively high

Figure 7 DBA Systems Data Reduction

AN/SRN-9 Analyzed Data Single DR Velocity Input

SINGLE DR VELOCITY INPUT

Satellite Pass			LORAC Position		Position		POSITION – NO EDIT				POSITION AUTO EDIT				
Day	Time	Number	Lat	Long	Input	Elevation	Lat	Long	Δ Lat	Δ Long	Lat	Long	Δ Lat	Δ Long	
269	1434	30140	27° 8.48	76° 25.17	DR PLOT	46.2	27° 8.84	76° 25.50	+0.40	-0.33	27° 8.84	76° 25.50	+0.40	-0.33	
269	1758	30130	27° 6.78	76° 20.38		21.4	27° 6.72	76° 20.53	-0.06	-0.15	27° 6.66	76° 20.37	-0.12	+0.01	
269	1946	30130	27° 7.98	76° 22.33		44.6	27° 7.80	76° 21.77	-0.18	+0.56	27° 7.83	76° 21.91	-0.15	+0.42	(2)
269	2212	30180	27° 5.67	76° 25.90		21.6	27° 5.47	76° 26.32	-0.20	-0.42	27° 5.52	76° 26.20	-0.15	+0.30	
270	0000	30180					Did not Reduce to Fix								(1)
270	0148	30140	27° 4.64	76° 28.16		81.6	27° 4.59	76° 28.45	-0.05	-0.29	27° 4.59	76° 28.10	-0.05	+0.06	
270	0336	30140	27° 9.74	76° 22.28		9.7	27° 9.55	76° 21.95	-0.19	+0.33	27° 10.32	76° 22.58	+0.77	-0.30	(2)
270	0454	30120	27° 6.94	76° 22.13		6.7	27° 7.04	76° 22.19	+0.10	-0.06	27° 7.04	76° 22.19	+0.10	-0.06	
270	0736	30130	27° 7.74	76° 24.07		52.3	27° 7.72	76° 24.03	-0.02	+0.04	27° 7.72	76° 24.03	-0.02	+0.04	
270	1120	30180	27° 8.24	76° 33.34		72.4	27° 8.11	76° 32.38	-0.13	+0.96	27° 8.15	76° 32.67	-0.09	+0.67	
270	1304	30180	27° 6.68	76° 22.88		9.6	27° 9.11	76° 21.84	+2.43	+1.04	27° 9.11	76° 21.84	+2.43	+1.04	(6)
270	1340	30140	27° 6.78	76° 18.04		70.8	27° 6.75	76° 18.32	-0.03	-0.28	27° 6.75	76° 18.29	-0.03	-0.25	
270	1424	30120	27° 6.29	76° 11.99		42.7	27° 6.61	76° 15.52	+0.32	-3.53	27° 6.31	76° 12.04	+0.02	+0.05	
270	1528	30140	27° 7.26	76° 15.76		13.0	27° 7.20	76° 15.83	-0.06	-0.07	27° 7.20	76° 15.83	-0.06	-0.07	(3)
270	1606	30120	27° 7.09	76° 20.56		22.5	27° 7.64	76° 19.69	+0.55	+0.87	27° 7.64	76° 19.69	+0.55	+0.87	(2,3)
270	2044	30130	27° 5.63	76° 27.80		11.8	27° 6.26	76° 28.22	+0.63	-0.42	27° 5.73	76° 27.84	+0.10	-0.04	
270	2310	30180	27° 5.60	76° 43.27		67.9	27° 5.59	76° 43.68	-0.01	-0.41	27° 5.60	76° 43.37	0.00	-0.10	
