CENTER FOR AEROSPACE ANALYSIS

TECHNICAL NOTE

CAA-TN-89-010

26 JUN 89

SATELLITE EPHEMERIS ERROR MODEL (SEEM) IMPLEMENTATION/VALIDATION ON GOVERNMENT MICRO-COMPUTERS

CAPT DAVID VALLADO, USAFA/DFAS
JOHN HANSON, ANSER, INC

UNITED STATES SPACE COMMAND

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APPROVED FOR RELEASE

David Finkleman

DAVID FINKLEMAN/DIRECTOR, ES-4

ABSTRACT

This technical note describes the efforts and analyses which went into the implementation and evaluation of SEEM's effectiveness on the micro-computer. The report gives a brief introduction to the SEEM program, and then describes the validation tests performed.

SEEM was developed by ANSER Inc to calculate satellite ephemeris error propagations between, and after sensor observations. These errors are the result of sensor measurement errors and sensor location errors. The results may be used for a variety of uses including assessments of how ephemeris predictions are degraded by the loss of certain sensors. SEEM includes data for electro-optical, dish radar, and phased array sensors, and has the capability for using user defined land, airborne, and satellite sensors.

Based on the results of this study, we are confident SEEM accurately measures the growth of error resulting from measurement error, for one or two passes, for the types of orbits and sensors considered, and for the predicted times of the errors. SEEM compared at least on the same order of magnitude in error to the SSCCES, and in many cases was closer to the "real-world" numbers. It represents a valuable tool in the analysis of strategies and deployments of sensor assets.

Two areas for improvement would be the inclusion of a capability to process range rate information and additional information to allow some kind of processing which would account for real-world variations of the data from the sensors. The second of these is important since it would give SEEM the capability to determine reasonably precise error bounds associated with actual data from particular sensors, not resulting just from inherent noise and bias sigmas.

CAA-TN-89-010

TECHNICAL NOTE

Satellite Ephemeris Error Model (SEEM) Evaluation

June 1989

Capt David Vallado, USAFA/DFAS

John Hanson, ANSER Inc

1. **PURPOSE:** This technical note describes the efforts and analyses which went into the implementation and evaluation of SEEM's effectiveness on the micro-computer. This effort was done in the Center for Aerospace Analysis under the general guidance of Mr. Ronald Roehrich. Technical consultation and guidance on sensor data was provided by Mr. Paul Major, AFSPACECOM/DOAS. The report gives a brief introduction to the SEEM program, and then describes the validation tests performed.

2. **BACKGROUND:** SEEM is a program developed by ANSER Inc whose purpose is to calculate satellite ephemeris error propagations between, and after sensor observations. These errors are the result of measurement errors by the sensors, and sensor location errors. The results may then be used for a variety of uses including assessments of how ephemeris predictions are degraded by the loss of certain sensors. SEEM includes data for electro-optical, dish radar, and phased array sensors, and has the capability for using user defined land, airborne, and satellite sensors.

SEEM's overall approach is to ignore drag and geoid uncertainties by estimating ephemeris errors under a Keplerian approximation. The rationale for this approach is that the error of a Keplerian satellite from a Keplerian estimated position should approximate the distance of a real-world satellite from a position estimated through perturbation theory. Previous studies with SEEM show its validity to model drag force errors and gravitational errors for up to three sensor passes, and up to nine hours past the predicted times.

The program actually consists of three programs which are run in series. Sensor Coverage Input (SCIN) essentially sets up the program and allows any additional sensors to be input by the user. It will also run from data sets previously set up by the user. The Appendices include this type of file from which SCIN may be executed. Sensor Coverage (SENCOV) performs the orbital dynamics (Keplerian or NORAD propagator) needed to determine when and where the observations will occur, using the information provided in data files from SCIN. Finally, SEEM is run to calculate the covariance matrices, to propagate them, and to allow the user to plot the results and run different parametric analyses.

3. **PROBLEM DESCRIPTION:** The problem tasked was to implement the latest version of SEEM on a micro-computer and calibrate against the current Space Surveillance Network. The inputs were then modified to reflect hypothetical Space Based Surveillance platforms (i.e. Space Satellite Tracking Sensor, SSTS), in order to study possible contributions of an SSTS to the routine satellite catalog mission.

Installation of the program on the Microcomputer was very easy, and once the program was installed and operating, several changes were added to allow the user greater flexibility in running the program. The Ryan-McFarland FORTRAN compiler (Ver 2.11) was used, and anyone implementing this software is strongly encouraged to use a math co-processor.

