5823

(2)

Naval Research Laboratory

Washington, DC 20375-5000 NRL Memorandum Report 5823 August 15, 1986

MILSTAR/FEP Ephemeris Package

ROBERT R. DASENBROCK AND WILLIAM H. HARR

Digital Systems Branch
Space Systems and Technology Division

Approved for public release; distribution unlimited

AD-A171829

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b RESTRICTIVE MARKINGS:

2a SECURITY CLASSIFICATION AUTHORITY:

2b DECLASSIFICATION / DOWNGRADING SCHEDULE:

3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4 PERFORMING ORGANIZATION REPORT NUMBER(S): NRL Memorandum Report 5823

5 MONITORING ORGANIZATION REPORT NUMBER(S):

6a NAME OF PERFORMING ORGANIZATION: Naval Research Laboratory

6b OFFICE SYMBOL (If applicable): Code 7750

7a NAME OF MONITORING ORGANIZATION: Space & Naval Warfare Systems Command

6c ADDRESS (City, State, and ZIP Code): 4555 Overlook Ave., SW, Washington, DC 20375-5000

7b ADDRESS (City, State, and ZIP Code): PDW- 106-13, Washington, DC

8a NAME OF FUNDING / SPONSORING ORGANIZATION: Space & Naval Warfare Sys. Com.

8b OFFICE SYMBOL (If applicable):

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c ADDRESS (City, State, and ZIP Code): SPAWAR 004-13, Washington, DC 20362-5100

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
77-1757-0-6			

11 TITLE (Include Security Classification): MILSTAR/FEP Ephemeris Package (U)

12 PERSONAL AUTHOR(S): Dasenbrock, Robert R., and Harr, William H.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Memorandum	FROM 9/84 TO 9/85	1986 August 15	70

16 SUPPLEMENTARY NOTATION:

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Orbit Determination; Communication Satellite; Ephemeris Compression; FLTSATCOM

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Design constraints require that as earth terminal attempting communications with a FLTSATCOM EHF Package (FEP) located onboard a FLTSATCOM satellite be provided with as accurate FEP package. To be precise, the terminal is provided with a coefficient element set from which the ephemeris of a satellite may be computed. This report describes the operation of a user-friendly computer program that produces the above-mentioned coefficient set so as to provide reference benchmarks from which the ephemeris related operations of the terminal can be judged.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code)	22c OFFICE SYMBOL
Robert R. Dasenbrock	(202) 767-2611	Code 7750

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

U.S. Government Printing Office: 1985—507-047

CONTENTS

MILSTAR/FEP EPHEMERIS PACKAGE

Design constraints require that an earth terminal attempting communications with a FLTSATCOM EHF Package (FEP) located onboard a FLTSATCOM satellite be provided with an accurate FEP package. To be precise, the terminal is provided a coefficient element set from which the ephemeris of a satellite may be computed. This report describes the operation of a user-friendly computer program that produces the above-mentioned coefficient set so as to provide reference benchmarks from which the ephemeris related operations of the terminals can be judged.

1. Introduction and Background

Design constraints require that an earth terminal attempting communications with a FLTSATCOM EHF Package (FEP) located onboard a FLTSATCOM satellite be provided with an accurate FEP package [1]. To be precise, the terminal is provided a coefficient element set from which the ephemeris of a satellite may be computed during a specified 30-day time span. The Navy EHF SATCOM Program (NESP) is building terminals which will accept the above mentioned coefficient element set. As part of the acceptance test procedures for these terminals, the Naval Electronic Systems Command (NAVELEXSYSCOM) will be providing the terminal contractors with ephemeris test data. The data is to provide reference benchmarks from which the ephemeris related operations of the terminals will be judged.

Operationally the ephemeris coefficients to be used by the NESP terminal will originate at the Satellite Control Facility (SCF) in Sunnyvale, CA. The present task is to simulate that aspect of the SCF operation related to generation of the FEP ephemeris coefficient element set.

The SCF is tasked to track each FLTSATCOM and produce a two-month time-position predict file for each. The technique (or intermediate step) of generating the coefficients from the ephemeris is merely an ephemeris compression technique and provides the terminal a quick and efficient [1] means to obtain the ephemeris without having to reconstruct (by numerical integration) or read/interpolate the lengthy file that the SCF now produces.

The program fits a low-order polynomial and trigonometric representation of the equinoctial element set to a one-month predicted ephemeris that is produced by the SCF. Provision is made to reconstruct (by integrating the state vector) this lengthy ephemeris should it not be available. This polynomial representation is then to be transmitted to the field sites to generate the azimuth, elevation, range, and range rate predictions as required.

Manuscript approved May 16, 1986

Ideally, an SCF-supplied ephemeris tape would be available, but at present they are not tasked to provide this service. Eventually they will be tasked and the ephemeris file (when available) will probably contain the satellite state vector every 30 minutes for a period of 60 days in the form of spherical (ADBARV) coordinates. We were (on a one-time basis) able to obtain a 60-day ephemeris tape for FLTSATCOM's 6391 and 6392 from the SCF. A sample of this listing is shown in Table 1, Appendix A. The 7-track tape that the SCF did finally provide cannot be read on our DEC VAX 11/780 system as 9-track drives have replaced the older and obsolete 7-track drives nearly everywhere. The tape as provided was in text format and we were able to read it by means of a PDP 11/70 which was equipped with a functional 7-track drive. Most of the results as described in this report were generated using the data provided from this tape.

We decided that at the present time it is not feasible to provide a VAX software package that requires a 7-track tape as input and decided that a backup option was necessary. The SCF routinely provides a hardcopy paper listing of the 60-day ephemeris on which the satellite state vector is listed in several easily readable forms. It can be manually entered into the program via a keyboard (e.g. a VT100). The state vector can then be numerically propagated for the necessary time period (usually 30 days) and the polynomial coefficients determined from the reconstructed ephemeris. This reconstruction can be best performed by use of the same orbit prediction program that was used to originally construct the ephemeris.

This method has one serious drawback however. The program that the SCF currently uses to propagate/fit the orbital state is written in JOVIAL and is not available for off-site use. If it were available, the 60-day ephemeris provided by the SCF could be reconstructed exactly at a customer/user field site. The only required input would be the satellite state vector and time of epoch (seven numbers). If we attempt to reconstruct the ephemeris by using a different orbit propagator a slow divergence from the SCF solution can be expected since the model used will probably be slightly different. This divergence can be up to 10 Km in position after a 30-day propagation. A major contributor to the error is the model used for the solar radiation pressure. Therefore, although this scheme can be used to generate the coefficient set from the reconstructed ephemeris, the errors are significant enough to produce only marginally acceptable results.

We can better reconstruct the SCF solution by the following procedure. The initial SCF-supplied state vector can be adjusted slightly (in velocity only) to force position agreement with the SCF solution at 30 days. This is easily carried out by use of the cartesian state transition matrix. Therefore, our reconstructed solution will match the SCF solution exactly in position at both endpoints, but will have small deviations within the 30-day time span. However, most of the errors due to the modeling differences will have been accounted for. The advantage of this scheme is that a lengthly ephemeris file from the SCF is not required to produce the coefficient array. The required input can be obtained via the telephone, i.e., the time, position, and velocity at epoch and the time and position at the 30-day point. (11 numbers). The disadvantage is that an additional 3-5 Km satellite position error and a 1/2 Km slant range error can be introduced. Since this is still well within the allowable error budget, this procedure is considered to be a promising and viable backup.

2. Orbital Perturbations

The perturbations experienced by a satellite in a geosynchronous orbit are very complex. The primary gravitational perturbations are due to the earth triaxiality and third body effects due to the sun and moon. All three effects are roughly equal in magnitude and none can be said to dominate the other two. If the oblateness effect (J_2) were to dominate, the ascending node would regress uniformly and the inclination would remain constant with respect to the equatorial plane. This is shown in Fig. 1A.

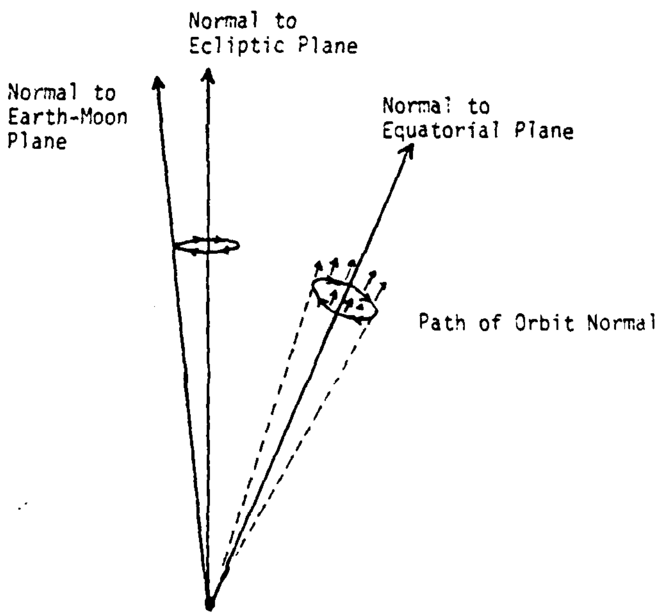

Figure 1A. Path of orbit normal(J_2 only)

If the solar gravitational force were to dominate, the ascending node would regress uniformly and the inclination would remain constant with respect to the earth-moon plane as is shown in Fig. 1B. If the moon were to dominate, the ascending node would regress uniformly and the inclination would remain constant with respect to the or earth-sun (ecliptic) plane - see Fig. 1C. In practice each force tends to exert a torque on the orbit about a different axis and the resulting sum total behavior is nearly impossible to explain in simple

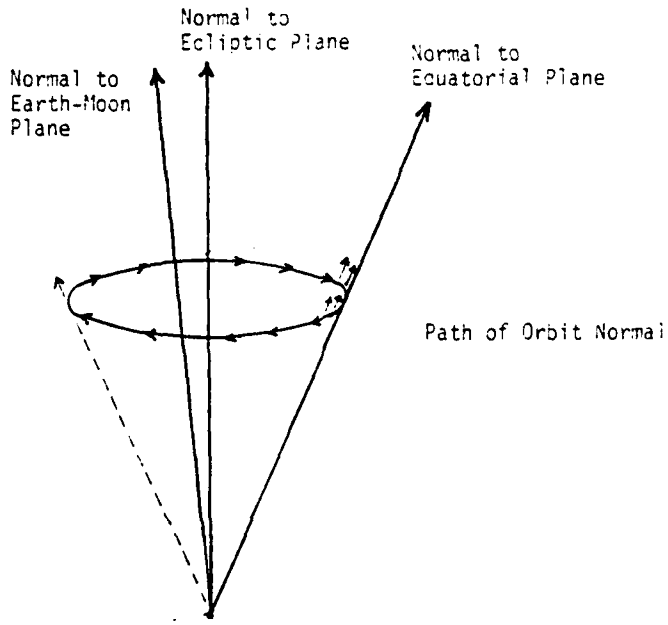

Figure 1B. Path of orbit normal (Sun only)

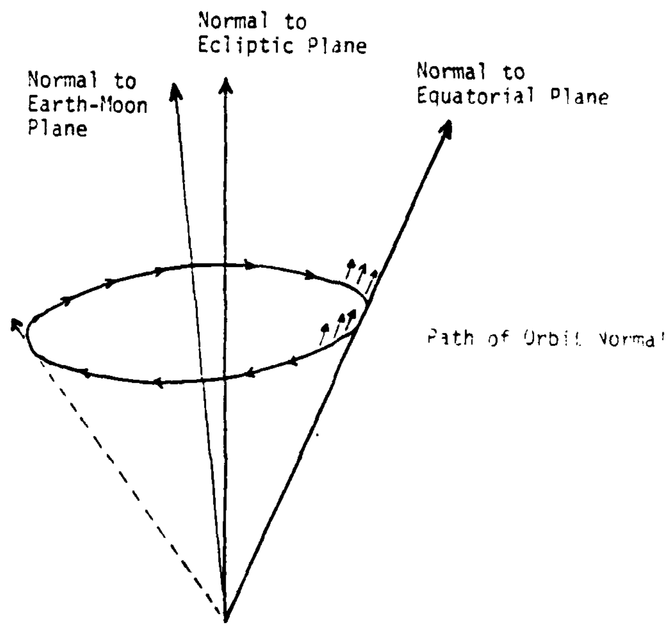

Figure 1C. Path of orbit normal (Moon only) terms. To complicate matters further, the lunar normal vector rotates about the ecliptic pole with a period of 18.6 years. Fig. 1D shows an example of the behavior of the orbit normal vector when all three torques are acting at once.

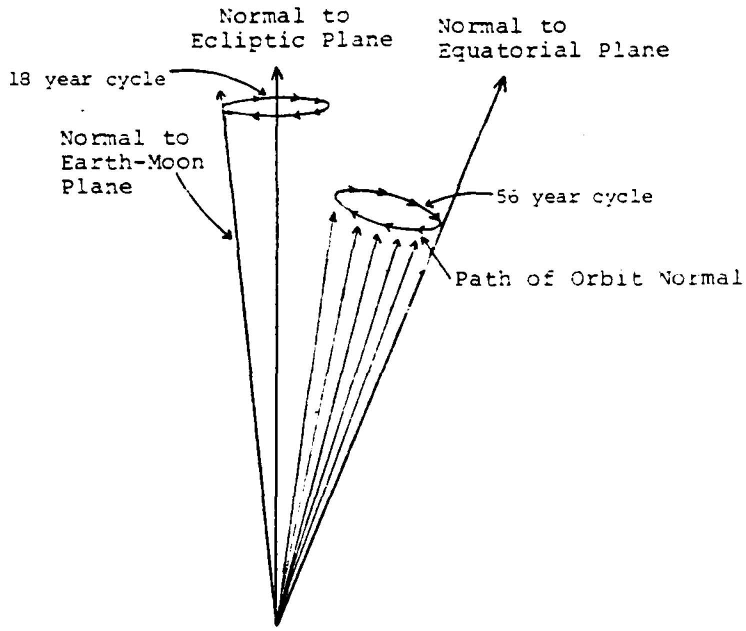

Figure 1D. Path of orbit normal (J_2, Sun, Moon)

For the case depicted in Fig. 1D, the initial inclination with respect to the equator is nearly zero and therefore the torque due to the oblateness (J_2) is nearly zero. The remaining, and therefore dominant, gravitational torques are due to the sun and moon. These forces will cause the node to regress uniformly with respect to the ecliptic plane. The inclination will remain roughly constant with respect to the ecliptic plane but not constant with respect to the equatorial plane. For example, if we initially choose the inclination with respect to the ecliptic at 23.5 degrees and choose 3.0 degrees (decreasing) with respect to the equator, its inclination with respect to the equator will decrease about 0.9 degrees/year until a zero degree angle is reached. The inclination will then gradually increase at a rate of 0.9 degrees per year for several years. After there has been a significant inclination buildup, however, the torque due to J_2 will increase and will act to halt the rate of inclination increase. This time history of the inclination behavior with respect to the equator is shown in Fig. 2.

The North/South stationkeeping of a geostationary satellite is quite expensive. If the inclination is to be maintained near zero, a 54 meter/sec per year velocity change is required.