270	1856	30130	27° 8.08	76° 21.42		76.2	27° 7.93	74° 54.67	-0.15	+86.75	27° 5.15	76° 29.10	-2.93	7.68	(5)
271	0058	30140	27° 6.41	76° 48.39		31.9	27° 6.29	76° 48.61	-0.12	-0.22	27° 6.33	76° 48.46	-0.08	-0.07	
271	0208	30120	27° 6.86	76° 43.07		34.3	27° 6.84	76° 43.24	-0.02	-0.17	27° 6.84	76° 43.08	-0.02	-0.01	
271	0244	30140	27° 6.94	76° 38.42		29.3	27° 6.85	76° 38.52	-0.09	-0.10	27° 6.85	76° 38.52	-0.09	-0.10	
271	0356	30120	27° 7.18	76° 30.40		24.6	27° 7.29	76° 30.43	+0.11	-0.03	27° 7.29	76° 30.43	+0.11	-0.03	
271	0650	30120	27° 7.13	76° 18.38		66.3	27° 7.11	76° 18.53	-0.02	-0.15	27° 7.11	76° 18.53	-0.02	-0.15	
271	0836		27° 7.37	76° 21.18		14.0	27° 6.63	76° 19.30	-0.74	-1.88	27° 7.10	76° 21.06	-0.27	+0.12	(4)
271	0838	30130	27° 7.36	76° 21.35		14.0	27° 6.80	76° 19.33	-0.56	+2.02	27° 7.16	76° 21.40	-0.20	-0.05	
271	1028	30180	27° 7.62	76° 18.61		37.7	27° 7.60	76° 18.42	+0.02	+0.19	27° 7.60	76° 18.42	-0.02	+0.19	
271	1220	30180	27° 10.07	76° 22.76		26.9	27° 10.34	76° 22.30	+0.24	+0.46	27° 10.34	76° 22.30	+0.24	+0.46	
271	1252	30140	27° 9.00	76° 25.87		27.4	27° 8.91	76° 26.08	-0.09	-0.21	27° 8.91	76° 26.08	-0.09	-0.21	
271	1326		27° 6.76	76° 23.62			Did not Reduce to Fix								(1)
271	1516	30120	27° 5.35	76° 20.39		63.5	27° 5.19	76° 21.08	-0.16	-0.69	27° 5.19	76° 21.08	-0.16	-0.69	
271	1810	30130	27° 8.60	76° 18.44		31.2	27° 8.47	76° 18.07	-0.13	+0.37	27° 8.47	76° 18.07	-0.13	+0.37	(2)
271	1958	30130	27° 9.28	76° 23.79		31.2	27° 9.37	76° 22.91	+0.09	+0.88	27° 9.37	76° 22.91	+0.09	+0.88	
271	2222	30180	27° 7.42	76° 21.88		31.1	27° 7.42	76° 21.89	0.00	-0.07	27° 7.42	76° 21.89	0.00	-0.01	
272	0942						Did not Reduce to Fix								(1)
272	2054	30130	28° 15.28	79° 59.90		11.0	28° 15.73	80° 0.02	+0.45	-0.12	27° 15.73	80° 0.02	+0.45	-0.12	
272	1720	30130	28° 0.61	78° 59.83		8.4	27° 59.98	79° 0.50	-0.63	-0.67	27° 59.98	79° 0.50	-0.63	-0.67	(3)
272	1606	30120	27° 55.61	78° 40.04		25.1	27° 56.00	78° 39.94	-0.39	+0.10	27° 56.00	78° 39.94	+0.39	+0.10	(2)
272	0306	30120	27° 6.03	76° 20.81		67.0	27° 6.04	76° 20.52	+0.01	+0.29	27° 6.04	76° 20.52	+0.01	+0.29	