In an attempt to "calibrate" the results of SEEM, several cases were examined from the Final Report of the Space Surveillance Command and Control Evaluation Study, Vol III, 24 May 89 (SSCCES). Although SAIC produced the SSCCES, several references are made to the Aerospace Corporation who actually performed the covariance analyses for use in the final report. The results of the SSCCES and SEEM program were then used as a basis of comparison.

4. **DISCUSSION:** There were three basic areas of study examined in this effort. First, SEEM was compared to the covariance analysis test cases for which the SSCCES report used two specific satellites. The report gave data from the sensor sites along with the "real-world" error data and error calculations. Next, SEEM was compared to the New Foreign Launch (NFL) data given for three satellites. Finally, the results of the Flash Element Set Calibration Accuracy study were examined. These tests were designed to give an idea of the statistical accuracy of the sensor sites over time.

Before examining the results in detail, it is necessary to point out the differences in the sensor databases. SEEM uses an error database created from the USSPACECOM/DOA Technical Note 7 Feb 1984. The current document, USSPACECOM/DOA Technical Note 89-2, contains some different data. The 1984 study included data for both Bias and Noise Sigmas, while the 1989 study contains Noise sigmas and Bias values. Discussions with Paul Major on 7 Jun 89 indicated the Bias sigmas had not been calculated for the 1989 report. While this doesn't cause a great deal of concern for our results, since the data are very close between the two reports, the question about the impact of slightly different databases remains.

In addition to this, the SSCCES contains apparent inconsistencies with regard to the specific numbers for the radars bias and noise values. Mean bias and noise sigmas were given for some sensors (Table 3.1-15), however there were different values for subsequent cases. (Tables 3.2-6, 4.1-2 and 4.1-3). The data used in this study is listed in the Appendix and it conforms reasonably well to the 1984 report.

Finally, recall these results are being compared between a large mainframe program (Aerospace Corporation TRACE program), and the micro-computer SEEM program. Despite the obvious differences, the two programs are very similar in actual processing of data, however SEEM does NOT model range rate errors, while TRACE does. Further study would be necessary to determine what affect this has since the code would have to be changed, and the sensors which use range rate data would need to be updated in the database.

FIRST CASES - Covariance Analysis Validation Cases

The first test cases consisted of runs made against satellites 19193, and 19519. The results in the report indicated the comparisons would be made to "real-world" data. This data was calculated by considerable refining of orbit element sets given to Aerospace Corporation by Paul Major. The complete results are shown in the Appendix along with the specifics of the input data. Although initial orbital elements were obtained from Aerospace, the refinement appears not to be documented, thus the exact geometry of the flights had to be approximated. Use of the sensor characteristics given in the study caused SEEM to be closer to the SSCCES, and to the real-world values. Results for satellite 19193 are as follows: (Note the times are 330 minutes after the pass)

	SEEM	Real-World	SSCCES
1st Pass	218.50	224.9	258.9
2nd pass	89.78	150.0	157.2
Both Passes	7.90	9.8	22.6

Table 1 : Resultant Error One Sigma Values (km) for 19193

Due to the unknown differences resulting from the geometries, the pass durations had to be adjusted (shortened) to match the given data. The minimum elevation was also set to 10 degrees. Looking at the table then, notice the results are the same order of magnitude, and the results from SEEM appear to more closely approximate the "real world" for the case using both passes. It should be noted that pass geometry heavily influences covariance results, so any discrepancies could be due to this factor alone.

The results for the second satellite, 19519, are again detailed in the appendix, and summarized in the following table. (Note the times are again 330 minutes after the pass)

	SEEM	Real-World	SSCCES
1st Pass	88.05	102.3	80.9
2nd pass	300.52	367.2	142.1
Both Passes	4.62	5.9	11.8

Table 2 : Resultant Error One Sigma Values (km) for 19519

Again, the geometry of the specific orbits was unknown and could still be a major factor in the process. However, by constraining the length of each pass to the given data, acceptable results were obtained. Notice the order of magnitude correlation, and the more accurate approximation on multiple passes.

These tests were then used to essentially validate the covariance results of SEEM, and from the results listed above, SEEM may be taken as accurately predicting the propagation error for orbits of the type tested (low altitude circular and elliptical) for one or two passes, and up to six hours past the observations.

Both Passes	8.0	2.67	3.0
Satellite B			
1st Pass	25.0	85.33	22.67

* - 1984 data base sensor errors
** - SSCCES data base Noise Sigma Errors

Notice the use of the SSCCES noise sigmas yielded much closer results. Also, although SEEM results were lower for the cases which considered both passes, both SEEM and the real-world data were lower than the SSCCES covariance analysis results for the Covariance Analyses test cases.