With no stationkeeping, a geostationary satellite will undergo a slow

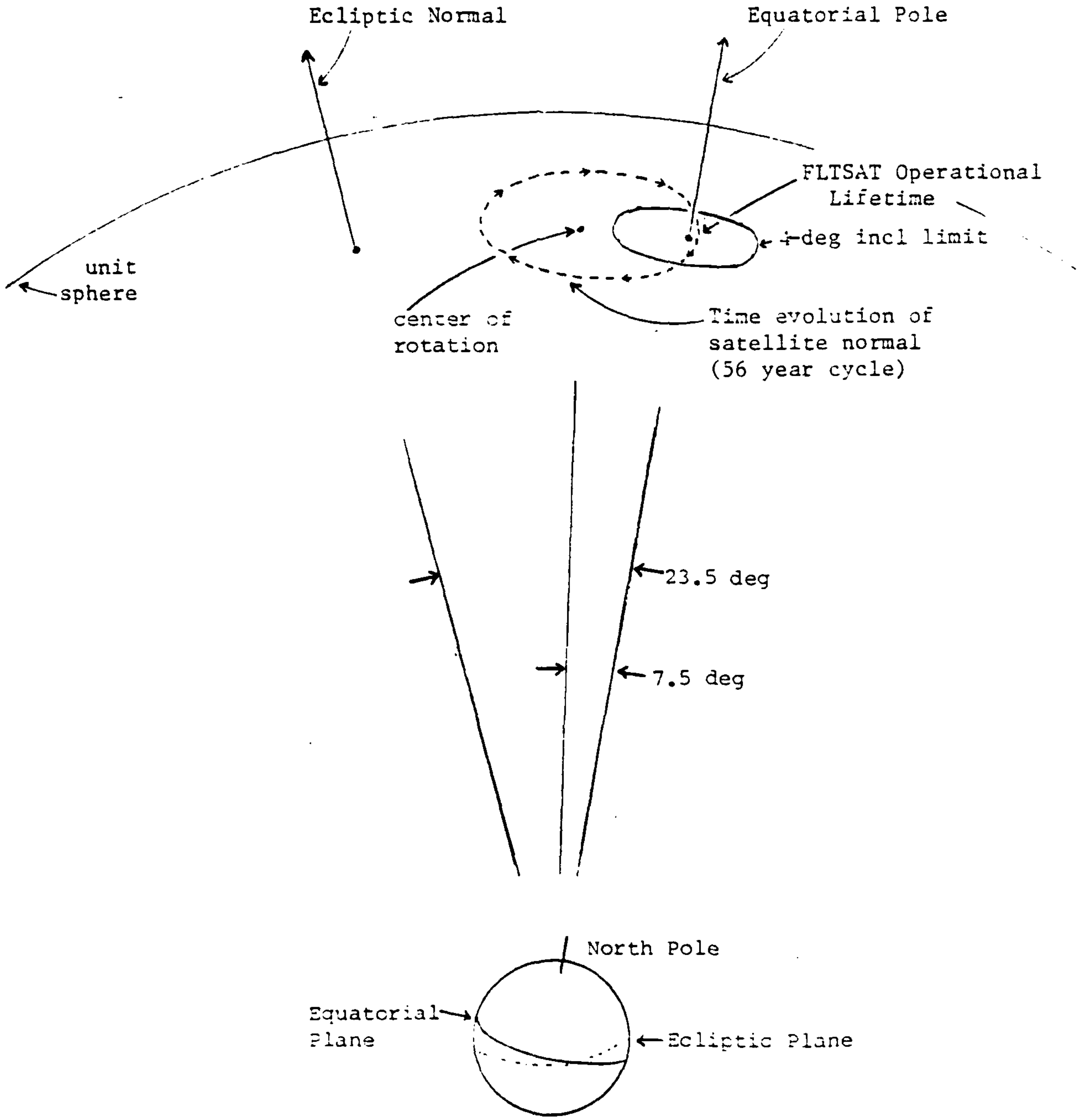

Figure 2. Generic inclination behavior of a geostationary satellite vs. time

east-west oscillation [2] [3] with a period of about 850 days. The half-amplitude of the fluctuation will equal its initial distance from the nearest stable equilibrium point. This east-west motion is due to weak longitude-dependent forces that "push" in the same direction for long periods of time. Table 1. shows the accelerations experienced for FLTSATCOMS 6391-6395 as a result of these longitude-dependent accelerations. East/West station-keeping fuel requirements are almost negligible as compared to the North/South requirements.

TABLE 1. E-W Stationkeeping Requirements (Earth's geopotential only)

Satellite	6391	6392	6393	6394	6395
Longitude(deg)	100W	72.5E	23W	172E	45W
E-W Accel(m/sec x 10(-8))	0.72	0.80	1.96	1.90	4.33
DV/year(m/sec per year)	0.23	0.25	0.62	0.60	1.36

The short periodic radial fluctuations experienced by satellite in a geosynchronous orbit can be summarized as follows. The radial fluctuation due to the oblateness effect (J_2) is:

$$DR \cong \left(\frac{1}{4}\right) a\, J_2 \left(\frac{R_e}{a}\right)^2 \sin(i)^2 \cos(2Up)$$

The radial fluctuation due to the sun is of the order of:

$$DR \cong a \left(\frac{Mu_s}{R_s^3}\right) / \left(\frac{Mu_e}{a^3}\right) \cos(2*S)$$

The radial fluctuation due to the moon is of the order of:

$$DR \cong a \left(\frac{Mu_m}{R_m^3}\right) / \left(\frac{Mu_e}{a^3}\right) \cos(2*S)$$

where

a: Semimajor axis

Mu_s: Solar gravitational constant

Mu_m: Lunar gravitational constant

Mu_e: Earth gravitational constant

R_s: Distance to the sun

R_m: Distance to the moon

i: Orbital inclination

J_2: Earth oblateness

Up: Argument of latitude

S: included angle between the earth and the third body as measured from the earth.

R_e: radius of earth

We can now compute the twice-per-orbit half amplitude fluctuations due to the three major perturbing forces on a synchronous orbit. From the above formulae it is calculated that the radial fluctuation due to J_2 can be at most 260 meters for a synchronous polar orbit. It decreases to zero as the inclination goes to zero. The radial fluctuation due to the sun is of the order of 310 meters whereas the radial fluctuation due to the moon is twice or nearly 670 meters.

3. Ephemeris Element Set

The equinoctial element set is to be used by the FLTSATCOM EHF Package (c.f. [4],[5],[6]). This element set is free of the singularities that plague the Keplerian element set at near-zero eccentricity and inclination. The equinoctial elements are related to the more-familiar Keplerian elements by:

$$
\begin{aligned}
a &= \text{semi-major axis} \quad \text{(earth radii)} \\
h &= e \sin(w + \Omega) \\
k &= e \cos(w + \Omega) \\
p &= \tan(i/2) \sin(\Omega) \\
q &= \tan(i/2) \cos(\Omega) \\
\text{lambda} &= M + w + \Omega \quad \text{(revolutions)}
\end{aligned}
$$

where:

e = eccentricity
w = argument of perigee
Ω = right ascension of the ascending node
i = inclination
M = mean anomaly at epoch

Each element in the equinoctial element set is to be expressed as a mean element time history. The time history for each element is to be expressed as a low-order polynomial [2] plus trigonometric expression:

$$E = A_o+A_1*T+A_2*T^2+E_o+E_1*(t-t_b)$$
$$+B_1*\sin(1*Z_m)+C_1*\cos(1*Z_m)$$
$$+B_2*\sin(2*Z_m)+C_2*\cos(2*Z_m)$$
$$+B_3*\sin(3*Z_m)+C_3*\cos(3*Z_m)$$
$$+D_2*\sin(2*Z_s)+F_2*\cos(2*Z_s)$$

where:

A_j = polynomial coefficients. (j=0,1,2).

E_j = a priori values of a, lambda, and d(lambda)/dt which is expressed in rev/day. (j=0,1).

B_j = lunar trigonometric coefficients. (j=1,2,3).

C_j = lunar trigonometric coefficients. (j=1,2,3).

D_2 = solar trigonometric coefficient.

F_2 = solar trigonometric coefficient.

T = $(t - t_b)/t_e$

t_b = epoch

t_e = lifetime of element set (nominally 30 days).

Z_m = $(t - t_b)$ * (lunar angular rate).

Z_s = $(t - t_b)$ * (solar angular rate).

MSJD = MILSTAR Julian Date = Julian Date - 2,446,000.5

The element set is referenced to the true equinox and equator of date reference frame as per [5]. The coefficients A_j (j=0,1,2), D_2, and F_2 cannot be independently determined for a short ephemeris (two months or less) and therefore D_2 and F_2 were set to zero. Their effects are absorbed in A_j. The coefficients F_2 and D_2 are reserved for future use should a six month time of validity be required.

4. Theory of Orbit Determination

The mathematics required to fit/determine the coefficient set to the data set are quite simple and straightforward and will not be elaborated on here. For a more-detailed discussion of this subject see references [7],[8]. The "data" are the x-y-z positional vectors as provided by the SCF (or reconstructed) in the form of state vectors every 30 minutes. An abridged listing of such a file is shown in Table A1 in Appendix A. We arbitrarily use the position vectors at intervals of 7.5 hours over the 30 day time span. Considering the endpoints, this amounts to 97 position vector data points or 291 scalar data points. A sample listing of this file is shown in Table A2. This is more than enough data to solve for the 48 separate coefficients and avoid any aliasing effects that may arise in the use of undersampled data. Table 2. shows the breakdown of the number of coefficients per element for each of the six equinoctial elements.

TABLE 2. Coefficients per element

Element	Number of coefficients in solution
a:	3
h:	9
k:	9
p:	9
q:	9
l(lambda):	9
	48 total

To determine the coefficients, we employ an unweighted least squares batch method. This method is summarized by the so-called normal equations.

$$X_{new} = X_{old} + (Apr + H^T H)^{-1} H^T * (Y - H*X_{old})$$

where:

X_{old_i}: initial estimate of the coefficient array before inclusion of the measurements. (i=1,2,3, ... ,48)

X_{new_i}: updated estimate of the coefficient array after inclusion of the measurements. (i=1,2,3, ... ,48)

H_{ij}: sensitivity matrix - the sensitivity of the ith predicted measurement to a change in the jth component of the coefficient array. "H" is a 291 x 48 array.

Apr: small a priori information matrix.

Y_i: measurement vector. (i=1,2,3, ... ,291)

The lengthy sensitivity matrix "H" and the numerical integration is only computed/performed once. In order to stabilize the solution iteration process for short data spans, a small a priori weighting matrix "Apr" is added to the H^TH information matrix. This will guarantee a solution for short data spans of several days or less. We choose "Apr" such that for long data spans, i.e., a month or more, the tracking information matrix H^TH will be much larger than the "Apr" array and will thus be ignored.

The coefficient array is determined in three iterations of the normal solution. A 4x4 model of the earth's geopotential plus third body luni-solar effects are used to perform the numerical integration. The solar radiation pressure is also included in the model. This perturbation model is very simple to implement in a program of this scope and appears to work well in this application. A Cholesky decomposition is used to rapidly solve the normal equations.

5. Coefficient Representation on Paper Tape

The terminal is designed to initially input the coefficient set from a five-level paper tape. This allows the terminal to "bootstrap" its initial conditions. The coefficient set is encoded upon this tape in a very particular format [9],[10]. The format is specified by several particulars. These include:

1. A tape can contain more than one element set. The sets are not delimited, ie., there is no separator between sets. Each tape does contain a leader and trailer section, however. The leader is the sequence

   LF,LF,LETTERS SHIFT,A,SPACE,E,P,H,E,M,R,S,CR,CR,CR,LF,CR

   and the trailer is

   CR,CR,LF,LF,LF,LF,LF,LF,LF,LF,N,N,N,N

where LF is the linefeed character, and CR is the carriage return character. [5]

2. The coefficients are stored in a particular order, as specified in [5].

3. Each real number in the tape is stored as a two's complement, fixed point number. Each number occupies a specified number of bytes, and each number has a specified range. The range is determined by specifying the power of 2 that the least significant bit(LSB) represents [5].

4. The numbers are stored least significant bit first.

5. Once the data stream representing the data is formed as a series of 208 bytes, the data is converted into BAUDOT characters by extracting each nibble(4 bits), interpreting the 4 bits as a number from 0 to 15, and converting that binary number into a BAUDOT character by the simple progression 0=A,1=B ..,15=P. Thus each byte is translated into two BAUDOT characters [10].

6. At least every 60 BAUDOT characters there should be carriage control characters(eg., (LF, CR, CR), or (CR, CR, LF) [10].

7. For each 16 bit word, the nibbles are sent most significant nibble first. Although the data is originally ordered least significant bit by coefficient boundaries, once it has been converted to the "pseudo-hex" BAUDOT characters, the characters within a 16 bit word boundary are sent most significant nibble first [10].

8. A CRC-16 checksum is calculated for each coefficient set. If, in the same message, the checksum for two consecutive sets happens to be identical(an unlikely event), two bits in the information bytes at the beginning of the second set are inverted, and the checksum is recalculated. This prevents any two consecutive data sets from having the same checksum [5].

9. All of the bits in the yaw schedule numbers bytes are set to 1

10. All of the yaw transition times are set to 0.0

11. All of the Station times are set to 1.0

Due to the amount of processing that is done to the data in order to put it into the final tape format, it is important to understand the exact order of the operations involved, and the exact range of data that each operation acts upon. The following discussion will describe in a step-by-step manner how the program works with the data.

1. The coefficients are computed by the major portion of the program. These coefficients are passed as an array of 80 real numbers(48 non-zero coefficients and the epoch and lifetime) to the formatting part of the

program.

2. The coefficients are stored in a real array corresponding to their positions on the tape. Because the FEP uses the same format as the MILSTAR message, there is a considerable amount of data in the message that is not used by the FEP.

3. A few questions are asked of the operator about information specific to the satellite and the data set. These questions include the satellite number, expected update interval, the current leap second offset, and the month of the next leap second increment.

4. The data from the questions is compacted into bit fields in the two information bytes.

5. The numbers in the real array are converted one at a time into the two's complement fixed point format, and the results are stored into a byte array. The two information bytes and the three bytes representing the yaw schedule numbers are also transferred to the byte array. The numbers are stored least significant bit first within each coefficient field.

6. The cyclic redundancy check (CRC-16) is now calculated. The program uses an implementation of this algorithm designed for rapid evaluation in software, rather than hardware [11].

7. If this is the first satellite set calculated, the program continues. If it is not the first satellite set, the program compares the computed CRC value with that of the previous satellite set. If they are identical, the two check sum bits in the information bytes are complemented, and the CRC is re-evaluated.

8. Each byte is now split into two nibbles, and each nibble is converted into its BAUDOT representation. Thus a nibble with all zeros is the number 0, which is to be represented by the BAUDOT character A. The BAUDOT character A has the value 3 on tape (that is, bit numbers 1 and 2 are set). If the program is to be run on a computer which is hard-wired to a tape punch, it would depend upon the interface between the punch and the computer whether the character 'A' would be sent to the terminal, or the value 3 would be sent. At present the question is moot, as we do not have a 5-level paper tape punch attached to a VAX. At this point in the program, however, the value 3, representing the character 'A', is stored. That is, 0 = A = 3.

9. At this point we have an array of 416 bytes containing 416 nibbles of information, one nibble per byte(a byte is the smallest addressable piece of storage on a VAX).

10. We now have an array of 416 bytes containing 416 nibbles of BAUDOT values, stored least significant nibble first per coefficient. The array is now reordered most significant nibble first, 16 bit word at a time. Effectively, each 4 nibbles has its order reversed. Thus the first 8

nibbles, representing two 16 bit words, are reordered from 1,2,3,4,5,6,7,8 to 4,3,2,1,8,7,6,5.

11. The program is now finished with this satellite set. If there are more satellite sets to process, the program continues to process them, adding their sets to the array of nibbles. There is no separator between the sets, their fixed length serves to identify them. When the last satellite has been processed, the program adds the leader and trailer codes, and outputs the complete tape.

12. Because currently the program cannot output directly to paper tape, the output array is converted back from the BAUDOT internal representation to a standard ASCII representation, and prints out the output in a readable form. Thus, in the output, a printed 'A' represents the BAUDOT character 'A', which stands for a nibble containing all zeroes.

13. The output is printed with the leader and trailer on separate lines, and the data sets printed out 52 characters per line, with each line followed by a LF, CR, CR. For legibility in copying, the characters are separated by the character '|' every ten characters. The control characters are represented as :

    f - linefeed
    r - carriage return
    l - letters shift

    With 52 characters per line, there are thus 8 lines per data set. Note that the LF, CR, CR , represented on the printout by "f, r, r", are meant to be part of the paper tape.

    An example of the output tape printout is show in table A6 in Appendix A.

    A standalone version of the coefficient conversion routine is available. It uses as input any number of coefficient files(equivalent to "FS91.CFF" in the examples). This allows production of a paper tape from a run which produced a coefficient file, but at the time of the run the paper tape option was not chosen.

6. Program Operation and Description

The main driver program is arranged into 11 separate sections. These are nearly independent from each other and perform separate tasks depending upon which option is selected.

Choose program options "A","B","C","D" or "E". These five options are;

A: The 30-day time-position file is available on the disk in the correct format. There is no need to reconstruct the lengthy ephemeris.

B: Requires the satellite state vector at epoch and at the 30-day endpoint. The ephemeris will be reconstructed from these two state vectors. It is assumed that this will be the primary mode of operation of the program.

C: Requires the satellite state vector at epoch only. The ephemeris will be reconstructed this single state vector. Somewhat larger representation errors as compared to Option "B" will be realized.

D: Compute a satellite look-angle file from a user-specified ground site.

E: Output psuedo-hex characters for paper tape and stop program.