Notes

(1) Did not reduce to position fix

(2) Ship in turn during pass

(3) Loss of data at Mid-Pass

(4) Before injection results for 271/0838

(5) Manual Edit 27° 8.02 76° 20.95

(6) RMS of Residuals Excessively High

Figure 8 DBA Systems Data Reduction

In addition to determining AN/SRN-9 position using SINS or LORAC position at two minute intervals, the data was reduced using a single course and speed for the entire satellite pass. This course and speed was determined from plots of the ship's movement using either SINS or LORAC positions. Thus these results should be similar to those results previously obtained with positions inserted at even two minute periods. Figure 8 is a tabulation of the results. The columns are identical with those of the previous figure except for the method of inserting the effect for ship's movement into the computer program.

ANALYSIS - POST MISSION DATA REDUCTIONS

Examination of the position fixes with the most error revealed either that a loss of data occured in the middle of the satellite pass or that the RMS of the residuals was excessively high for the number of doppler counts received. Satellite passes in which loss of data occured at mid-pass were 270/1528, 270/1606, and 272/1720. Satellite pass 270/1304 had an RMS of the residuals of 4.6 meters with only three doppler counts. Generally an RMS of residuals of less than a meter can be expected from such a satellite pass. Because the foregoing satellite passes are considered faulty, they are not included in the statistical population of the variates in the calculation for the three sigma deviation.

Satellite passes 270/0000, 271/1326, and 272/0942 did not reduce to a position fix. The cause for this failure is not known, however, it can be assumed that some error occured in the collection or editing of the data.

Satellite pass 270/1856 did not reduce to a reasonable fix without data editing of the residuals. Calculation of the three sigma deviation were made both with this pass included in the population of variates and without it.

Calculated three sigma (3 σ) of the satellite data reductions for Latitude and Longtitude in nautical miles are shown in Figure 9.

	LAT.	LONG.
AN/SRN-9 Position Fixes		
SINS/LORAC Position Inputs At Two Minute Intervals		
Without Editing	20.76	4.46
Without Editing Less Pass 270/1856	0.51	1.01
Automatic Editing	0.39	0.54
DR Input for Entire Pass		
Without Editing	0.69	41.85
Without Editing	0.69	0.74
Automatic Editing	1.71	3.83
Automatic Editing	0.63	0.84
Less Pass 270/1856		

Three Sigma Deviations in nautical miles

Figure 9

EFFECT OF SHIPS' TURN ON POSITION FIX ACCURACY

Five satellite passes were received while the ship was turning. A LORAC plot of ship's position at one minute intervals was used to determine an average course and speed for the ship. From the data in figure 7 for AN/SRN-9 positions with automatic editing, three sigma deviations for the five passes were calculated at 1.11 nautical miles in Latitude and 1.05 nautical miles in Longitude. Although the sample size is small, the effect of the turn is demonstrated by comparing the foregoing three sigma deviations to the three sigma deviations for twenty-nine satellite passes of 0.63 nautical miles in Latitude and 0.84 nautical miles in Longitude.

CONCLUSION

Conclusions relative to the accuracy and performance of the AN/SRN-9 Navigation Satellite System are as follows:

1. The AN/SRN-9 "STAND ALONE" computer program with two minute SINS position input and with the automatic editing feature does meet the accuracy requirements for SPAMS. Three sigma deviation for Latitude and Longitude for twenty nine satellite passes using synthesized data were calculated at 0.39 and 0.54 nautical miles respectively.

2. Erratic refraction counts are being printed out both in the thermal printer data associated with the AN/SRN-9 equipment and in the high speed printer associated with the UNIVAC 1230 computer. Normally, the refraction counts for each two minute period can be expected to follow a sinusoidal curve, however, in the data analyzed there were frequent excursions of over a thousand cycles in refraction count when compared to the refraction count for the previous two minute period. This is indicative of a malfunction in the digital processing unit (DPU) of the AN/SRN-9 receiver.

3. The AN/SRN-9 computer program presently implemented in the "STAND BY" mode needs to be improved. The shipboard results for this program and method of implementation are shown in figure 5. The three sigma deviations for this data were calculated to be 0.87 nautical miles in Latitude and 4.81 nautical miles in Longitude for the method by which the data is processed entirely by the UNIVAC 1230 computer. These results are indicative of the need for a more refined AN/SRN-9 data reduction program as a routine in the STAND BY mode operation program.

4. Analysis of computed data is required to obtain accurate AN/SRN-9 position fixes. Fixes either where data is lost during mid-pass or where the

RMS of the residuals is excessively high for the number of doppler counts generally are inaccurate and should not be used.

5. Training of personnel in the collection and analysis of the AN/SRN-9 data is required if the AN/SRN-9 is to provide position fixes to the required accuracy.