THIRD CASES - Flash element set calibration

The final series of tests which were conducted were aimed at reproducing the calibration portion of the SSCCES. This effort examined the flash element sets reported by various sensors for the SSCCES. Although numerical results were obtained for this portion, the accuracies of the results are suspect owing to the assumptions and real-world constraints limiting the data. There were several areas causing differences between the two studies, including real-world limitations of sensor gathering information, the type of processing performed during the SSCCES evaluation, and the lack of orbital pass geometries used in SSCCES.

SEEM models the sensors as though they exist in a theoretically perfect world. As such, the program uses data from every pass the satellite makes, and has coverage the complete time of the pass. Although these may be limited by the user in a particular run, such as the covariance analysis tests previously discussed, SEEM does not model the random length and times of actual trackings as an integral part of its operation. Also, as the SSCCES noted, different sensors use different processing algorithms to develop flash element sets. There was no information in the SSCCES to indicate which sensors use which method, or which sites are prone to incomplete or missing passes.

The second area causing differences in this portion of the test is the actual processing of the data used in the flash element section of the SSCCES. The report indicates a significant amount of processing went into refining the data, smoothing, having analysts examine and make decisions on, removing discontinuities (maneuvers) from the observations, etc. SEEM has the capability to model a fair amount of these changes, however significantly more information would be necessary to make a one-to-one comparison of the two.

Finally, the SSCCES gave results for six sensors that reported nine or more samples of flash element sets. The largest sample was thirteen. Without full knowledge of the orbital element set used, and the pass geometries obtained, SEEM cannot attempt to duplicate the results.

5. **CONCLUSIONS:** In conclusion, we are are confident SEEM accurately measures the growth of error resulting from measurement error, for one or two passes, for the types of orbits and sensors considered, and for the predicted times of the errors. Each of the test cases showed similar results. SEEM compared at least on the same order of magnitude in error to the SSCCES, and in many cases was closer to the "real-world" numbers. It represents a valuable tool in the analysis of strategies and deployments of sensor assets.

Two areas for improvement would be the inclusion of a capability to process range rate information and additional information to allow some kind of processing which would account for real-world variations of the data from the sensors. The second of these is important since it would give SEEM the capability to determine reasonably precise error bounds associated with actual data from particular sensors, not resulting just from inherent noise and bias sigmas.

A very useful study would examine the effectiveness of SEEM predicting errors for longer predicted times, for multiple sensors passes, and for other targets (Deep Space, etc.)

As with any program that deals with statistical analysis, the use of the results as absolutes is cautioned since they are only as good as the databases and the mathematical technique used in their calculation. A different database, and/or mathematical treatment could cause different results.

SEEM was originally validated (for cases similar to those considered here) in 1979. The comparisons reported here indicate SEEM still gives good results when compared to those resulting from sensor measurement errors.

BIBLIOGRAPHY

1. SAIC, Final Report of the Space Surveillance Command and Control Evaluation Study, May 1989, Vol II, III, IV.

2. Hanson, J., Predicting Satellite Ephemeris errors resulting from sensor position and measurement errors, ANSER Inc, SPDN 89-1, Feb 1989.

3. Evans M, Hanson, J. and Kirkham J, Users guide for ANSER computer programs SCIN, SENCOV, and SEEM, ANSER Inc, SPDN 88-2, Aug 1988.

4. GE Aerospace, System and Operations Description Document, 28 Apr 89, Document Number 7700-0064 on contract SDIO84-88-C-0020.