The 11 sections are:

1. Enter state vector at the initial(epoch) time.
2. Enter state vector (position component only) at the 30-day final time.
3. Numerically integrate the initial state vector over the 30-day time span.
4. Compare the position obtained via the numerical integration with the SCF listing at the 30-day endpoint.
5. Correct the velocity of the initial state vector to force position agreement at the 30-day endpoint.
6. Using the corrected state vector, produce a new time-position history for the 30-day time span.
7. Fit the 48 polynomial coefficients to this corrected solution.
8. Write results to disk. This includes the coefficient array in two separate forms.
9. Convert coefficient array into paper tape format.
10. Using the just-determined coefficient file, produce an azimuth-elevation, range, and range rate file for a station of the user's choice.
11. At end of run, output paper tape file, if requested.

Figure 3 describes the overall program flow chart. If Option "A" is selected, it is assumed that a 30-day ephemeris file is available in the format

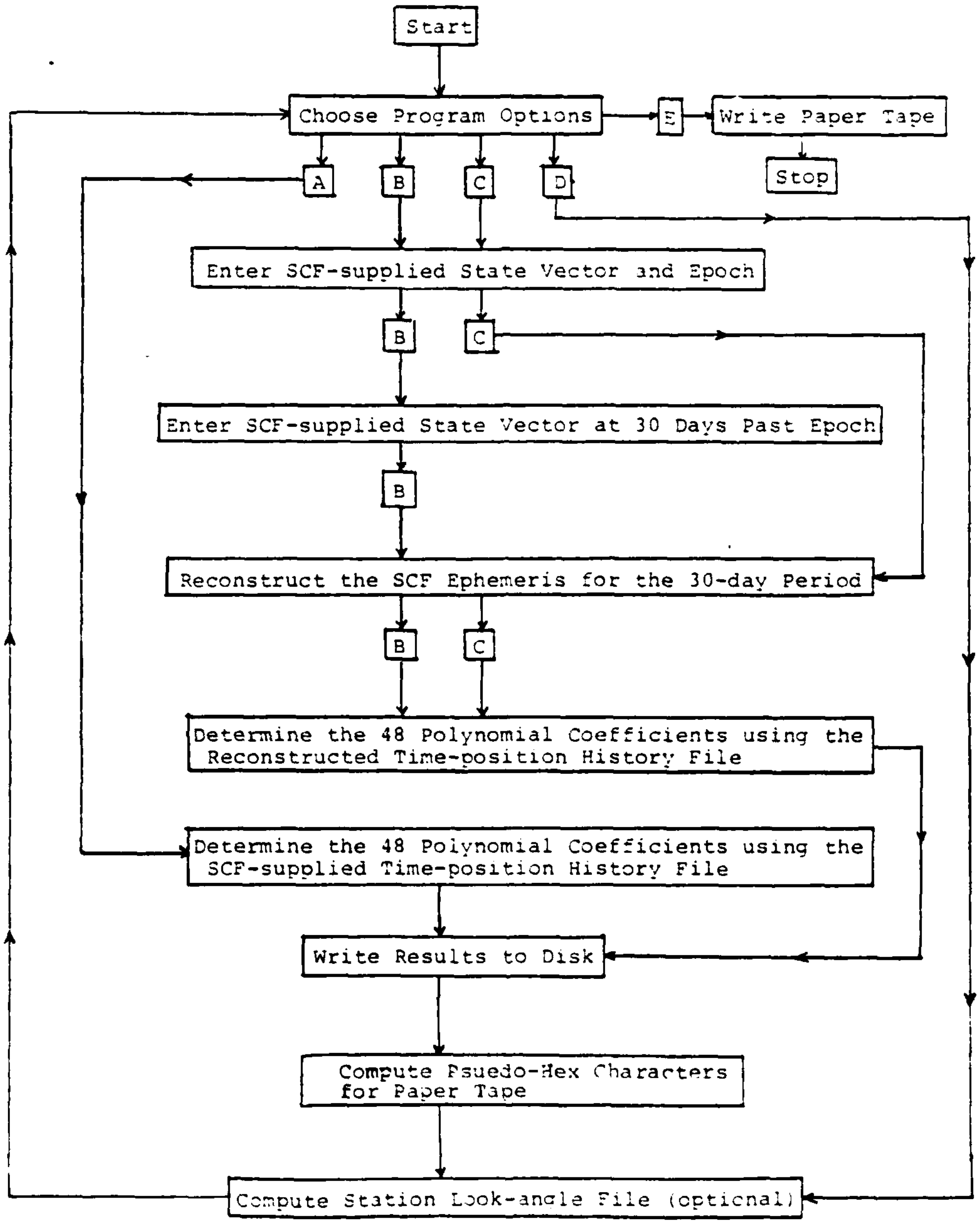

Figure 3. Program Flow Chart

shown in Table A2, Appendix A. There is no need to manually enter the state vector and epoch since the state is uniquely defined in each entry of the ephemeris file. The epoch will correspond to the time of the first entry in the file. After Option "A" is specified the program then proceeds directly to the section where the ephemeris file is to be read and the coefficient element set is determined. The user will then be queried for the name of the SCF ephemeris file which is assumed to be available. After this file has been read and after some lengthy computations have been performed, the user will again be queried for the output file names (two separate files) of the coefficient array which are to be saved to the disk. A sample of the terminal session using option "A" is listed in Appendix B. All user terminal entries are in boldface in this listing.

Option "B" assumes that the 30-day time position file is not available, but that such information is available in the form of a computer listing. The program will query the user for two state vectors from that listing, i.e., the state vector at epoch and again at 30 days past epoch. The ephemeris will thus be reconstructed from these two state vectors and an element coefficient set will be determined from the reconstructed ephemeris. The user need not physically possess the ephemeris listing since the required information (7-11 numbers) could be obtained via the telephone. A sample computer run using option "B" is listed in Appendix B. It is assumed that Option "B" will be the primary mode of operation of this program. A shorter time span than the recommended 30-day time can be used to fit the coefficients however it should be pointed out that poor results may be encountered when using a time span of two weeks or less regardless of the amount of data. This is due to the difficulty in separating the monthly effects from those arising from the quadratic effects. Please use the recommended 30-day time span.

Option "C" is similar to "B" except that the state vector at 30 days past epoch is not required. The 30-day ephemeris will be reconstructed solely from the initial state vector. Larger errors in the reconstructed ephemeris will naturally result. Appendix B. lists a sample run.

Option "D" allows the user to immediately compute a ground station look-angle file. The user is immediately asked for the input file name of the already-computed coefficient element set. The user is then queried for the start/stop times, print interval, and station location. The user will next be queried for the name of the output file which will contain the range, range rate, azimuth, and elevation time history from a specific ground site of the user's choosing. A example of the use of option "D" is shown in Appendix B.

Option "E" ends the input loop and, if a paper tape was requested, outputs a file for copying to paper tape.

The coefficient array is the primary program output when using option "A","B". or "C". It is written to the disk in two separate forms. The first form is required as input to the standalone formatting program whereas the second form is an easily readable version for archival purposes. Examples of both are shown in Appendix A, Tables A3 and A4 respectively. Table A5 gives an example of the look-angle file produced by Option D.

Option "B" or "C" requires about 1 minute 20 seconds cpu time from start to finish (Batch) on a VAX 11/780. Option "A" requires about 30 seconds cpu time since the ephemeris reconstruction is not required. A VAX 11/750 will require about double these times. The quoted cpu times are the times required for batch operation and do not include the time necessary for the user enter the required data. The program length is about 310K bytes. Most of the required storage (about 210K bytes) is taken up by the sensitivity matrix "H" as it is dimensioned 307x78. If this program size is considered excessive for a particular installation, the measurement vector can easily be reduced from the 97 vector data points presently used to a lesser amount with little loss in accuracy. To reduce storage requirements to a minimum, some of the large arrays may be equivalenced to share space with the "H" array.

In order for the user to become familiar with the operation of the program, there is a canned test available for use. If this feature is desired, the user should answer "Y" to the appropriate query and answer all subsequent queries with a carriage return. This applies to options "A", "B", and "C" only. When using option "D" the user must specifically answer all remaining queries.

The complete program consists of a driver "NESP.FOR" and a large subroutine library "FS.FOR". Supporting data files include the SCF supplied file(called "FS91.SCF" in the examples), the output coefficient file (called "FS91.CFF" in the examples), and the paper tape file(called "FS91.TAP" in the examples). In order to run the program the user must enter the following VMS commands:

```
$FOR NESP.FOR
$FOR FS.FOR
$LINK NESP,FS
$RUN NESP
```

Options "B" and "C" do not require any additional supporting files since the required input is entered via the keyboard. If Option "A" is exercised and the canned test case is to be run, the 97 point state vector file, "FS91.SCF", is required and is supplied with the software package for the purpose of running test cases. An abridged listing of this file is shown in Table A2, Appendix A. If the canned test case in not used, the user must supply the time-position history file equivalent to "FS91.SCF".

If Option "D" is exercised separately, the coefficient file similar to

"FS91.CFF" is required. The file containing the coefficient array, "FS91.CFF", is included should the user wish to run this test case. This user-named file will be the normal output to the coefficient determination process.

The library file, "FS.FOR", consists of several dozen Fortran subroutines. These consist of some new routines especially designed for this application and many others that we have using for many years in other related programs. We made no special effort to optimize this latter group for this FLTSATCOM application.

7. Discussion and Results

Since the polynomial series that represents each equinoctial element does not include short periodic effects, the resulting ephemeris representation can be expected to have errors on the order of several hundred meters. These short periodic effects are mainly due to three sources. They are; earth oblateness (J_2), lunar, and solar effects. For a near-zero inclination orbit the short period effects due to J_2 are diminished. However, the lunar-solar effects are quite pronounced, especially when the third-body effects are in phase, i.e., when the earth, moon, and sun lie on a straight line. The near-polar orbit experiences a significant twice-per-orbit radial and tangential fluctuation due to J_2 in addition to the lunar-solar effects. The near-equatorial orbit, e.g., FLTSATCOM 6391, experiences strong short periodic effects due to the lunar and solar third body gravity effects. A correction term [1] could have been added to the polynomial series to account for these short periodic effects; however, neglecting these terms still results in quite acceptable performance unless sub-kilometer range accuracy is required.

There are no significant small monthly effects on the semi-major axis "a" due to the sun and moon, hence these coefficients are set to zero. The longitudinal-dependent gravity terms (i.e., J_{22}, J_{33}, J_{44} etc.) in the earth's geopotential field will cause long period changes in the semimajor axis. These resonance effects are accounted for in the coefficients A1 and A2 that describe the mean element behavior of the semimajor axis "a". These orbits are well above the drag region.

To avoid biases, we fit the coefficient array to the position vectors directly. We could produce the six individual element time histories from the SCF state vector file and fit the coefficients representing each individual element to them. This is probably a faster method than the direct method we have described. However, unless short periodic effects are accounted for, small positional biases will result when the ephemeris is reconstructed on the terminal. This is due to some missing coupling effects that would be present if the short periodic terms were present. Our method eliminates any possibility of a positional bias, however, the individual time-element histories may have biases. Since our desired end product is a correct time-position history and not necessarily a bias-free time-element history, we choose to fit the positional data directly.

In fitting the coefficient element set to the 6391 ephemeris, we included the time-position history for 30 days taking a position vector every 7.5 hours. This amounts to 91 vector data points (x-y-z) or 291 scalar points. Fig. 4 describes the results.

It has never been intended that the coefficient element set be used outside the 30-day fitting span although we did extrapolate for an additional 30 days to determine the additional time of validity if any. The results show that, although the position errors grow from the 1.5 kilometer level to over 10 kilometers, the range errors do not exceed 4 kilometers. Fortunately the position errors do not map directly into range errors on a 1:1 basis. This means that the coefficient element set can be used for an additional 30 days without serious degradation. Similar results are obtained for 6392 and are described by Fig. 5.

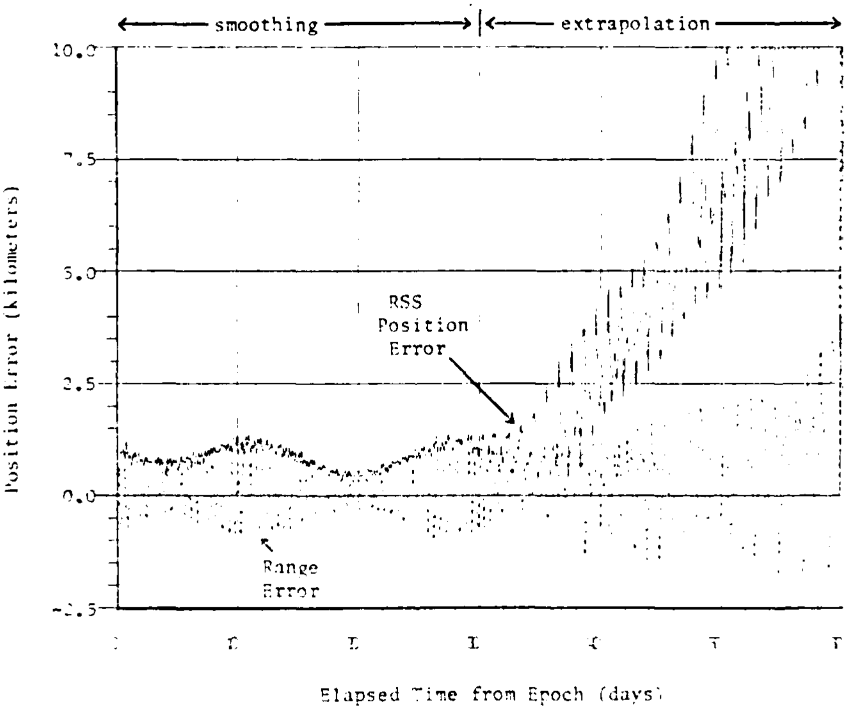

Figure 4. Coefficient element representation of FLTSATCOM 6391 using an SCF supplied ephemeris

We simulated a high-inclination orbit (85 degrees) by integrating a

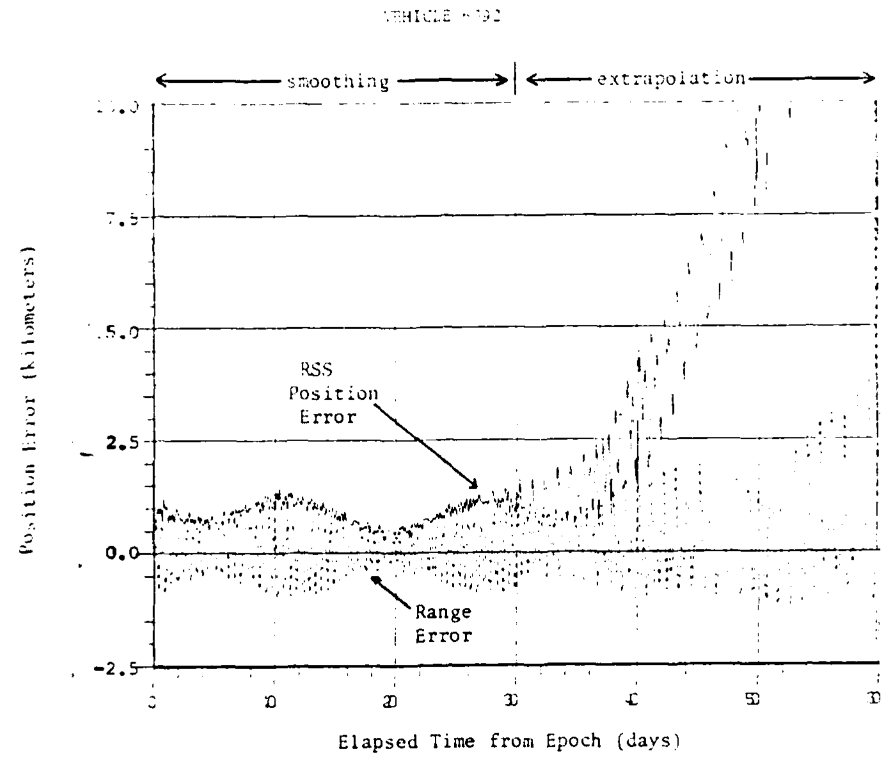

Figure 5. Coefficient element representation of FLTSATCOM 6392 using an SCF supplied ephemeris

geosynchronous orbit of our choosing for 60 days and in effect constructed an ephemeris. These results are shown in Fig. 6. The short periodic effects (due to J_2) are somewhat higher and this is clearly shown by the slightly higher errors in the mean element representation. The range errors remain below 1.5 kilometers during the 30-day smoothing segment but approach nearly 10 kilometers during the additional 30-day extrapolation. Even so, the extrapolation is valid for the additional 30 days should a new coefficient set not become available in time.