6. While other error sources such as geodial height, refraction, and NNSS errors have an effect, error in the determination of velocity has the most effect on the accuracy of an AN/SRN-9 position fix.

RECOMMENDATIONS

1. The AN/SRN-9 data reduction programs should be modified to make use of MK19/EM Log dead-reckoned position data at two minute intervals. This is required because, when a malfunction to the SINS occurs or when the SINS is in the Theta 'D' calibration mode of operation, correct position data at two minute intervals is not available for use by the AN/SRN-9 data reduction programs.

2. The "Stand Alone" data reduction program with the automatic data editing feature should be incorporated into the "STAND BY" (Navigation mode) of computer operation. The present method of using this "STAND ALONE" program requires the computer to be reprogrammed in order to obtain a fix. When on mission status, the hourly reprogramming may not be possible.

3. An at sea test should be conducted to evaluate the modifications that have been made to the AN/SRN-9 data reduction program since the time of the at sea evaluation for which this report was written.

4. Additional training in the collection and anaylsis of AN/SRN-9 data is required in order to obtain position fixes to the accuracy that this navigation system is capable.

APPENDIX

The twenty seven word message provided by the AN/SRN-9 receiver consists of twenty five words defining the orbit of the satellite, one word for the doppler count, and one word for the correction due to refraction. Each of these words are enumerated with their symbol, definition, format, and units as follows:

WORD	SYMBOL	DEFINITION	FORMAT (1)	UNITS
1		Doppler Count	XXXXXXX	cycles
2		Refraction Count	XXXX	cycles
3 to 10		Variable parameters	(2)	
11	t_p	time of satellite perigee (GMT)	YXXX.XXXXY	minutes
12	n	mean motion of satellite	Y.XXXXXXXY	degrees/minute minus three
13	ω_0	argument of perigee at tp	YXXX.XXXXY	degrees
14	$\dot{\omega}$	precision rate of perigee	Y.XXXXXXXY	degrees/minute
15	ϵ	eccentricity	YX.XXXXXXY	none
16	A_0	mean semi-major axis	YXXXX.XXY	kilometers
17	Ω	right ascension of ascending node	YXXX.XXXXY	degrees
18	$\dot{\Omega}$	precision rate of node	X.XXXXXXXY	degrees/minute
19	C_i	cosine of inclination	SX.XXXXXXY	none
20	Λ_G	longitude of Greenwich at tp	YXXX.XXXXY	degrees
21		Unused		
22	t_i	predicted time of satellite injection	XXXX.XXXXY	minutes
23	S_i	sine of inclination	YX.XXXXXXY	none
24	Unused			
25	Unused			
26	Unused			
27	Unused			

NOTES

(1) Code X represents BCD - X3 Character of Data

Code Y represents BCD - X3 Character of Unused Data

Code S represents BCD - X3 Character of Sign

(2) Format and interpretation of variable parameters is.

S	S	X X	X X X	X X X	X
1	2	3 4	5 6 7	8 9 10	11
A	B	C	D	E	F

A Sign of ΔE_k

B Sign of ΔA_k

C tk designates number of even two minute period following hour/or half hour

D ΔE_k 0.0XXX degrees

E ΔA_k X.XX kilometers

F one digit of η_k

ΔE_k Incremental eccentric anomaly

ΔA_k Incremental length of semi-major axis of orbit ellipse

η_k incremental out-of-plane component of satellite

k digit received	(m)
0	0
1	-4
2	-3
3	-2
4	-1
5	+0

6	+1
7	+2
8	+3
9	+4

The variable memory quantity η, the out-of-plane orbit component, is assigned to the ninth digit in each variable memory word. Since the desired magnitude of N is 0.XX kilometers it is partitioned in the following manner. Each variable parameter word whose fiducial (GMT) time(in minutes) is devisable by 4, carries the most significant decimal digit of $\eta^{(m)}$. The next variable parameter words contain the least significant decimal digit of η, defined as $\eta^{(1)}$. $\eta^{(m)}$ and $\eta^{(1)}$ can be combined to yield η for the fiducial time.