APPENDICES

APPENDIX A: Sensor Data File

```
211 33.81724 -106.66030 ** GEODSS-SOCORRO **           0.000  90.000  6
       Range           Azimuth        Elevation        BoreSight
   100.00   92600.00   0.00   360.00  20.00     90.00   90.00    Search
   100.00   92600.00   0.00   360.00   5.00     90.00   90.00    Track
  9999.00              0.0017          0.0010                    Bias
  9999.00              0.0033          0.0027                    Noise

221 35.74405  128.60787 ** GEODSS-TAEGU **             0.000  90.000  6
       Range           Azimuth        Elevation        BoreSight
   100.00   92600.00   0.00   360.00  20.00     90.00   90.00    Search
   100.00   92600.00   0.00   360.00   5.00     90.00   90.00    Track
  9999.00              0.0023          0.0010                    Bias
  9999.00              0.0023          0.0020                    Noise

231 20.70801 -156.25794 ** GEODSS-MAUI **              0.000  90.000  6
       Range           Azimuth        Elevation        BoreSight
   100.00   92600.00   0.00   360.00  20.00     90.00   90.00    Search
   100.00   92600.00   0.00   360.00   5.00     90.00   90.00    Track
  9999.00              0.0023          0.0017                    Bias
  9999.00              0.0037          0.0030                    Noise

241 -7.41165   72.45191 ** GEODSS-DIEGO GARCIA **      0.000  90.000  6
       Range           Azimuth        Elevation        BoreSight
   100.00   92600.00   0.00   360.00  20.00     90.00   90.00    Search
   100.00   92600.00   0.00   360.00   5.00     90.00   90.00    Track
  9999.00              0.0017          0.0023                    Bias
  9999.00              0.0043          0.0043                    Noise

251 40.00000   -8.00000 ** GEODSS-SITE V **            0.000  90.000  6
       Range           Azimuth        Elevation        BoreSight
   100.00   92600.00   0.00   360.00  20.00     90.00   90.00    Search
   100.00   92600.00   0.00   360.00   5.00     90.00   90.00    Track
  9999.00              0.0020          0.0015                    Bias
  9999.00              0.0030          0.0030                    Noise

331 15.25000  145.79000 ** SAIPAN **                   0.000  90.000  6
       Range           Azimuth        Elevation        BoreSight
   100.00    4630.00   0.00   360.00   2.00     90.00   90.00    Search
   100.00    4630.00   0.00   360.00   2.00     90.00   90.00    Track
    92.04              0.0130          0.0090                    Bias
   102.00              0.0280          0.0250                    Noise

334  9.39539  167.47913 ** ALTAIR **                   0.000  90.000  6
       Range           Azimuth        Elevation        BoreSight
   100.00    4500.00   0.00   360.00   1.00     90.00   90.00    Search
   100.00    4500.00   0.00   360.00   1.00     90.00   90.00    Track
   108.00              0.0140          0.0161                    Bias
   162.90              0.0318          0.0129                    Noise
•  130.00              0.0180          0.0290                    Noise
***  30.00             0.0230          0.0210                    Noise
```

• - SSCCES Vol III, Table 3.1.15
*** - SSCCES Vol III, Table 4.1-4

APPENDIX A: Sensor Data File

```
 337 37.90521   39.99319 ** PIRINCLIK **                 0.000  90.000  6
        Range            Azimuth         Elevation       BoreSight
   100.00   5100.00   0.00   360.00   2.00     86.00     90.00   Search
   100.00   5100.00   0.00   360.00   2.00     86.00     90.00   Track
   409.00             0.0264          0.0193                     Bias
    38.80             0.0337          0.0290                     Noise
•  100.00             0.0220          0.0250                     Noise
**  16.00             0.0160          0.0210                     Noise

 342 54.36715   -0.66682 ** FYLINGDALES **               0.000  90.000  6
        Range            Azimuth         Elevation       BoreSight
   100.00   4820.00 285.00   189.00   4.00     70.00     90.00   Search
   100.00   4820.00 285.00   189.00   4.00     70.00     90.00   Track
  2253.00             0.0690          0.0255                     Bias
  2199.00             0.1034          0.0364                     Noise
• 1281.00             0.0500          0.0280                     Noise
** 2718.00            0.0420          0.0310                     Noise

 346 15.00080  120.06960 ** SAN MIGUEL **                0.000  90.000  6
        Range            Azimuth         Elevation       BoreSight
   100.00   3190.00   0.00   360.00   1.00     88.00     90.00   Search
   100.00   3190.00   0.00   360.00   1.00     88.00     90.00   Track
    87.10             0.0381          0.0190                     Bias
    68.70             0.0315          0.0433                     Noise
•  129.00             0.0180          0.0160                     Noise
**  18.00             0.0140          0.0090                     Noise

 354 -7.90668  -14.40265 ** ASCENSION **                 0.000  90.000 30
        Range            Azimuth         Elevation       BoreSight
   100.00   1600.00   0.00   360.00   1.00     90.00     90.00   Search
   100.00   1900.00   0.00   360.00   1.00     90.00     90.00   Track
    92.20             0.0133          0.0085                     Bias
   101.70             0.0283          0.0248                     Noise
*  168.00             0.0220          0.0180                     Noise
** 115.00             0.0120          0.0230                     Noise

 359 64.29115 -149.19298 ** CLEAR **                     0.000  90.000  6
        Range            Azimuth         Elevation       BoreSight
   100.00   4910.00 170.00   110.00   1.50     90.00     90.00   Search
   100.00   4910.00 170.00   110.00   1.50     90.00     90.00   Track
   153.20             0.0355          0.0171                     Bias
    62.50             0.0791          0.0240                     Noise
•   98.00             0.0370          0.0310                     Noise
**  26.00             0.0420          0.0320                     Noise

 363 17.14360  -61.79267 ** ANTIGUA **                   0.000  90.000  6
        Range            Azimuth         Elevation       BoreSight
   100.00   2550.00   0.00   360.00   0.00     90.00     90.00   Search
   100.00   2550.00   0.00   360.00   0.00     90.00     90.00   Track
    80.00             0.0081          0.0045                     Bias
    92.50             0.0224          0.0139                     Noise
•  137.00             0.0150          0.0140                     Noise
**  89.00             0.0010          0.0150                     Noise
```