We should point out that we are describing errors with respect to the integrated ephemeris and not with respect to the "real" time-position history of the satellite. The integrated ephemeris will have additional errors with respect to the "real" ephemeris (which nobody can really determine). These additional errors will probably be equal to or higher than those produced by the ephemeris compression procedure. In the MILSTAR environment, more accurate range predictions will be required than needed in the FLTSATCOM terminal testing era. Naturally, a more accurate integrated ephemeris than the one used here will be required in order for the coefficient determination algorithm to be consistent. In other words, it makes no sense to fit the integrated ephemeris to several hundred meters or less if its inherent accuracy is several kilometers or more.

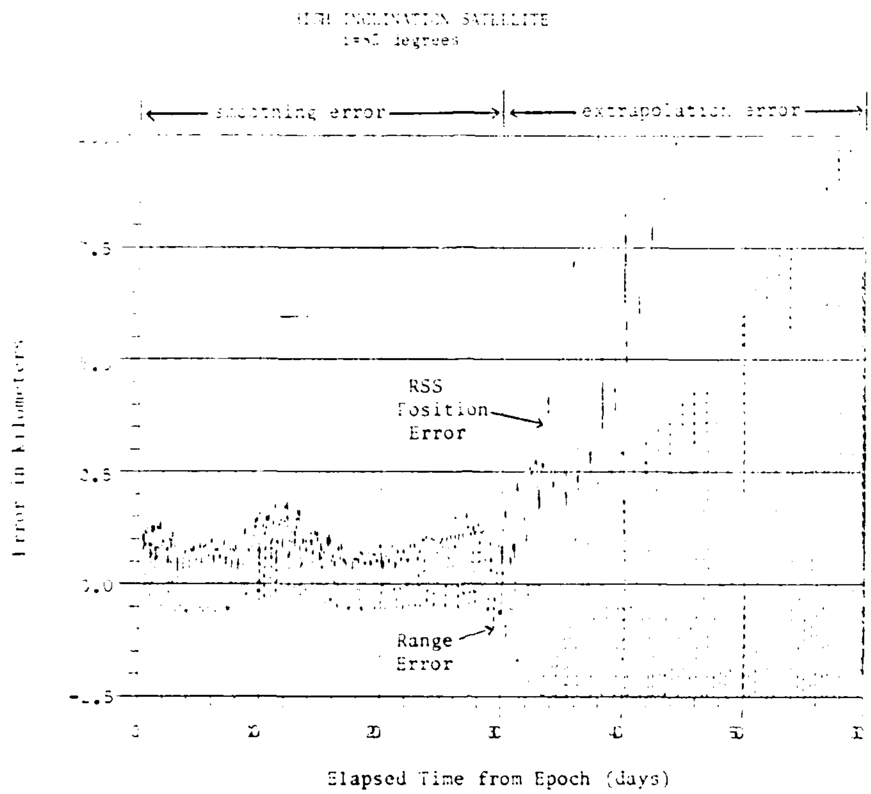

Figure 6. Coefficient element representation of a high-inclination geosynchronous orbit

We also ran the backup option "B" for the above three cases. The results for 6391 are shown in Fig. 7. The position errors grow to nearly the 5 kilometer level, however, the range errors remain in the 1 to 2 Km region. Even when extrapolating the ephemeris for the additional 30 days the range errors still appear to remain within the 10 Km. range. As before the same behavior was seen for 6392 (Fig. 8) and the high-inclination case.

We also fit a coefficient-element set to the full 60-day ephemeris of 6392. These results are shown in Fig. 9. The errors with respect to the integrated trajectory appear to be about double that of the 30-day fit. We could not extrapolate the element set beyond 60 days since the ephemeris limit was reached, however, this appears to be preferable to fitting for 30 days and then extrapolating for the additional 30 days. This procedure is only recommended if it is anticipated in advance that a new coefficient element set cannot be generated every 30 days.

There appears to be some slight truncation error when the coefficient array is transformed into the specified format. Fig. 10 describes the ephemeris error for 6391 when the formatted coefficients are used to reconstruct the ephemeris. Fig. 11 shows the high-inclination case.

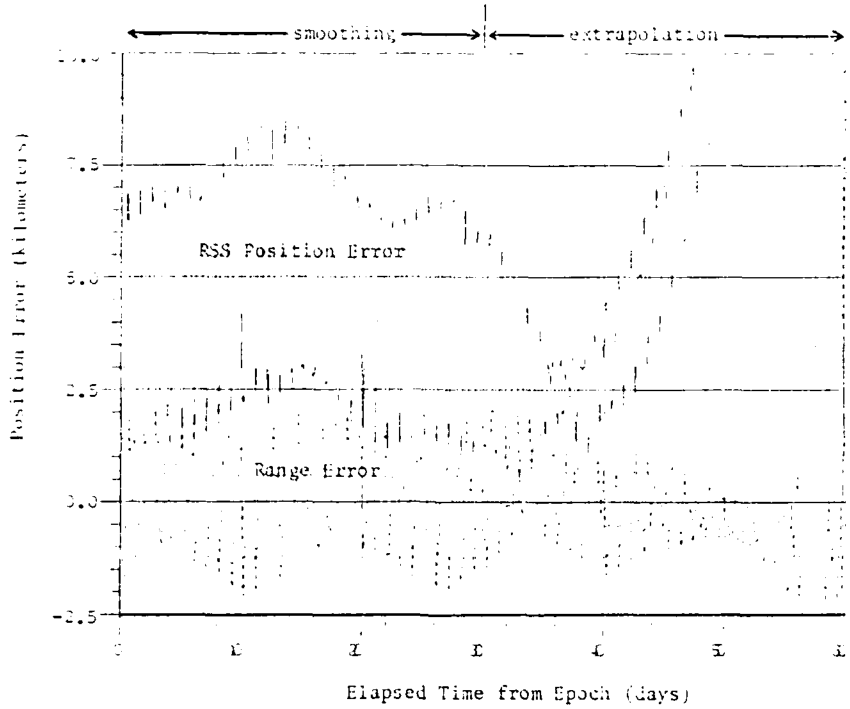

Figure 7. Coefficient element representation of FLTSATCOM 6391 using a reconstructed ephemeris.

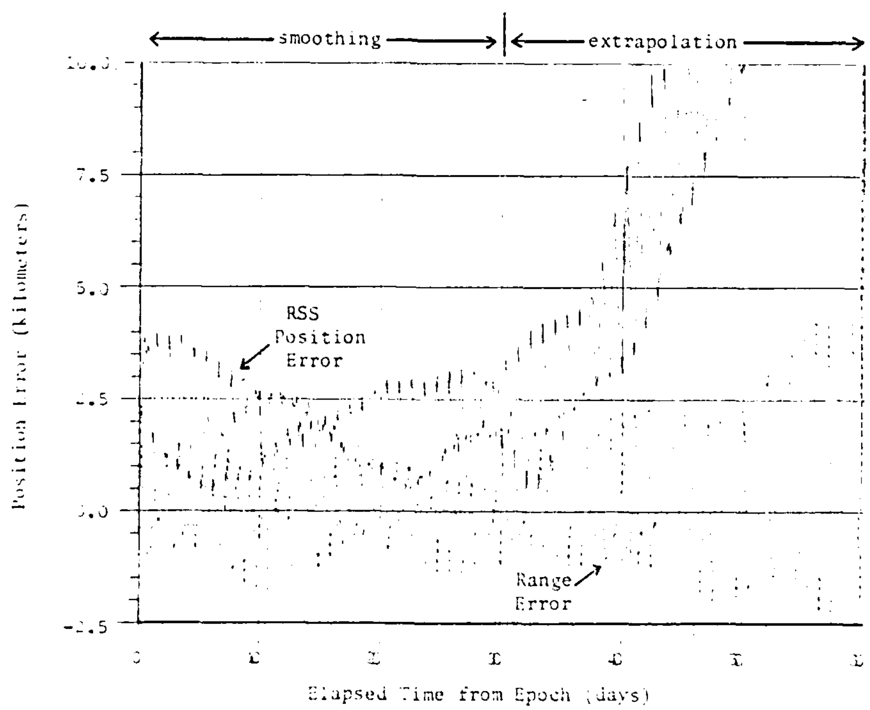

Figure 8. Coefficient element representation of FLTSATCOM 6392 using a reconstructed ephemeris.

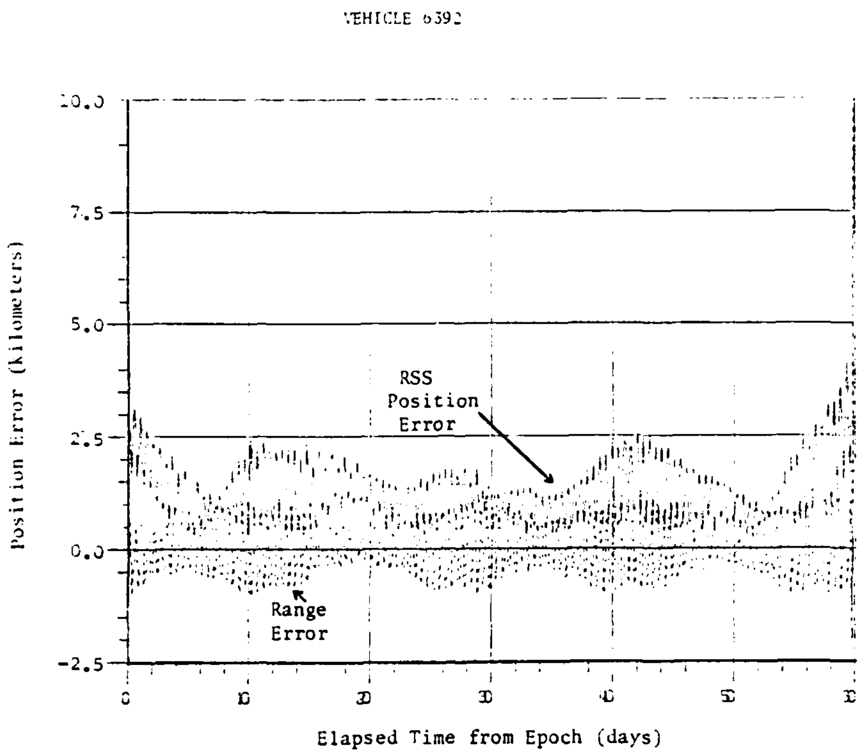

Figure 9. Coefficient element representation of FLTSATCOM 6392 over a 60 day time span

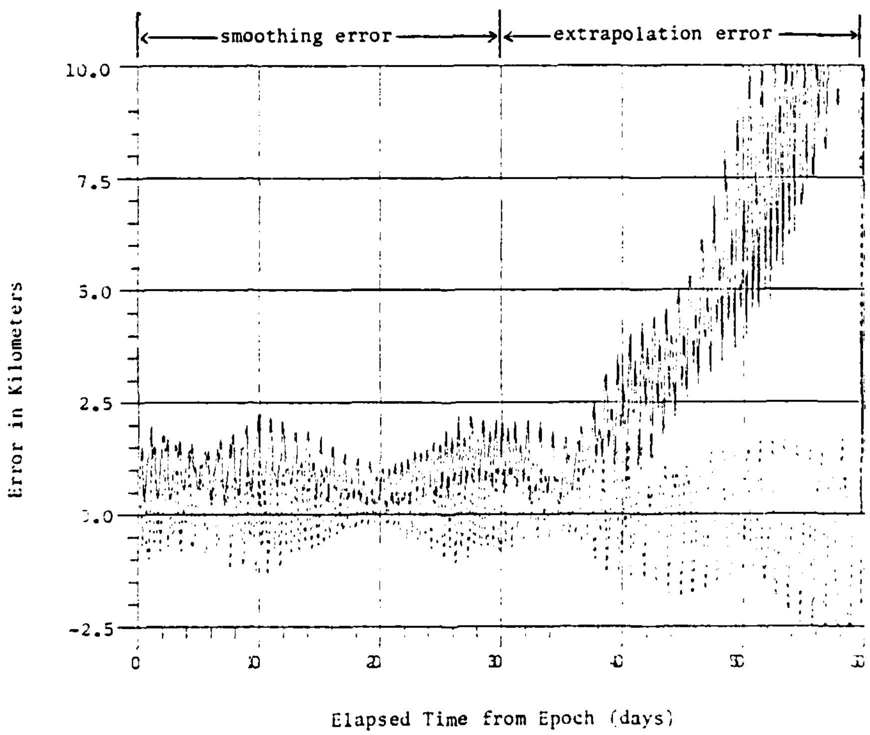

Figure 10. Formatted coefficient element representation of FLTSATCOM 6391. (Compare with Fig. 4)

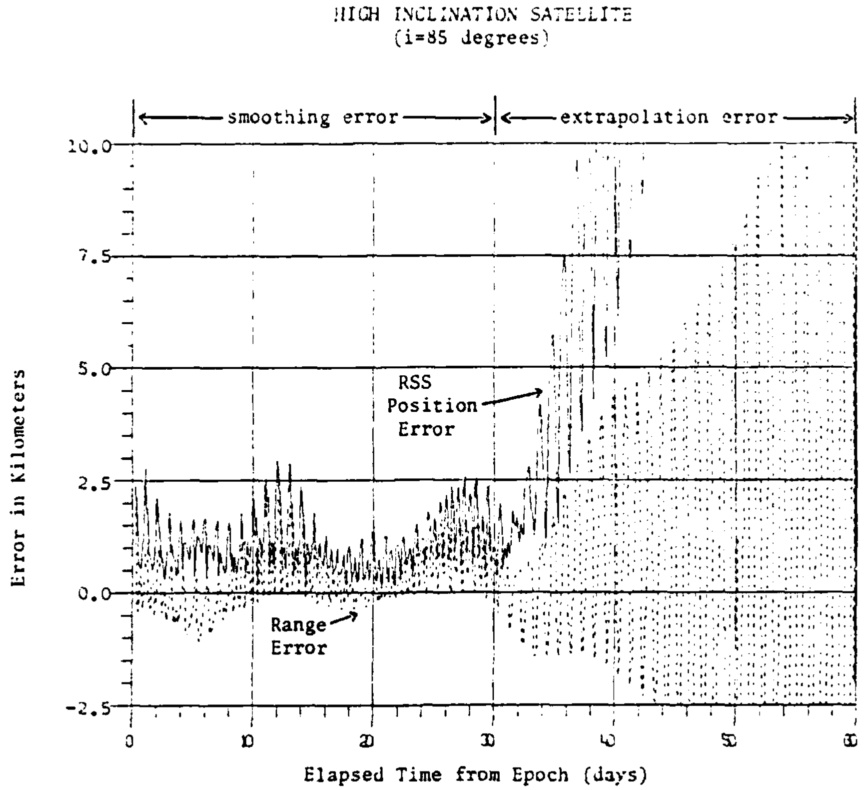

Figure 11. Formatted coefficient element representation of a high-inclination geosynchronous ephemeris. (Compare with Fig. 5)

References

1. Johnson, P.W., Work Task Statement

2. Kamel, A.A., "Synchronous Satellite Ephemeris Due to Earth's Triaxiality and Luni-Solar Effects". AIAA/AAS Astrodynamics conference, Palo Alto, CA. No. 78-1441, August 7-9, 1978.

3. Srivastava, S., "Perturbations of a Synchronous Satellite Due to Geopotential", Lincoln Laboratory Technical Note 1974-8., February 1, 1974.

4. "Milstar Ephemeris Representation Analysis", Progress Review, prepared for Lockheed Missiles & Space Co., Sunnyvale, CA, prepared by The Charles Stark Draper Laboratory, Inc., Cambridge, Mass., 02139, March 29, 1984.

5. Interface Revision Notice (IRN) #1005-37b. ICD MLST-LL-ICD006-00-0.

6. FEP/MILSTAR Ephemeris Representation Implementation, Report No. TOR-0084(4404-22)-01, B.E. Baxter, 13 August 1984, Preliminary Issue.