• - SSCCES Vol III, Table 3.1.15

** - SSCCES Vol III, Table 4.1-2

APPENDIX A: Sensor Data File

```
 369 42.61740  -71.49105 ** MILLSTONE **                     0.000  90.000  6
         Range            Azimuth          Elevation       BoreSight
    300.00   40744.00   0.00    360.00    0.00     90.00     90.00    Search
    300.00   40744.00   0.00    360.00    0.00     90.00     90.00    Track
    150.00              0.0001            0.0001                      Bias
    150.00              0.0100            0.0100                      Noise
***  5.00              0.0050            0.0050                      Noise

 382 30.97826 -100.55298 ** PPSWSE FACE **                 130.000  20.000 10
         Range            Azimuth          Elevation       BoreSight
    100.00    5555.00  70.00    190.00    3.00     80.00     60.00    Search
    100.00    5555.00  70.00    190.00    3.00     80.00     60.00    Track
     70.80              0.0130            0.0075                      Bias
     26.00              0.0260            0.0220                      Noise
*   111.00              0.0300            0.0260                      Noise
**   29.00              0.0300            0.0210                      Noise

 383 30.97826 -100.55298 ** PPSWSW FACE **                 250.000  20.000 10
         Range            Azimuth          Elevation       BoreSight
    100.00    5555.00 190.00    310.00    3.00     80.00     60.00    Search
    100.00    5555.00 190.00    310.00    3.00     80.00     60.00    Track
     70.80              0.0130            0.0075                      Bias
     26.00              0.0260            0.0220                      Noise
•    97.00              0.0280            0.0280                      Noise
**   31.00              0.0240            0.0210                      Noise

 384 32.58123  -83.56936 ** PPSENE FACE **                  70.000  20.000 10
         Range            Azimuth          Elevation       BoreSight
    100.00    5555.00  10.00    130.00    3.00     85.00     60.00    Search
    100.00    5555.00  10.00    130.00    3.00     85.00     60.00    Track
     70.80              0.0130            0.0075                      Bias
     26.00              0.0260            0.0220                      Noise
•   105.00              0.0360            0.0250                      Noise
••     3.50              0.0370            0.0260                      Noise

 385 32.58123  -83.56936 ** PPSES FACE **                  190.000  20.000 10
         Range            Azimuth          Elevation       BoreSight
    100.00    5555.00 130.00    250.00    3.00     85.00     60.00    Search
    100.00    5555.00 130.00    250.00    3.00     85.00     60.00    Track
     70.80              0.0130            0.0075                      Bias
     26.00              0.0260            0.0220                      Noise
•   122.00              0.0310            0.0270                      Noise
**   36.00              0.0310            0.0250                      Noise

 386 41.75242  -70.53827 ** PPENE FACE **                   47.000  20.000 10
         Range            Azimuth          Elevation       BoreSight
    100.00    5555.00 347.00    107.00    3.00     80.00     60.00    Search
    100.00    5555.00 347.00    107.00    3.00     80.00     60.00    Track
     70.80              0.0130            0.0075                      Bias
     26.00              0.0260            0.0220                      Noise
•   117.00              0.0330            0.0310                      Noise
**   37.00              0.0390            0.0340                      Noise
```

•   - SSCCES Vol III, Table 3.1.15

** - SSCCES Vol III, Table 4.1-2

*** - SSCCES Vol III, Table 4.1-4

•	149.00		0.0280		0.0250			Noise

389 39.13604 -121.35087 ** PPWNW FACE ** 306.000 20.000 10

	Range		Azimuth		Elevation		BoreSight	
	100.00	5555.00	246.00	6.00	3.00	80.00	60.00	Search
	100.00	5555.00	246.00	6.00	3.00	80.00	60.00	Track
	92.00		0.0160		0.0130			Bias
	35.00		0.0320		0.0330			Noise
•	129.00		0.0320		0.0270			Noise