7. Bryson, A. and Ho, Y., Applied Optimal Control, Hemisphere Press, New York, 1976.

8. Gelb, A. (ed), Applied Optimal Estimation, The MIT Press, Cambridge, MA, 1974.

9. Johnson, P.W., NRL Technical Memorandum 7550-378A, 9 Oct 1984

10. Johnson, P.W., NRL Technical Memorandum 7550-192A, 10 June 1985

11. Perez, A, "Byte-wise CRC Calculations", IEEE Micro, June, 1983

8. Appendix A. Sample Input/Output File Formats.

TABLE A1. Sample Listing of the SCF-supplied Ephemeris File

JNO= F91085A 6391 EPHEM ERIS, ANGLES, AND TWINKS 10DEC84 PA

VEHICLE F91DEC11/ 6391 REV NUMBER 2501 GMT DATE 11 DEC 1984 EPHEMERIS DATA - EARTH-FIXED/INERTIAL SPHERICAL

	UNIV HR	MIN	TIME SEC	SYSTIME SEC	GEOD LAT DEG	LONGITUDE DEG	ALTITUDE NM	RT ASCEN DEG	DECL DEG	FL T PATH DEG	INER AZ DEG	RAD DIST NM	INER VE FT/SEC
	0	0	.000	0	2.7988S	100.7616W	19320.4310	339.1299	-2.7960	.0025	91.5661	22764.3210	10088.47
	0	30	.000	1800	2.9799S	100.7527W	19320.5756	346.6593	-2.9769	.0028	91.1864	22764.4619	10088.38
	1	0	.000	3600	3.1097S	100.7418W	19320.7320	354.1907	-3.1066	.0030	90.7863	22764.6155	10088.29
	1	30	.000	5400	3.1859S	100.7295W	19320.8939	1.7235	-3.1827	.0031	90.3725	22764.7757	10088.20
ML	1	56	35.732	6995	3.2077S	100.7182W	19321.0377	8.4020	-3.2044	.0031	90.0000	22764.9190	10088.13
	2	0	.000	7200	3.2073S	100.7167W	19321.0559	9.2569	-3.2041	.0031	89.9522	22764.9373	10088.12
	2	30	.000	9000	3.1734S	100.7040W	19321.2136	16.7901	-3.1702	.0030	89.5328	22765.0957	10088.05
	3	0	.000	10800	3.0849S	100.6924W	19321.3638	24.3223	-3.0818	.0028	89.1214	22765.2478	10087.99
	3	30	.000	12600	2.9432S	100.6824W	19321.5046	31.8528	-2.9402	.0027	88.7252	22765.3916	10087.93
	4	0	.000	14400	2.7508S	100.6748W	19321.6354	39.3809	-2.7481	.0025	88.3510	22765.5263	10087.89
	4	30	.000	16200	2.5111S	100.6700W	19321.7571	46.9063	-2.5086	.0023	88.0053	22765.6524	10087.86
	5	0	.000	18000	2.2282S	100.6682W	19321.8715	54.4286	-2.2260	.0022	87.6940	22765.7715	10087.84
	5	30	.000	19800	1.9070S	100.6695W	19321.9814	61.9478	-1.9051	.0022	87.4225	22765.8860	10087.82
	6	0	.000	21600	1.5530S	100.6739W	19322.0902	69.4640	-1.5515	.0022	87.1953	22765.9991	10087.81
	6	30	.000	23400	1.1723S	100.6809W	19322.2014	76.9776	-1.1712	.0022	87.0163	22766.1140	10087.79
	7	0	.000	25200	.7715S	100.6900W	19322.3184	84.4890	-.7707	.0024	86.8887	22766.2337	10087.77
	7	30	.000	27000	.3574S	100.7006W	19322.4439	91.9989	-.3571	.0025	86.8144	22766.3608	10087.73
LT	7	55	31.445	28531	.0000N	100.7102W	19322.5585	98.3877	.0000	.0027	86.7943	22766.4759	10087.70
	8	0	.000	28800	.0628N	100.7120W	19322.5794	99.5081	.0627	.0027	86.7949	22766.4968	10087.69
	8	30	.000	30600	.4820N	100.7233W	19322.7253	107.0173	.4815	.0029	86.8304	22766.6418	10087.63
	9	0	.000	32400	.8929N	100.7338W	19322.8801	114.5273	.8920	.0030	86.9203	22766.7947	10087.56
	9	30	.000	34200	1.2886N	100.7428W	19323.0409	122.0388	1.2873	.0030	87.0631	22766.9525	10087.48
	10	0	.000	36000	1.6621N	100.7497W	19323.2029	129.5525	1.6605	.0030	87.2565	22767.1106	10087.39
	10	30	.000	37800	2.0072N	100.7539W	19323.3600	137.0688	2.0052	.0028	87.4970	22767.2633	10087.29
	11	0	.000	39600	2.3178N	100.7553W	19323.5049	144.5879	2.3154	.0025	87.7807	22767.4035	10087.20
	11	30	.000	41400	2.5885N	100.7537W	19323.6297	152.1101	2.5859	.0021	88.1026	22767.5236	10087.11

TABLE A2. Abridged Version of the SCF Ephemeris as used in the Program

yr	mo	dy	hr	mn	sec	sub sat point		altitude	rt ascn	dec	fpa	az	radius	speed
						(deg)	(deg)	(nm)	(deg)	(deg)	(deg)	(deg)	(nm)	(ft/sec)
84	12	11	0	0	0.00	2.7988S	100.7616W	19320.4310	339.1299	-2.7960	0.0025	91.5661	22764.3210	10088.47
84	12	11	7	30	0.00	0.3574S	100.7006W	19322.4439	91.9989	-0.3571	0.0025	86.8144	22766.3608	10087.73
84	12	11	15	0	0.00	3.0797N	100.6908W	19323.3920	204.8167	3.0766	-0.0038	90.9058	22767.2761	10087.08
84	12	11	22	30	0.00	2.0304S	100.7439W	19319.9246	317.5717	-2.0283	0.0001	92.4870	22763.8275	10088.81
84	12	12	6	0	0.00	1.5054S	100.6444W	19322.2645	70.4792	-1.5038	0.0028	87.1644	22766.1740	10087.68
84	12	12	13	30	0.00	3.2015N	100.6923W	19323.8356	183.2392	3.1983	-0.0006	89.7107	22767.7171	10086.95
84	12	12	21	0	0.00	0.9750S	100.7046W	19320.1336	296.0350	-0.9740	-0.0037	93.0614	22764.0477	10088.73
84	12	13	4	30	0.00	2.4458S	100.6090W	19321.7172	48.9385	-2.4433	0.0045	87.9127	22765.6136	10087.85
84	12	13	12	0	0.00	2.8741N	100.6906W	19323.8323	161.6649	2.8712	0.0010	88.5535	22767.7207	10087.10
84	12	13	19	30	0.00	0.2194N	100.6509W	19321.1574	274.5127	0.2192	-0.0063	93.2079	22765.0746	10088.18
84	12	14	3	0	0.00	3.0453S	100.6011W	19320.6568	27.3705	-3.0422	0.0051	88.9563	22764.5417	10088.39
84	12	14	10	30	0.00	2.1430N	100.6706W	19323.7858	140.1090	2.1408	0.0014	87.5979	22767.6871	10087.13
84	12	14	18	0	0.00	1.3847N	100.5981W	19322.4699	252.9895	1.3833	-0.0058	92.9054	22766.3805	10087.51
84	12	15	1	30	0.00	3.2181S	100.6133W	19319.6640	5.7824	-3.2149	0.0025	90.1487	22763.5451	10088.92
84	12	15	9	0	0.00	1.1111N	100.6265W	19323.6231	118.5771	1.1100	0.0031	86.9782	22767.5361	10087.07
84	12	15	16	30	0.00	2.3571N	100.5619W	19323.4251	231.4497	2.3547	-0.0035	92.1959	22767.3230	10087.15
84	12	16	0	0	0.00	2.9398S	100.6265W	19319.4817	344.1931	-2.9368	-0.0020	91.3210	22763.3688	10089.00
84	12	16	7	30	0.00	0.0762S	100.5675W	19322.8426	97.0601	-0.0762	0.0062	86.7804	22766.7600	10087.35
84	12	16	15	0	0.00	3.0005N	100.5494W	19323.9239	209.8863	2.9975	-0.0021	91.1787	22767.8098	10087.08
84	12	16	22	30	0.00	2.2503S	100.6209W	19320.2531	322.6228	-2.2480	-0.0053	92.3081	22764.1527	10088.56
84	12	17	6	0	0.00	1.2533S	100.5130W	19321.3948	75.5388	-1.2520	0.0077	87.0311	22765.3066	10088.09
84	12	17	13	30	0.00	3.2255N	100.5532W	19324.3380	188.3066	3.2222	-0.0018	89.9960	22768.2189	10086.90
84	12	17	21	0	0.00	1.2474S	100.5874W	19321.3745	301.0803	-1.2461	-0.0056	92.9730	22765.2865	10087.98
84	12	18	4	30	0.00	2.2566S	100.4801W	19319.9718	53.9957	-2.2544	0.0055	87.6953	22763.8714	10088.83
84	12	18	12	0	0.00	3.0013N	100.5553W	19324.6633	166.7284	2.9983	0.0004	88.8133	22768.5491	10086.60
84	12	18	19	30	0.00	0.0708S	100.5334W	19322.1687	279.5584	-0.0708	-0.0044	93.2249	22766.0860	10087.70
84	12	19	3	0	0.00	2.9473S	100.4738W	19319.3299	32.4260	-2.9444	0.0011	88.6814	22763.2169	10089.12
84	12	19	10	30	0.00	2.3598N	100.5394W	19324.3530	145.1684	2.3574	0.0049	87.7950	22768.2509	10086.65
84	12	19	18	0	0.00	1.1172N	100.4770W	19322.6770	258.0388	1.1160	-0.0046	93.0297	22766.5900	10087.65
84	12	20	1	30	0.00	3.2293S	100.4847W	19319.5414	10.8391	-3.2261	-0.0023	89.8534	22763.4223	10088.89
84	12	20	9	0	0.00	1.3895N	100.5000W	19323.1851	123.6318	1.3881	0.0085	87.0818	22767.0957	10087.27
84	12	20	16	30	0.00	2.1530N	100.4355W	19323.4833	236.5043	2.1508	-0.0061	92.4130	22767.3844	10087.32
84	12	21	0	0	0.00	3.0624S	100.4952W	19320.0157	349.2527	-3.0593	-0.0030	91.0489	22763.9002	10088.57
84	12	21	7	30	0.00	0.2234N	100.4445W	19321.6744	102.1114	0.2232	0.0086	86.7722	22765.5916	10088.09
84	12	21	15	0	0.00	2.8925N	100.4154W	19324.6462	214.9485	2.8896	-0.0053	91.4582	22768.5343	10086.64
84	12	21	22	30	0.00	2.4680S	100.4895W	19320.2521	327.6824	-2.4655	-0.0029	92.1014	22764.1481	10088.52

TABLE A3. The Coefficient Array

```
XC( 1)=-1.250714922D-04
XC( 2)=-1.658517543D-05
XC( 3)= 5.878008672D-05
XC( 4)= 2.765649890D-02
XC( 5)=-4.112975905D-03
XC( 6)=-5.913384828D-06
XC( 7)= 5.590658372D-05
XC( 8)= 3.307136087D-05
XC( 9)= 1.737446652D-04
XC(10)= 9.043628966D-04
XC(11)= 2.438109138D-04
XC(12)= 1.344825192D-03
XC(13)= 2.140708501D-05
XC(14)=-2.736764834D-06
XC(15)= 5.856577294D-06
XC(16)=-1.401343652D-05
XC(17)=-1.139667319D-04
XC(18)=-2.937006968D-04
XC(19)= 6.610587160D+00
XC(20)= 0.000000000D+00
XC(21)= 0.000000000D+00
XC(22)= 0.000000000D+00
XC(23)= 0.000000000D+00
XC(24)= 9.421197840D-01
XC(25)= 0.000000000D+00
XC(26)= 0.000000000D+00
XC(27)= 0.000000000D+00
XC(28)= 0.000000000D+00
XC(29)= 0.000000000D+00
XC(30)= 1.002772332D+00
XC(31)= 0.000000000D+00
XC(32)= 1.524398198D-05
XC(33)= 1.159419553D-05
XC(34)= 3.618567470D-07
XC(35)= 2.475757094D-06
XC(36)=-1.754873740D-06
XC(37)= 0.000000000D+00
XC(38)=-2.741390171D-05
XC(39)= 5.009150138D-06
XC(40)=-1.156909456D-05
XC(41)= 1.813177666D-06
XC(42)= 5.875818403D-06
XC(43)= 0.000000000D+00
XC(44)=-1.056635680D-06
XC(45)= 1.341243874D-06
XC(46)= 2.316424431D-05
XC(47)=-2.848991794D-05
XC(48)= 7.734851930D-06
XC(49)= 0.000000000D+00
```

```
XC(50)= 1.392302670D-07
XC(51)=-1.647768180D-06
XC(52)= 2.620586291D-05
XC(53)= 2.648935369D-05
XC(54)= 7.045017019D-06
XC(55)= 0.000000000D+00
XC(56)=-3.322356877D-06
XC(57)=-1.012518640D-06
XC(58)= 3.371745538D-06
XC(59)= 2.462167847D-06
XC(60)= 7.517977303D-07
XC(61)= 0.000000000D+00
XC(62)= 2.261477973D-06
XC(63)=-4.898894721D-06
XC(64)=-1.978026491D-06
XC(65)= 3.689528214D-06
XC(66)=-7.896587574D-07
XC(67)= 0.000000000D+00
XC(68)= 0.000000000D+00
XC(69)= 0.000000000D+00
XC(70)= 0.000000000D+00
XC(71)= 0.000000000D+00
XC(72)= 0.000000000D+00
XC(73)= 0.000000000D+00
XC(74)= 0.000000000D+00
XC(75)= 0.000000000D+00
XC(76)= 0.000000000D+00
XC(77)= 0.000000000D+00
XC(78)= 0.000000000D+00
XC(79)= 4.715712000D+08  <-- EPOCH in seconds elapsed from
                              Jan 1, 0hrs, 1970.
XC(80)= 2.592000000D+06  <-- COEFFICIENT LIFETIME in seconds.
                              (2.592x10+6 sec = 30 days)
```

TABLE A4. Sample Listing of the Coefficient Array - Archival Form

THE COEFFICIENT ARRAY FS91.CFF
THIS LISTING NAMED AS FS91.ARK

EPOCH - YR MO DY HR MN SEC
84 12 11 0 0 0.00

CONSTANT, LINEAR, AND QUADRATIC TERMS

	A0	A1*TT	A2*TT**2	E0	E1*(t-tb)
A	-1.25071D-04	5.59066D-05	2.14071D-05	6.61059D+00	0.00000D+00
H	-1.65852D-05	3.30714D-05	-2.73676D-06	0.00000D+00	0.00000D+00
K	5.87801D-05	1.73745D-04	5.85658D-06	0.00000D+00	0.00000D+00
P	2.76565D-02	9.04363D-04	-1.40134D-05	0.00000D+00	0.00000D+00
Q	-4.11298D-03	2.43811D-04	-1.13967D-04	0.00000D+00	0.00000D+00
L	-5.91338D-06	1.34483D-03	-2.93701D-04	9.42120D-01	1.00277D+00

LUNAR TERMS

	B1*SIN(ZM)	C1*COS(ZM)	B2*SIN(2*ZM)	C2*COS(2*ZM)	B3*SIN(3*ZM)	C3*COS(3*ZM)
A	0.00000D+00	0.00000D+00	0.00000D+00	0.00000D+00	0.00000D+00	0.00000D+00
H	1.52440D-05	-2.74139D-05	-1.05664D-06	1.39230D-07	-3.32236D-06	2.26148D-06
K	1.15942D-05	5.00915D-06	1.34124D-06	-1.64777D-06	-1.01252D-06	-4.89889D-06
P	3.61857D-07	-1.15691D-05	2.31642D-05	2.62059D-05	3.37175D-06	-1.97803D-06
Q	2.47576D-06	1.81318D-06	-2.84899D-05	2.64894D-05	2.46217D-06	3.68953D-06
L	-1.75487D-06	5.87582D-06	7.73485D-06	7.04502D-06	7.51798D-07	-7.89659D-07

SOLAR TERMS

	D2*SIN(2*ZS)	F2*COS(2*ZS)
A	0.00000D+00	0.00000D+00
H	0.00000D+00	0.00000D+00
K	0.00000D+00	0.00000D+00
P	0.00000D+00	0.00000D+00
Q	0.00000D+00	0.00000D+00
L	0.00000D+00	0.00000D+00