393 52.73726 174.09093 ** COBRA DANE ** 319.000 20.000 10

	Range		Azimuth		Elevation		BoreSight	
	463.00	4500.00	259.00	19.00	0.60	80.00	60.00	Search
	463.00	4500.00	259.00	19.00	0.60	80.00	60.00	Track
	41.70		0.0067		0.0084			Bias
	20.80		0.0303		0.0210			Noise
•	118.00		0.0190		0.0130			Noise
	100.00	5555.00	57.00	177.00	3.00	80.00	60.00	Search
	100.00	5555.00	57.00	177.00	3.00	80.00	60.00	Track
	70.80		0.0130		0.0075			Bias
	26.00		0.0260		0.0220			Noise
*	147.00		0.0330		0.0330			Noise
**	42.00		0.0440		0.0370			Noise

395 76.57029 -68.29923 ** THULEN FACE ** 357.000 20.000 10

	Range		Azimuth		Elevation		BoreSight	
	100.00	5555.00	297.00	57.00	3.00	80.00	60.00	Search
	100.00	5555.00	297.00	57.00	3.00	80.00	60.00	Track
	70.80		0.0130		0.0075			Bias
	26.00		0.0260		0.0220			Noise
•	144.00		0.0280		0.0290			Noise

• - SSCCES Vol III, Table 3.1.15

** - SSCCES Vol III, Table 4.1-2

APPENDIX A: Sensor Data File

```
 396 48.72479  -97.89974 ** PARCS **                            8.000  25.000  6
        Range            Azimuth          Elevation        BoreSight
   100.00     3300.00 313.00    62.00   1.90     45.00      60.00   Search
   100.00     3300.00 298.00    78.00   1.90     95.00      60.00   Track
    49.90               0.0036          0.0038                      Bias
    28.00               0.0125          0.0086                      Noise
•  124.00               0.0090          0.0080                      Noise
**  45.00               0.0090          0.0100                      Noise

 399 30.57242  -86.21485 ** EGLIN **                          180.000  45.000 10
        Range            Azimuth          Elevation        BoreSight
   100.00    13210.00 145.00   215.00   1.00    105.00      60.00   Search
   100.00    13210.00 120.00   240.00   1.00    105.00      60.00   Track
     4.30               0.0100          0.0094                      Bias
    32.10               0.0154          0.0147                      Noise
*  117.00               0.0170          0.0200                      Noise
**  21.00               0.0190          0.0230                      Noise

 745 33.55396  -98.76306 ** NAVSPASUR **                        0.000   0.000  6
        Range            Azimuth          Elevation        BoreSight
     0.00     8150.00  90.00   270.00  -7.50     -7.60       0.00   Search
     0.00     8150.00  90.00   270.00  -7.50     -7.60       0.00   Track
   436.81               0.0110          0.0140                      Bias
  1905.00               0.0396          0.0445                      Noise
* 1576.00               0.0190          0.0210                      Noise
** 423.00               0.0090          0.0160                      Noise

 932 21.57208 -158.26674 ** KAENA POINT **                      0.000  90.000  6
        Range            Azimuth          Elevation        BoreSight
   100.00     6380.00   0.00   360.00   0.00    180.00      90.00   Search
   100.00     6380.00   0.00   360.00   0.00    180.00      90.00   Track
    80.00               0.0081          0.0045                      Bias
    92.50               0.0224          0.0139                      Noise
*  123.00               0.0130          0.0100                      Noise

6002 -1.71000   36.50000 ** NAIROBI **                          0.000  90.000  6
        Range            Azimuth          Elevation        BoreSight
   300.00    40000.00   0.00   360.00   1.00     90.00      90.00   Search
   300.00    40000.00   0.00   360.00   1.00     90.00      90.00   Track
   150.00               0.0001          0.0001                      Bias
   150.00               0.0100          0.0100                      Noise

6003 -4.80000   55.50000 ** MAHE ISLAND **                      0.000  90.000  6
        Range            Azimuth          Elevation        BoreSight
   300.00    40000.00   0.00   360.00   1.00     90.00      90.00   Search
   300.00    40000.00   0.00   360.00   1.00     90.00      90.00   Track
   150.00               0.0001          0.0001                      Bias
   150.00               0.0100          0.0100                      Noise
```

• - SSCCES Vol III, Table 3.1.15

** - SSCCES Vol III, Table 4.1-2

```
            Additional ground-based sensor #
          0  Additional ground-based sensor #
N  Change any sensor characteristics?
N  Enter observation time length?
N  Ground-based sensors airborne?
          1  How many targets?
          2  1=New launch, 2=On-orbit, 3=Missile
          1  1=Input apogee & perigee, 2=Period & ecc
    423.13699300     409.32959000     65.03749850     328.95278900  Orbital ele
          2  1=x-axis thru Greenwich, 2=Right ascension
     20.11750000  Ascending node
    -31.04719920  Argument of perigee
          0  Number of maneuvers
          1  1=Duration in hours, 2=Duration in revs
      6.00000000  Duration in hours
      1.00000000  How accurate is simulation in seconds?
N  Set min el to 7 degrees?
```