TABLE A5. Sample Listing of Station Look-Angle File

STATION LOOK-ANGLE FILE USING COEFFICIENT FILE fs91.cff
STATION LOCATION IN DEGREES AND KILOMETERS

LAT = 38.637
LON = -77.004
ALT = 0.089

YR	MO	DY	HR	MN	SEC	RANGE (MS)	RG RATE (Hz/GHz)	AZ (DEG)	ELV (DEG)
84	12	11	0	0	0.00	127.007	-30.393	213.48	36.13
84	12	11	0	50	0.00	127.080	-17.699	213.30	35.87
84	12	11	1	40	0.00	127.112	-4.125	213.20	35.75
84	12	11	2	30	0.00	127.104	9.564	213.19	35.79
84	12	11	3	20	0.00	127.056	22.616	213.27	35.97
84	12	11	4	10	0.00	126.970	34.341	213.44	36.30
84	12	11	5	0	0.00	126.851	44.159	213.70	36.74
84	12	11	5	50	0.00	126.707	51.633	214.04	37.29
84	12	11	6	40	0.00	126.544	56.481	214.45	37.91
84	12	11	7	30	0.00	126.371	58.578	214.90	38.58
84	12	11	8	20	0.00	126.195	57.944	215.38	39.26
84	12	11	9	10	0.00	126.026	54.716	215.85	39.92
84	12	11	10	0	0.00	125.869	49.125	216.29	40.54
84	12	11	10	50	0.00	125.733	41.468	216.68	41.08
84	12	11	11	40	0.00	125.622	32.091	216.99	41.53
84	12	11	12	30	0.00	125.542	21.370	217.21	41.85
84	12	11	13	20	0.00	125.495	9.711	217.32	42.04
84	12	11	14	10	0.00	125.484	-2.451	217.31	42.08
84	12	11	15	0	0.00	125.510	-14.649	217.20	41.96
84	12	11	15	50	0.00	125.571	-26.384	216.99	41.71
84	12	11	16	40	0.00	125.667	-37.135	216.70	41.31
84	12	11	17	30	0.00	125.793	-46.376	216.34	40.80
84	12	11	18	20	0.00	125.943	-53.599	215.94	40.20
84	12	11	19	10	0.00	126.112	-58.361	215.52	39.53
84	12	11	20	0	0.00	126.290	-60.315	215.08	38.83
84	12	11	20	50	0.00	126.471	-59.254	214.67	38.14
84	12	11	21	40	0.00	126.643	-55.143	214.27	37.48
84	12	11	22	30	0.00	126.798	-48.131	213.92	36.90
84	12	11	23	20	0.00	126.929	-38.561	213.62	36.41

TABLE A6. FS91.TAP Output tape format

f = line feed
l = letters shift
r = carriage return
| = ten character delimiter(for legibility, not actually on tape)

```
f f l A   E P H E M R S r r f r
L M B O A A C N A A|A D A D A A A I A A|B M G I P P I B A A|C O A A B L A A A A|A A A A A A A A A A|A A f r r
A A A A A A A A A A|A A P H A A G J M E|A A A A A A A A A A|A A A A A A A A A A|A A A A A A A A L M|A A f r r
P P P P A A J P P P|P B P P A I P C P O|A B A A A A A A A A|A A A A A A A A A A|A A A A A A A A A A|P I f r r
E D A A P A A D A G|P P A A A B P P A D|A A P N A A A A A A|A A A A A A A A A A|A A A A J F A A A A|O C f r r
A H I N P P M I A G|A A P N A B P P A H|A A A A A A A A N O|F E N E P P E B A B|A B P P A B P I A H|A A f r r
A A A B A A A A P D|A A M M P P M P A K|P K P N A C B B B A|A N A A P O A A A A|A A A A A A A A A A|A A f r r
A A A A A A A A A A|A A A A A A A A A A|A A A A A A A A A A|A A A A A A G C A A|H I J H C N G M A A|E A f r r
C A A A A A A A A A|C A C A A A A A A A|A A C A A A A A A A|A A A A A A A A A A|P P A A P P P P L H|B C f r r
r r f f f f f f f f N N N N
```

9. Appendix B. Computer Listings of Sample Runs

9.1 Option A Test Case

```
$ RUN NESP
ENTER "A" IF YOU HAVE A 30-DAY TIME-POSITION FILE FROM THE SCF
ENTER "B" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH AND AT 30 DAYS PAST EPOCH
ENTER "C" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH - NO ADDITIONAL 30-DAY VECTOR
ENTER "D" FOR AN AZ-EL, RANGE, RANGE RATE PRINTOUT
ENTER "E" TO EXIT PROGRAM AND WRITE TAPE
A

CANNED TESTCASE ?
ENTER (Y/N)
N


ENTER NAME OF TIME-POSITION HISTORY INPUT FILE
FS91.SCF
READ "FS91.SCF                                      "
NUMBER OF SCALAR DATA POINTS IS:  291


ITERATION NUMBER  1
  ELAPSED TIME  RSS POS ERROR
        (DAYS)   (KILOMETERS)
        0.0000         0.0000
        0.3125         5.7832
        0.6250        12.0420
        0.9375        11.9791
        1.2500        15.9625
        1.5625        25.0607
        1.8750        21.9881
       28.1250       277.6179
       28.4375       289.7742
       28.7500       258.0765
       29.0625       284.5952
       29.3750       297.6830
       29.6875       265.1330
       30.0000       288.3146
    RMS =     100.8497


ITERATION NUMBER  2
  ELAPSED TIME  RSS POS ERROR
        (DAYS)   (KILOMETERS)
        0.0000         0.3960
        0.3125         1.0133
        0.6250         0.9111
```

```
        0.9375          0.7331
        1.2500          0.7959
        1.5625          0.8705
        1.8750          0.7971
       28.1250          1.9471
       28.4375          1.4155
       28.7500          1.1154
       29.0625          2.0286
       29.3750          0.2999
       29.6875          1.8776
       30.0000          1.5433
    RMS =       0.5902


ITERATION NUMBER  3
  ELAPSED TIME  RSS POS ERROR
        (DAYS)   (KILOMETERS)
        0.0000          0.4595
        0.3125          0.9846
        0.6250          0.9083
        0.9375          0.7248
        1.2500          0.7895
        1.5625          0.8771
        1.8750          0.8019
       28.1250          1.2693
       28.4375          1.2843
       28.7500          0.9638
       29.0625          1.0832
       29.3750          1.1524
       29.6875          1.0266
       30.0000          0.7702
    RMS =       0.5153

ENTER NAME OF COEFFICIENT OUTPUT FILE -  FORMATTING VERSION
FS91.CFF
WRITE "FS91.CFF"
DO YOU WISH TO PRODUCE A TAPE?
Y
WHAT IS UPDATE ADVISORY?(0=1,1=7 DAYS,2=30 DAYS,3=60 DAYS)
2
WHAT IS SATELLITE SEQUENCE NUMBER(0-15)
15
WHAT IS DELTA LEAP
4
WHAT IS LEAP MONTH
0

ENTER NAME OF COEFFICIENT OUTPUT FILE -  ARCHIVAL VERSION
FS91.ARK
WRITE "FS91.ARK"
```

```
FROM NOW ON ANSWER ALL QUERIES
FROM NOW ON ANSWER ALL QUERIES
FROM NOW ON ANSWER ALL QUERIES
FROM NOW ON ANSWER ALL QUERIES



COMPUTE LOOK-ANGLE FILE ? - (Y/N)
N
ENTER "A" IF YOU HAVE A 30-DAY TIME-POSITION FILE FROM THE SCF
ENTER "B" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH AND AT 30 DAYS PAST EPOCH
ENTER "C" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH - NO ADDITIONAL 30-DAY VECTOR
ENTER "D" FOR AN AZ-EL, RANGE, RANGE RATE PRINTOUT
ENTER "E" TO EXIT PROGRAM AND WRITE TAPE
E
WHAT IS OUTPUT FILE NAME FOR THE TAPE?
FS91.TAP
FORTRAN STOP
```

9.2 Option B Test Case

```
$ RUN NESP
ENTER "A" IF YOU HAVE A 30-DAY TIME-POSITION FILE FROM THE SCF
ENTER "B" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH AND AT 30 DAYS PAST EPOCH
ENTER "C" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH - NO ADDITIONAL 30-DAY VECTOR
ENTER "D" FOR AN AZ-EL, RANGE, RANGE RATE PRINTOUT
ENTER "E" TO EXIT PROGRAM AND WRITE TAPE
B

CANNED TESTCASE ?
ENTER (Y/N)
N

CARTESIAN OR SPHERICAL COORDINATE ENTRY ?
ENTER (C/S)
S

ENTER EPOCH
 YR MN DAY HR MN SEC.SS
 84 12  11
YR MN DAY HR MN   SEC
84 12  11  0  0  0.00

ENTER RIGHT ASCENSION IN DEGREES
339.1299

ENTER DECLINATION IN DEGREES
```

-2.7960

ENTER FLIGHT PATH ANGLE IN DEGREES
0.0025

ENTER INERTIAL AZIMUTH IN DEGREES
91.5661

ENTER GEOCENTRIC RANGE IN NAUTICAL MILES
22764.3210

ENTER SATELLITE SPEED IN FEET/SEC
10088.47

STATE AND EPOCH ARE:
UNITS: KILOMETERS AND DEGREES

A =	42163.2173	X =	39346.5617	GC XLAT =	-2.7960
E =	0.00009789	Y =	-15001.4683	GC XLON =	259.2372
I =	3.2044	Z =	-2056.5432	MSJD =	45
NODE =	98.3998	XD =	1.0913434	Y/M/D =	84/12/11
PERI =	214.2964	YD =	2.8735582	H/M/S =	00/00/ 0.00
MEAN =	26.4669	ZD =	-0.0839459	STEP =	600.0000

ENTER OBSERVED ECI POSITION AT 30 DAYS PAST EPOCH
ENTER POSTION(PREFERABLY) AT:

```
YR MN DAY HR MN   SEC
85  1  10  0  0  0.00
```

ENTER TIME

```
 YR MN DAY HR MN SEC.SS
 85  1  10
YR MN DAY HR MN   SEC
85  1  10  0  0  0.00
```

ENTER RIGHT ASCENSION IN DEGREES
9.4942

ENTER DECLINATION IN DEGREES
-3.3038

ENTER GEOCENTRIC RANGE IN NAUTICAL MILES
22760.7638

NOW INTEGRATING STATE VECTOR FOR 30.0 DAYS
AT THE END OF 30.0 DAYS THE TWO SOLUTIONS
DIFFER BY 6.8 KILOMETERS

COMPUTE NEIGHBORING SOLUTION - POSITION ONLY
NUMBER OF SCALAR DATA POINTS IS: 291

ITERATION NUMBER 1

ELAPSED TIME (DAYS)	RSS POS ERROR (KILOMETERS)
0.0000	0.0000
0.3125	5.9768
0.6250	11.9651
0.9375	11.9033
1.2500	15.9359
1.5625	24.9651
1.8750	21.6017
28.1250	278.0539
28.4375	290.2983
28.7500	256.4791
29.0625	284.8253
29.3750	298.8911
29.6875	263.7758
30.0000	288.4894

RMS = 100.2750

ITERATION NUMBER 2

ELAPSED TIME (DAYS)	RSS POS ERROR (KILOMETERS)
0.0000	0.3142
0.3125	1.0532
0.6250	0.9542
0.9375	0.7685
1.2500	0.8873
1.5625	0.9066
1.8750	0.7994
28.1250	1.9620
28.4375	1.4310
28.7500	1.0647
29.0625	2.0246
29.3750	0.2816
29.6875	1.8619
30.0000	1.6371

RMS = 0.5925

ITERATION NUMBER 3

ELAPSED TIME (DAYS)	RSS POS ERROR (KILOMETERS)
0.0000	0.3707
0.3125	1.0285
0.6250	0.9446
0.9375	0.7625

```
      1.2500          0.8811
      1.5625          0.9127
      1.8750          0.8031
     28.1250          1.3512
     28.4375          1.2677
     28.7500          0.9564
     29.0625          1.0814
     29.3750          1.1519
     29.6875          1.0078
     30.0000          0.9174
   RMS =       0.5190

ENTER NAME OF COEFFICIENT OUTPUT FILE -  FORMATTING VERSION
TEST.CFF
WRITE "TEST.CFF                                 "
DO YOU WISH TO PRODUCE A TAPE?
N

ENTER NAME OF COEFFICIENT OUTPUT FILE -  ARCHIVAL VERSION
TEST.ARK
WRITE "TEST.ARK                                 "


FROM NOW ON ANSWER ALL QUERIES
FROM NOW ON ANSWER ALL QUERIES
FROM NOW ON ANSWER ALL QUERIES
FROM NOW ON ANSWER ALL QUERIES



COMPUTE LOOK-ANGLE FILE ? - (Y/N)
Y

ENTER NAME OF LOOK-ANGLE OUTPUT FILE
TEST.EPH

 STATION #1           STATION #2

 LAT =   38.637       LAT =  14.500
 LON =  -77.004       LON = 144.760
 ALT =    0.089       ALT =    0.200


FROM WHAT STATION ?
ENTER "1" OR "2"
ENTER "3" FOR OTHER LOCATION
3

STATION # 3 SELECTED

ENTER LATITUDE  IN DEGREES - N(+)  S(-)
```

```
DD.DD
42.31

ENTER LONGITUDE IN DEGREES - E(+)  W(-)
DD.DD
-93.2

ENTER ALTITUDE  IN METERS ABOVE GEOID
DD.DD
239.0

 STATION LOCATION IN DEGREES AND KILOMETERS

 LAT =    42.310
 LON =   -93.200
 ALT =     0.239



ENTER START TIME IN DAYS ELAPSED PAST EPOCH
DD.DD
0.0
  0.000


ENTER STEP SIZE IN MINUTES
DD.DD
60.0
 60.000


ENTER TIME SPAN IN DAYS ELAPSED FROM START
DD.DD
1.0
  1.000


 YR MO DY HR MN     SEC     RANGE       RG RATE     AZ      ELV
                             (MS)      (Hz/GHz)   (DEG)    (DEG)


 84 12 11  0  0    0.00  126.630       -33.187  190.61    37.51
 84 12 11  1  0    0.00  126.720       -16.822  190.52    37.18
 84 12 11  2  0    0.00  126.749         0.815  190.47    37.07
```

```
 84 12 11  3  0   0.00  126.715       18.333  190.45   37.21
 84 12 11  4  0   0.00  126.619       34.366  190.49   37.58
 84 12 11  5  0   0.00  126.470       47.711  190.58   38.15
 84 12 11  6  0   0.00  126.280       57.436  190.72   38.89
 84 12 11  7  0   0.00  126.062       62.951  190.90   39.74
 84 12 11  8  0   0.00  125.832       64.030  191.11   40.65
 84 12 11  9  0   0.00  125.606       60.785  191.32   41.56
 84 12 11 10  0   0.00  125.399       53.608  191.51   42.41
 84 12 11 11  0   0.00  125.224       43.098  191.67   43.13
 84 12 11 12  0   0.00  125.092       29.993  191.78   43.68
 84 12 11 13  0   0.00  125.010       15.109  191.82   44.02
 84 12 11 14  0   0.00  124.984       -0.691  191.81   44.12
 84 12 11 15  0   0.00  125.015      -16.515  191.74   43.98
 84 12 11 16  0   0.00  125.102      -31.448  191.64   43.60
 84 12 11 17  0   0.00  125.239      -44.571  191.51   43.02
 84 12 11 18  0   0.00  125.420      -54.994  191.37   42.27
 84 12 11 19  0   0.00  125.631      -61.916  191.22   41.41
 84 12 11 20  0   0.00  125.860      -64.702  191.07   40.48
 84 12 11 21  0   0.00  126.092      -62.974  190.93   39.57
 84 12 11 22  0   0.00  126.308      -56.687  190.79   38.73
 84 12 11 23  0   0.00  126.495      -46.172  190.67   38.02
 84 12 12  0  0   0.00  126.637      -32.145  190.56   37.48
ENTER "A" IF YOU HAVE A 30-DAY TIME-POSITION FILE FROM THE SCF
ENTER "B" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH AND AT 30 DAYS PAST EPOCH
ENTER "C" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH - NO ADDITIONAL 30-DAY VECTOR
ENTER "D" FOR AN AZ-EL, RANGE, RANGE RATE PRINTOUT
ENTER "E" TO EXIT PROGRAM AND WRITE TAPE
E
FORTRAN STOP
```