NOTES :

1. Minimum elevation set to 10.0 degrees in file SCINSNCV.DAT prior to running SENCOV.
2. Pass 3 constrained to 1.324 min, and pass 4 constrained to 2.332 min while running SEEM.
3. Sensor errors were changed as follows: (SSCCES Vol III, Table 3.2-2)

Sensor	Range m	Azimuth deg	Elevation deg	
359	153.2	0.0355	0.0171	Bias Sigma
	174.4	0.029	0.0277	Noise Sigma

APPENDIX B: Covariance Analysis Test Cases

Satellite 19519, FILE => Info2.DAT

```
Y  Will SEEM be run?
           1  1 = exact sun position, 2 = arbitrary
        1988  Year
          12  Month
           9  Day
           1  1=Universal time, 2=local
          19  Hour
          48  Minutes after hour
          36  Seconds
           1  1=Data base sensors, 2=User input 3=Both
           0  0=No sensor group, 1=FY90, 2=CONUS, 3=Spacetrack
         337  Additional ground-based sensor #
           0  Additional ground-based sensor #
N  Change any sensor characteristics?
N  Enter observation time length?
N  Ground-based sensors airborne?
           1  How many targets?
           2  1=New launch, 2=On-orbit, 3=Missile
           1  1=Input apogee & perigee, 2=Period & ecc
     779.62902800    233.62100200    142.82919300     16.78479960  Orbital ele
           2  1=x-axis thru Greenwich, 2=Right ascension
     344.19259600  Ascending node
     -18.16160010  Argument of perigee
           0  Number of maneuvers
           1  1=Duration in hours, 2=Duration in revs
      16.00000000  Duration in hours
       1.00000000  How accurate is simulation in seconds?
N  Set min el to 7 degrees?
```

NOTES :

1. Minimum elevation set to 10.0 degrees in file SCINSNCV.DAT prior to running SENCOV.
2. Pass 1 constrained to 2.894 min, and pass 2 constrained to 1.296 min while running SEEM.
3. Sensor errors were changed as follows: (SSCCES Vol III, Table 3.2-2)

Sensor	Range m	Azimuth deg	Elevation deg	
337	38.7	0.0218	0.0181	Bias Sigma
	97.5	0.032	0.022	Noise Sigma

```
N
N  Enter observation time length?
N  Ground-based sensors airborne?
           1  How many targets?
           1  1=New launch, 2=On-orbit, 3=Missile
           1  1=Tyur, 2=Ples, 3=Kapus, 4=CC
I  A=Launch azimuth, I=Inclination
     68.00000000  Inclination
N  North or South launch
    100.00000000  First perigee
    420.20001200  First apogee
    200.50000000  Second perigee
           0  Number of maneuvers
           1  1=Duration in hours, 2=Duration in revs
      7.00000000  Duration in hours
      1.00000000  How accurate is simulation in seconds?
N  Set min el to 7 degrees?
```

NOTES :

1. Minimum elevation set to 2.0 degrees in file SCINSNCV.DAT prior to running SENCOV.
2. Once SEEM had ordered the passes, pass 3 was used as #1, and pass 4 was used as pass #2.
3. Sensor errors were changed as follows: (SSCCES Vol III, Table 3.2-6)

Sensor	Range m	Azimuth deg	Elevation deg	
334	101.0	0.023	0.053	Bias Sigma
	30.0	0.023	0.021	Noise Sigma
342	642.3	0.021	0.012	Bias Sigma
	584.0	0.032	0.017	Noise Sigma

APPENDIX C: New Foreign Launch Test Cases

Satellite A2, FILE => InfoNFL2.DAT

```
Y  Will SEEM be run?
          2  1 = exact sun position, 2 = arbitrary
   0.00000000E-01   0.00000000E-01  Sun latitude and longitude
          1  1=Data base sensors, 2=User input 3=Both
          0  0=No sensor group, 1=FY90, 2=CONUS, 3=Spacetrack
        334  Additional ground-based sensor #
        354  Additional ground-based sensor #
        342  Additional ground-based sensor #
        331  Additional ground-based sensor #
        346  Additional ground-based sensor #
        393
          0  Additional ground-based sensor #
N  Change any sensor characteristics?
N  Change any sensor characteristics?
N  Change any sensor characteristics?
N  Change any sensor characteristics?
N  Change any sensor characteristics?
N
Y  Enter observation time length?
        342  Code number of sensor to modify
   10.00000000  Observation time length
        354  Code number of sensor to modify
   30.00000000  Observation time length
          0  Code number of sensor to modify
N  Ground-based sensors airborne?
          1  How many targets?
          1  1=New launch, 2=On-orbit, 3=Missile
          2  1=Tyur, 2=Ples, 3=Kapus, 4=CC
I  A=Launch azimuth, I=Inclination
   72.80000310  Inclination
N  North or South launch
  100.00000000  First perigee
  386.00000000  First apogee
  213.00000000  Second perigee
          0  Number of maneuvers
          1  1=Duration in hours, 2=Duration in revs
    5.00000000  Duration in hours
    1.00000000  How accurate is simulation in seconds?
N  Set min el to 7 degrees?
```

NOTES :

1. Minimum elevation set to 2.0 degrees in file SCINSNCV.DAT prior to running SENCOV.
2. Once SEEM had ordered the passes, pass 2 was used as #1, and pass 3 was used as pass #2.
3. Sensor errors were changed as follows: (SSCCES Vol III, Table 3.2-6)

Sensor	Range m	Azimuth deg	Elevation deg	
334	101.0	0.023	0.053	Bias Sigma
	30.0	0.023	0.021	Noise Sigma
354	122.3	0.017	0.007	Bias Sigma
	115.0	0.012	0.023	Noise Sigma

APPENDIX C: New Foreign Launch Test Cases

Satellite B, FILE => InfoNFLB.DAT

```
Y  Will SEEM be run?
           2  1 = exact sun position, 2 = arbitrary
   0.00000000E-01   0.00000000E-01  Sun latitude and longitude
           1  1=Data base sensors, 2=User input 3=Both
           0  0=No sensor group, 1=FY90, 2=CONUS, 3=Spacetrack
         334  Additional ground-based sensor #
         337  Additional ground-based sensor #
         393
         354
         331
         342
           0  Additional ground-based sensor #
N  Change any sensor characteristics?
N  Change any sensor characteristics?
N
N
N
N
N  Enter observation time length?
N  Ground-based sensors airborne?
           1  How many targets?
           1  1=New launch, 2=On-orbit, 3=Missile
           1  1=Tyur, 2=Ples, 3=Kapus, 4=CC
I  A=Launch azimuth, I=Inclination
     66.68800000  Inclination
N  North or South launch
    100.00000000  First perigee
    469.10000600  First apogee
    457.60000600  Second perigee
           0  Number of maneuvers
           1  1=Duration in hours, 2=Duration in revs
      5.50000000  Duration in hours
      1.00000000  How accurate is simulation in seconds?
N  Set min el to 7 degrees?
```

NOTES :

1. Minimum elevation set to 2.0 degrees in file SCINSNCV.DAT prior to running SENCOV.
2. Once SEEM had ordered the passes, pass 3 was used as #1, and pass 4 was used as pass #2.
3. Sensor errors were changed as follows: (SSCCES Vol III, Table 3.2-6)

Sensor	Range m	Azimuth deg	Elevation deg	
334	101.0	0.023	0.053	Bias Sigma
	30.0	0.023	0.021	Noise Sigma
337	68.3	0.017	0.023	Bias Sigma
	16.0	0.016	0.021	Noise Sigma

APPENDIX D: Sensor Calibration Test Cases

```
Satellite 4393/4119, FILE => InfoCall.DAT

Y  Will SEEM be run?
           2  1 = exact sun position, 2 = arbitrary
   0.00000000E-01   0.00000000E-01  Sun latitude and longitude
           1  1=Data base sensors, 2=User input 3=Both
           0  0=No sensor group, 1=FY90, 2=CONUS, 3=Spacetrack
         354 ground-based sensor #
           0  Additional ground-based sensor #
N  Change any sensor characteristics?
N  Enter observation time length?
N  Ground-based sensors airborne?
           1  How many targets?
           2  1=New launch, 2=On-orbit, 3=Missile
           1  1=Input apogee & perigee, 2=Period & ecc
     630.00000000     581.00000000     81.19999690   0.00000000E-01  Orbital ele
           1  1=x-axis thru Greenwich, 2=Right ascension
   0.00000000E-01  Ascending node
     180.00000000  Argument of perigee
           0  Number of maneuvers
           2  1=Duration in hours, 2=Duration in revs
           1  Reference satellite number for duration
      96.00000000  Number of revs for simulation duration
       1.00000000  How accurate is simulation in seconds?
N  Set min el to 7 degrees?
```

NOTES :

1. The number of revs (duration) for each sensor was slightly different to obtain the correct number of passes. running SENCOV.