9.3 Option C Test Case

```
$ RUN NESP
ENTER "A" IF YOU HAVE A 30-DAY TIME-POSITION FILE FROM THE SCF
ENTER "B" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH AND AT 30 DAYS PAST EPOCH
ENTER "C" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH - NO ADDITIONAL 30-DAY VECTOR
ENTER "D" FOR AN AZ-EL, RANGE, RANGE RATE PRINTOUT
ENTER "E" TO EXIT PROGRAM AND WRITE TAPE
C

CANNED TESTCASE ?
ENTER (Y/N)
N

CARTESIAN OR SPHERICAL COORDINATE ENTRY ?
ENTER (C/S)
S

ENTER EPOCH
 YR MN DAY HR MN SEC.SS
 84 12  11
YR MN DAY HR MN   SEC
84 12  11  0  0  0.00

ENTER RIGHT ASCENSION IN DEGREES
339.1299

ENTER DECLINATION IN DEGREES
-2.7960

ENTER FLIGHT PATH ANGLE IN DEGREES
0.0025

ENTER INERTIAL AZIMUTH IN DEGREES
91.5661

ENTER GEOCENTRIC RANGE IN NAUTICAL MILES
22764.3210

ENTER SATELLITE SPEED IN FEET/SEC
10088.47

STATE AND EPOCH ARE:
UNITS:  KILOMETERS AND DEGREES

A    -  42163.2173   X  -   39346.5617   GC XLAT -     -2.7960
E    -  0.00009789   Y  -  -15001.4683   GC XLON -    259.2372
I    -      3.2044   Z  -   -2056.5432   MSJD -             45
NODE -     98.3998   XD -    1.0913434   Y/M/D -      84/12/11
```

```
PERI =     214.2964   YD =      2.8735582   H/M/S =  00/00/ 0.00
MEAN =      26.4669   ZD =     -0.0839459   STEP =       600.0000


NOW INTEGRATING STATE VECTOR FOR  30.0 DAYS
AT THE END OF  30.0 DAYS THE TWO SOLUTIONS
DIFFER BY     0.0 KILOMETERS


COMPUTE NEIGHBORING SOLUTION - POSITION ONLY
NUMBER OF SCALAR DATA POINTS IS:  291


ITERATION NUMBER  1
  ELAPSED TIME  RSS POS ERROR
        (DAYS)   (KILOMETERS)
        0.0000         0.0000
        0.3125         5.9558
        0.6250        11.8178
        0.9375        11.6784
        1.2500        15.7160
        1.5625        24.6264
        1.8750        21.1493
       28.1250       271.7970
       28.4375       284.0969
       28.7500       249.9551
       29.0625       278.4374
       29.3750       292.4475
       29.6875       257.0283
       30.0000       281.9599
    RMS =      98.0549


ITERATION NUMBER  2
  ELAPSED TIME  RSS POS ERROR
        (DAYS)   (KILOMETERS)
        0.0000         0.3152
        0.3125         1.0527
        0.6250         0.9541
        0.9375         0.7684
        1.2500         0.8871
        1.5625         0.9067
        1.8750         0.7995
       28.1250         1.9293
       28.4375         1.4121
       28.7500         1.0423
       29.0625         1.9816
       29.3750         0.3108
       29.6875         1.8215
       30.0000         1.5966
```

```
    RMS =       0.5868


ITERATION NUMBER  3
  ELAPSED TIME  RSS POS ERROR
        (DAYS)   (KILOMETERS)
        0.0000         0.3707
        0.3125         1.0285
        0.6250         0.9446
        0.9375         0.7625
        1.2500         0.8811
        1.5625         0.9127
        1.8750         0.8031
       28.1250         1.3509
       28.4375         1.2681
       28.7500         0.9561
       29.0625         1.0814
       29.3750         1.1521
       29.6875         1.0075
       30.0000         0.9178
    RMS =       0.5190

ENTER NAME OF COEFFICIENT OUTPUT FILE -  FORMATTING VERSION
TEST.CFF
WRITE "TEST.CFF                                    "
DO YOU WISH TO PRODUCE A TAPE?
N

ENTER NAME OF COEFFICIENT OUTPUT FILE -  ARCHIVAL VERSION
TEST.ARK
WRITE "TEST.ARK                                    "


FROM NOW ON ANSWER ALL QUERIES
FROM NOW ON ANSWER ALL QUERIES
FROM NOW ON ANSWER ALL QUERIES
FROM NOW ON ANSWER ALL QUERIES



COMPUTE LOOK-ANGLE FILE ? - (Y/N)
N
ENTER "A" IF YOU HAVE A 30-DAY TIME-POSITION FILE FROM THE SCF
ENTER "B" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH AND AT 30 DAYS PAST EPOCH
ENTER "C" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH - NO ADDITIONAL 30-DAY VECTOR
ENTER "D" FOR AN AZ-EL, RANGE, RANGE RATE PRINTOUT
ENTER "E" TO EXIT PROGRAM AND WRITE TAPE
E
FORTRAN STOP
```

9.4 Option D Test Case

```
$ RUN NESP
ENTER "A" IF YOU HAVE A 30-DAY TIME-POSITION FILE FROM THE SCF
ENTER "B" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH AND AT 30 DAYS PAST EPOCH
ENTER "C" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH - NO ADDITIONAL 30-DAY VECTOR
ENTER "D" FOR AN AZ-EL, RANGE, RANGE RATE PRINTOUT
ENTER "E" TO EXIT PROGRAM AND WRITE TAPE
D


ENTER NAME OF COEFFICIENT INPUT FILE
FS91.CFF

READ COEFFICIENT FILE  FS91.CFF

ENTER NAME OF LOOK-ANGLE OUTPUT FILE
TEST.EPH

 STATION #1           STATION #2

 LAT =   38.637       LAT =  14.500
 LON =  -77.004       LON = 144.760
 ALT =    0.089       ALT =    0.200


FROM WHAT STATION ?
ENTER "1" OR "2"
ENTER "3" FOR OTHER LOCATION
3

STATION # 3 SELECTED

ENTER LATITUDE  IN DEGREES - N(+)  S(-)
DD.DD
42.31

ENTER LONGITUDE IN DEGREES - E(+)  W(-)
DD.DD
-93.2

ENTER ALTITUDE  IN METERS ABOVE GEOID
DD.DD
239.0


 STATION LOCATION IN DEGREES AND KILOMETERS
```

LAT = 42.310
LON = -93.200
ALT = 0.239

ENTER START TIME IN DAYS ELAPSED PAST EPOCH
DD.DD
0.0
0.000

ENTER STEP SIZE IN MINUTES
DD.DD
60.0
60.000

ENTER TIME SPAN IN DAYS ELAPSED FROM START
DD.DD
1.0
1.000

YR	MO	DY	HR	MN	SEC	RANGE (MS)	RG RATE (Hz/GHz)	AZ (DEG)	ELV (DEG)
84	12	11	0	0	0.00	126.630	-33.195	190.61	37.51
84	12	11	1	0	0.00	126.720	-16.828	190.52	37.18
84	12	11	2	0	0.00	126.749	0.811	190.47	37.07
84	12	11	3	0	0.00	126.715	18.331	190.45	37.21
84	12	11	4	0	0.00	126.619	34.368	190.49	37.58
84	12	11	5	0	0.00	126.470	47.715	190.58	38.15
84	12	11	6	0	0.00	126.280	57.443	190.72	38.89
84	12	11	7	0	0.00	126.062	62.961	190.90	39.74
84	12	11	8	0	0.00	125.832	64.042	191.11	40.65
84	12	11	9	0	0.00	125.606	60.797	191.32	41.56
84	12	11	10	0	0.00	125.399	53.620	191.51	42.41
84	12	11	11	0	0.00	125.224	43.109	191.67	43.13
84	12	11	12	0	0.00	125.092	30.002	191.78	43.68
84	12	11	13	0	0.00	125.010	15.114	191.82	44.01
84	12	11	14	0	0.00	124.984	-0.689	191.81	44.12
84	12	11	15	0	0.00	125.015	-16.517	191.74	43.98
84	12	11	16	0	0.00	125.102	-31.454	191.64	43.60

```
 84 12 11 17  0   0.00  125.239      -44.580  191.51   43.02
 84 12 11 18  0   0.00  125.419      -55.006  191.37   42.27
 84 12 11 19  0   0.00  125.631      -61.929  191.22   41.41
 84 12 11 20  0   0.00  125.860      -64.716  191.07   40.48
 84 12 11 21  0   0.00  126.092      -62.988  190.93   39.57
 84 12 11 22  0   0.00  126.308      -56.699  190.79   38.73
 84 12 11 23  0   0.00  126.495      -46.182  190.67   38.02
 84 12 12  0  0   0.00  126.637      -32.152  190.56   37.48
ENTER "A" IF YOU HAVE A 30-DAY TIME-POSITION FILE FROM THE SCF
ENTER "B" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH AND AT 30 DAYS PAST EPOCH
ENTER "C" TO RECONSTRUCT EPHEMERIS FROM THE STATE
          VECTOR AT EPOCH - NO ADDITIONAL 30-DAY VECTOR
ENTER "D" FOR AN AZ-EL, RANGE, RANGE RATE PRINTOUT
ENTER "E" TO EXIT PROGRAM AND WRITE TAPE
E
FORTRAN STOP
```

10. Appendix C Terminal Test Cases

To fully test the four quadrant azimuth-elevation station look angles, the following test cases are listed. They include the coefficient files, archive files, and output tape files for a high(artificial) and a low(FLTSATCOM 6391) inclination satellite, and look-angle files for for two earth sites for these two satellites. One site is the NRL Waldorf, Maryland facility, and the other is the subsatellite equator crossing point(0, 100.7 W) for 6391. The latter site will produce a four quadrant azimuth test for the terminal software. For each satellite, two sets of coefficient files are listed. The first is the output from the program, and contains the values of the coefficients as computed by the program. The second coefficient file contains the values of the coefficients after they have been encoded into the paper tape format. The differences are due to the truncation caused by the fixed point format required by the tape format.

10.1 Coefficient file for FLTSATCOM 6391

```
XC( 1)=-1.207283941D-04
XC( 2)=-1.632337357D-05
XC( 3)= 5.908282264D-05
XC( 4)= 2.765872988D-02
XC( 5)=-4.110115522D-03
XC( 6)=-6.307759200D-06
XC( 7)= 4.360884754D-05
XC( 8)= 3.798117183D-05
XC( 9)= 1.991701641D-04
XC(10)= 9.218894961D-04
XC(11)= 2.233262234D-04
XC(12)= 1.318104073D-03
XC(13)= 2.592352909D-05
XC(14)=-3.563062402D-06
XC(15)=-3.909646768D-06
XC(16)=-2.654877909D-05
XC(17)=-9.094864986D-05
XC(18)=-2.674724542D-04
XC(19)= 6.610587160D+00
XC(20)= 0.000000000D+00
XC(21)= 0.000000000D+00
XC(22)= 0.000000000D+00
XC(23)= 0.000000000D+00
XC(24)= 9.421197840D-01
XC(25)= 0.000000000D+00
XC(26)= 0.000000000D+00
XC(27)= 0.000000000D+00
XC(28)= 0.000000000D+00
XC(29)= 0.000000000D+00
XC(30)= 1.002772332D+00
XC(31)= 0.000000000D+00
XC(32)= 1.559240067D-05
XC(33)= 1.142328296D-05
XC(34)= 1.609223061D-06
XC(35)= 2.399545460D-06
XC(36)=-2.655785450D-06
XC(37)= 0.000000000D+00
XC(38)=-2.712643917D-05
XC(39)= 5.598453806D-06
XC(40)=-1.277262951D-05
XC(41)=-7.733529639D-08
XC(42)= 6.393767414D-06
XC(43)= 0.000000000D+00
XC(44)=-1.311007071D-06
XC(45)= 1.503868598D-06
XC(46)= 2.251604017D-05
XC(47)=-2.897741954D-05
XC(48)= 8.076845836D-06
XC(49)= 0.000000000D+00
```

```
XC(50)=-2.109908788D-07
XC(51)=-1.462808931D-06
XC(52)= 2.601550530D-05
XC(53)= 2.583213878D-05
XC(54)= 7.551353989D-06
XC(55)= 0.000000000D+00
XC(56)=-3.618250353D-06
XC(57)=-9.345666185D-07
XC(58)= 4.080417545D-06
XC(59)= 2.419575293D-06
XC(60)= 1.100521876D-06
XC(61)= 0.000000000D+00
XC(62)= 2.319234180D-06
XC(63)=-5.017323787D-06
XC(64)=-2.155591450D-06
XC(65)= 4.474839590D-06
XC(66)=-8.855540934D-07
XC(67)= 0.000000000D+00
XC(68)= 0.000000000D+00
XC(69)= 0.000000000D+00
XC(70)= 0.000000000D+00
XC(71)= 0.000000000D+00
XC(72)= 0.000000000D+00
XC(73)= 0.000000000D+00
XC(74)= 0.000000000D+00
XC(75)= 0.000000000D+00
XC(76)= 0.000000000D+00
XC(77)= 0.000000000D+00
XC(78)= 0.000000000D+00
XC(79)= 4.715712000D+08
XC(80)= 2.592000000D+06
```

10.2 Coefficient file for FLTSATCOM 6391(Tape Format Values)

```
X( 1)= -1.21116638D-04
X( 2)= -1.62124634D-05
X( 3)=  5.91278076D-05
X( 4)=  2.76589394D-02
X( 5)= -4.11033630D-03
X( 6)= -6.19888306D-06
X( 7)=  4.38690186D-05
X( 8)=  3.79085541D-05
X( 9)=  1.99079514D-04
X(10)=  9.21726227D-04
X(11)=  2.23159790D-04
X(12)=  1.31797791D-03
X(13)=  2.57492065D-05
X(14)= -3.57627869D-06
X(15)= -3.81469727D-06
X(16)= -2.67028809D-05
X(17)= -9.10758972D-05
X(18)= -2.67505646D-04
X(19)=  6.61058712D+00
X(20)=  0.00000000D+00
X(21)=  0.00000000D+00
X(22)=  0.00000000D+00
X(23)=  0.00000000D+00
X(24)=  9.42119837D-01
X(25)=  0.00000000D+00
X(26)=  0.00000000D+00
X(27)=  0.00000000D+00
X(28)=  0.00000000D+00
X(29)=  0.00000000D+00
X(30)=  1.00277233D+00
X(31)=  0.00000000D+00
X(32)=  1.52587891D-05
X(33)=  1.14440918D-05
X(34)=  0.00000000D+00
X(35)=  3.81469727D-06
X(36)= -2.86102295D-06
X(37)=  0.00000000D+00
X(38)= -2.67028809D-05
X(39)=  5.72204590D-06
X(40)= -1.14440918D-05
X(41)=  0.00000000D+00
X(42)=  6.19888306D-06
X(43)=  0.00000000D+00
X(44)= -1.90734863D-06
X(45)=  1.90734863D-06
X(46)=  2.28881836D-05
X(47)= -3.05175781D-05
X(48)=  8.10623169D-06
X(49)=  0.00000000D+00
```

```
X(50)=  0.00000000D+00
X(51)= -1.90734863D-06
X(52)=  2.67028809D-05
X(53)=  2.67028809D-05
X(54)=  7.62939453D-06
X(55)=  0.00000000D+00
X(56)= -3.81469727D-06
X(57)=  0.00000000D+00
X(58)=  3.81469727D-06
X(59)=  3.81469727D-06
X(60)=  9.53674316D-07
X(61)=  0.00000000D+00
X(62)=  1.90734863D-06
X(63)= -5.72204590D-06
X(64)= -3.81469727D-06
X(65)=  3.81469727D-06
X(66)= -9.53674316D-07
X(67)=  0.00000000D+00
X(68)=  0.00000000D+00
X(69)=  0.00000000D+00
X(70)=  0.00000000D+00
X(71)=  0.00000000D+00
X(72)=  0.00000000D+00
X(73)=  0.00000000D+00
X(74)=  0.00000000D+00
X(75)=  0.00000000D+00
X(76)=  0.00000000D+00
X(77)=  0.00000000D+00
X(78)=  0.00000000D+00
X(79)=  4.71571200D+08
X(80)=  2.59200000D+06
```

10.3 Archive file for FLTSATCOM 6391

THE COEFFICIENT ARRAY FSBC.CFF
THIS LISTING NAMED AS FSBC.ARK

EPOCH -	YR	MO	DY	HR	MN	SEC
	84	12	11	0	0	0.00

CONSTANT, LINEAR, AND QUADRATIC TERMS

	A0	A1*TT	A2*TT**2	E0	E1*(t-tb)
A	-1.20728D-04	4.36088D-05	2.59235D-05	6.61059D+00	0.00000D+00
H	-1.63234D-05	3.79812D-05	-3.56306D-06	0.00000D+00	0.00000D+00
K	5.90828D-05	1.99170D-04	-3.90965D-06	0.00000D+00	0.00000D+00
P	2.76587D-02	9.21889D-04	-2.65488D-05	0.00000D+00	0.00000D+00
Q	-4.11012D-03	2.23326D-04	-9.09486D-05	0.00000D+00	0.00000D+00
L	-6.30776D-06	1.31810D-03	-2.67472D-04	9.42120D-01	1.00277D+00

LUNAR TERMS

	B1*SIN(ZM)	C1*COS(ZM)	B2*SIN(2*ZM)	C2*COS(2*ZM)	B3*SIN(3*ZM)	C3*COS(3*ZM)
A	0.00000D+00	0.00000D+00	0.00000D+00	0.00000D+00	0.00000D+00	0.00000D+00
H	1.55924D-05	-2.71264D-05	-1.31101D-06	-2.10991D-07	-3.61825D-06	2.31923D-06
K	1.14233D-05	5.59845D-06	1.50387D-06	-1.46281D-06	-9.34567D-07	-5.01732D-06
P	1.60922D-06	-1.27726D-05	2.25160D-05	2.60155D-05	4.08042D-06	-2.15559D-06
Q	2.39955D-06	-7.73353D-08	-2.89774D-05	2.58321D-05	2.41958D-06	4.47484D-06
L	-2.65579D-06	6.39377D-06	8.07685D-06	7.55135D-06	1.10052D-06	-8.85554D-07

SOLAR TERMS

	D2*SIN(2*ZS)	F2*COS(2*ZS)
A	0.000000D+00	0.000000D+00
H	0.000000D+00	0.000000D+00
K	0.000000D+00	0.000000D+00
P	0.000000D+00	0.000000D+00
Q	0.000000D+00	0.000000D+00
L	0.000000D+00	0.000000D+00

10.4 Tape file for FLTSATCOM 6391

```
f f l A   E P H E M R S r r f r
L M B O A A C N A A|A D A D A A A I A A|B M G I P P I B A A|C O A A B L A A A A|A A A A A A A A A A|A A f r r
A A A A A A A A A A|A A P H A A G J M E|A A A A A A A A A A|A A A A A A A A A A|A A A A A A A A L M|A A f r r
P P P P A A J P P P|P B P P A I P C P O|A B A A A A A A A A|A A A A A A A A A A|A A A A A A A A A A|P I f r r
E D A A P A A D A G|P P A A A B P P A D|A A P N A A A A A A|A A A A A A A A A A|A A A A J F A A A A|O C f r r
A H I N P P M I A G|A A P N A B P P A H|A A A A A A A A N O|F E N E P P E B A B|A B P P A B P I A H|A A f r r
A A A B A A A A P D|A A M M P P M P A K|P K P N A C B B B A|A N A A P O A A A A|A A A A A A A A A A|A A f r r
A A A A A A A A A A|A A A A A A A A A A|A A A A A A A A A A|A A A A A A G C A A|H I J H C N G M A A|E A f r r
C A A A A A A A A A|C A C A A A A A A A|A A C A A A A A A A|A A A A A A A A A A|P P A A P P P P L H|B C f r r
r r f f f f f f f f N N N N
```

10.5 Test Case 1. Look-angle file for FLTSATCOM 6391 from Pacific Ocean Site

STATION LOOK-ANGLE FILE USING COEFFICIENT FILE fsbc.cff
STATION LOCATION IN DEGREES AND KILOMETERS

LAT = 38.637
LON = -77.004
ALT = 0.089

YR	MO	DY	HR	MN	SEC	RANGE (MS)	RG RATE (Hz/GHz)	AZ (DEG)	ELV (DEG)
84	12	11	0	0	0.00	127.007	-30.385	213.48	36.13
84	12	11	0	50	0.00	127.080	-17.692	213.30	35.87
84	12	11	1	40	0.00	127.112	-4.120	213.20	35.75
84	12	11	2	30	0.00	127.104	9.567	213.19	35.79
84	12	11	3	20	0.00	127.056	22.616	213.27	35.97
84	12	11	4	10	0.00	126.970	34.339	213.44	36.30
84	12	11	5	0	0.00	126.851	44.154	213.70	36.74
84	12	11	5	50	0.00	126.707	51.626	214.04	37.29
84	12	11	6	40	0.00	126.544	56.472	214.45	37.91
84	12	11	7	30	0.00	126.371	58.567	214.90	38.58
84	12	11	8	20	0.00	126.195	57.932	215.38	39.26
84	12	11	9	10	0.00	126.026	54.703	215.85	39.92
84	12	11	10	0	0.00	125.870	49.112	216.29	40.54
84	12	11	10	50	0.00	125.733	41.456	216.68	41.08
84	12	11	11	40	0.00	125.622	32.081	216.99	41.53
84	12	11	12	30	0.00	125.542	21.362	217.21	41.85
84	12	11	13	20	0.00	125.495	9.705	217.32	42.04
84	12	11	14	10	0.00	125.484	-2.454	217.31	42.08
84	12	11	15	0	0.00	125.510	-14.648	217.20	41.96
84	12	11	15	50	0.00	125.572	-26.380	216.99	41.71
84	12	11	16	40	0.00	125.667	-37.129	216.70	41.31
84	12	11	17	30	0.00	125.793	-46.366	216.34	40.80
84	12	11	18	20	0.00	125.943	-53.588	215.94	40.20
84	12	11	19	10	0.00	126.112	-58.348	215.52	39.53
84	12	11	20	0	0.00	126.291	-60.301	215.09	38.83
84	12	11	20	50	0.00	126.471	-59.240	214.67	38.14
84	12	11	21	40	0.00	126.643	-55.129	214.27	37.48
84	12	11	22	30	0.00	126.798	-48.119	213.92	36.90
84	12	11	23	20	0.00	126.929	-38.551	213.62	36.41

10.6 Test Case 2. Look-angle file for FLTSATCOM 6391 from Waldorf, Maryland

STATION LOOK-ANGLE FILE USING COEFFICIENT FILE fsbc.cff
STATION LOCATION IN DEGREES AND KILOMETERS

LAT = 0.000
LON = -100.700
ALT = 0.000

YR	MO	DY	HR	MN	SEC	RANGE (MS)	RG RATE (Hz/GHz)	AZ (DEG)	ELV (DEG)
84	12	11	0	0	0.00	119.384	-2.618	181.30	86.70
84	12	11	0	50	0.00	119.391	-1.903	180.88	86.38
84	12	11	1	40	0.00	119.395	-0.877	180.48	86.23
84	12	11	2	30	0.00	119.396	0.247	180.09	86.26
84	12	11	3	20	0.00	119.393	1.241	179.73	86.47
84	12	11	4	10	0.00	119.388	1.907	179.42	86.85
84	12	11	5	0	0.00	119.382	2.111	179.18	87.38
84	12	11	5	50	0.00	119.376	1.810	179.04	88.03
84	12	11	6	40	0.00	119.372	1.064	179.12	88.78
84	12	11	7	30	0.00	119.370	0.020	180.22	89.58
84	12	11	8	20	0.00	119.372	-1.115	356.49	89.60
84	12	11	9	10	0.00	119.377	-2.112	357.82	88.79
84	12	11	10	0	0.00	119.384	-2.763	358.20	88.04
84	12	11	10	50	0.00	119.393	-2.925	358.50	87.39
84	12	11	11	40	0.00	119.401	-2.544	358.81	86.86
84	12	11	12	30	0.00	119.408	-1.669	359.13	86.48
84	12	11	13	20	0.00	119.411	-0.441	359.48	86.26
84	12	11	14	10	0.00	119.410	0.929	359.82	86.23
84	12	11	15	0	0.00	119.406	2.203	0.15	86.38
84	12	11	15	50	0.00	119.398	3.155	0.45	86.69
84	12	11	16	40	0.00	119.387	3.618	0.69	87.17
84	12	11	17	30	0.00	119.377	3.509	0.85	87.78
84	12	11	18	20	0.00	119.367	2.851	0.87	88.50
84	12	11	19	10	0.00	119.360	1.764	0.46	89.28
84	12	11	20	0	0.00	119.357	0.442	187.74	89.89
84	12	11	20	50	0.00	119.357	-0.878	182.09	89.08
84	12	11	21	40	0.00	119.362	-1.965	181.62	88.30
84	12	11	22	30	0.00	119.369	-2.636	181.30	87.61
84	12	11	23	20	0.00	119.377	-2.787	180.97	87.03

10.7 Coefficient file for high-inclination satellite

```
XC( 1)=-1.413463542D-04
XC( 2)=-5.610805557D-05
XC( 3)= 9.005383663D-05
XC( 4)=-3.244516056D-01
XC( 5)= 8.570849641D-01
XC( 6)=-1.419061116D-05
XC( 7)=-1.339626823D-04
XC( 8)= 2.073361307D-05
XC( 9)= 1.711218636D-04
XC(10)=-2.133491708D-03
XC(11)=-6.870411776D-04
XC(12)= 6.908862450D-04
XC(13)= 1.501208047D-04
XC(14)= 1.503954298D-06
XC(15)=-5.422989687D-05
XC(16)=-5.201546229D-06
XC(17)= 2.772105960D-04
XC(18)=-1.402068500D-04
XC(19)= 6.610626483D+00
XC(20)= 0.000000000D+00
XC(21)= 0.000000000D+00
XC(22)= 0.000000000D+00
XC(23)= 0.000000000D+00
XC(24)= 9.340164046D-01
XC(25)= 0.000000000D+00
XC(26)= 0.000000000D+00
XC(27)= 0.000000000D+00
XC(28)= 0.000000000D+00
XC(29)= 0.000000000D+00
XC(30)= 1.002763384D+00
XC(31)= 0.000000000D+00
XC(32)= 1.530026863D-05
XC(33)=-1.991198875D-05
XC(34)=-4.219278331D-07
XC(35)=-9.835921558D-06
XC(36)= 6.414329411D-07
XC(37)= 0.000000000D+00
XC(38)= 2.310711074D-05
XC(39)=-1.975975446D-05
XC(40)= 2.213054223D-05
XC(41)= 1.084649054D-05
XC(42)=-1.277499313D-06
XC(43)= 0.000000000D+00
XC(44)= 1.860043547D-06
XC(45)=-2.173606532D-06
XC(46)=-6.810324445D-05
XC(47)= 1.166580521D-04
XC(48)=-1.111174584D-05
XC(49)= 0.000000000D+00
```

```
XC(50)= 1.435592178D-06
XC(51)= 2.603093998D-06
XC(52)=-6.622401627D-05
XC(53)=-1.754997716D-05
XC(54)= 2.954537259D-05
XC(55)= 0.000000000D+00
XC(56)=-1.113169648D-05
XC(57)= 2.586758993D-06
XC(58)=-1.067123683D-05
XC(59)= 1.331964489D-06
XC(60)= 3.291578453D-06
XC(61)= 0.000000000D+00
XC(62)=-8.186134446D-06
XC(63)=-1.162781034D-05
XC(64)= 6.800218295D-06
XC(65)=-1.520894166D-05
XC(66)= 2.142577611D-06
XC(67)= 0.000000000D+00
XC(68)= 1.000000000D-05
XC(69)= 1.000000000D-05
XC(70)= 1.000000000D-05
XC(71)= 1.000000000D-05
XC(72)= 1.000000000D-05
XC(73)= 0.000000000D+00
XC(74)=-1.000000000D-05
XC(75)=-1.000000000D-05
XC(76)=-1.000000000D-05
XC(77)=-1.000000000D-05
XC(78)=-1.000000000D-05
XC(79)= 4.715712000D+08
XC(80)= 2.592000000D+06
```

10.8 Coefficient file for high-inclination satellite(Tape Format Values)

```
X( 1)= -1.41143799D-04
X( 2)= -5.60283661D-05
X( 3)=  9.01222229D-05
X( 4)= -3.24451447D-01
X( 5)=  8.57084751D-01
X( 6)= -1.43051147D-05
X( 7)= -1.33514404D-04
X( 8)=  2.07424164D-05
X( 9)=  1.71184540D-04
X(10)= -2.13336945D-03
X(11)= -6.87122345D-04
X(12)=  6.90937042D-04
X(13)=  2.86102295D-05
X(14)=  1.43051147D-06
X(15)= -5.41210175D-05
X(16)= -5.24520874D-06
X(17)=  2.77042389D-04
X(18)= -1.40190125D-04
X(19)=  6.61062622D+00
X(20)=  0.00000000D+00
X(21)=  0.00000000D+00
X(22)=  0.00000000D+00
X(23)=  0.00000000D+00
X(24)=  9.34016347D-01
X(25)=  0.00000000D+00
X(26)=  0.00000000D+00
X(27)=  0.00000000D+00
X(28)=  0.00000000D+00
X(29)=  0.00000000D+00
X(30)=  1.00276327D+00
X(31)=  0.00000000D+00
X(32)=  1.52587891D-05
X(33)= -1.90734863D-05
X(34)=  0.00000000D+00
X(35)= -1.14440918D-05
X(36)=  4.76837158D-07
X(37)=  0.00000000D+00
X(38)=  2.28881836D-05
X(39)= -1.90734863D-05
X(40)=  2.28881836D-05
X(41)=  1.14440918D-05
X(42)= -1.43051147D-06
X(43)=  0.00000000D+00
X(44)=  1.90734863D-06
X(45)= -1.90734863D-06
X(46)= -6.86645508D-05
X(47)=  1.18255615D-04
X(48)= -1.09672546D-05
X(49)=  0.00000000D+00
```

```
X(50)=  1.90734863D-06
X(51)=  1.90734863D-06
X(52)= -6.48498535D-05
X(53)= -1.90734863D-05
X(54)=  2.95639038D-05
X(55)=  0.00000000D+00
X(56)= -1.14440918D-05
X(57)=  1.90734863D-06
X(58)= -1.14440918D-05
X(59)=  0.00000000D+00
X(60)=  3.33786011D-06
X(61)=  0.00000000D+00
X(62)= -7.62939453D-06
X(63)= -1.14440918D-05
X(64)=  7.62939453D-06
X(65)= -1.52587891D-05
X(66)=  1.90734863D-06
X(67)=  0.00000000D+00
X(68)=  0.00000000D+00
X(69)=  0.00000000D+00
X(70)=  1.00135803D-05
X(71)=  1.00135803D-05
X(72)=  1.00135803D-05
X(73)=  0.00000000D+00
X(74)=  0.00000000D+00
X(75)=  0.00000000D+00
X(76)= -1.00135803D-05
X(77)= -1.00135803D-05
X(78)= -1.00135803D-05
X(79)=  4.71571200D+08
X(80)=  2.59200000D+06
```

10.9 Archive file for high-inclination satellite

THE COEFFICIENT ARRAY FSHI.CFF
THIS LISTING NAMED AS FSHI.ARK

EPOCH - YR	MO	DY	HR	MN	SEC
84	12	11	0	0	0.00

CONSTANT, LINEAR, AND QUADRATIC TERMS

	A0	A1*TT	A2*TT**2	E0	E1*(t-tb)
A	-1.41346D-04	-1.33963D-04	1.50121D-04	6.61063D+00	0.00000D+00
H	-5.61081D-05	2.07336D-05	1.50395D-06	0.00000D+00	0.00000D+00
K	9.00538D-05	1.71122D-04	-5.42299D-05	0.00000D+00	0.00000D+00
P	-3.24452D-01	-2.13349D-03	-5.20155D-06	0.00000D+00	0.00000D+00
Q	8.57085D-01	-6.87041D-04	2.77211D-04	0.00000D+00	0.00000D+00
L	-1.41906D-05	6.90886D-04	-1.40207D-04	9.34016D-01	1.00276D+00

LUNAR TERMS

	B1*SIN(ZM)	C1*COS(ZM)	B2*SIN(2*ZM)	C2*COS(2*ZM)	B3*SIN(3*ZM)	C3*COS(3*ZM)
A	0.00000D+00	0.00000D+00	0.00000D+00	0.00000D+00	0.00000D+00	0.00000D+00
H	1.53003D-05	2.31071D-05	1.86004D-06	1.43559D-06	-1.11317D-05	-8.18613D-06
K	-1.99120D-05	-1.97598D-05	-2.17361D-06	2.60309D-06	2.58676D-06	-1.16278D-05
P	-4.21928D-07	2.21305D-05	-6.81032D-05	-6.62240D-05	-1.06712D-05	6.80022D-06
Q	-9.83592D-06	1.08465D-05	1.16658D-04	-1.75500D-05	1.33196D-06	-1.52089D-05
L	6.41433D-07	-1.27750D-06	-1.11117D-05	2.95454D-05	3.29158D-06	2.14258D-06

SOLAR TERMS

	D2*SIN(2*ZS)	F2*COS(2*ZS)
A	0.000000D+00	0.000000D+00
H	1.000000D-05	-1.000000D-05
K	1.000000D-05	-1.000000D-05
P	1.000000D-05	-1.000000D-05
Q	1.000000D-05	-1.000000D-05
L	1.000000D-05	-1.000000D-05

10.10 Tape file for high-inclination satellite

```
f f l A   E P H E M R S r r f r
L I B O A A C N A A|A D A D A A A I A A|B M G I P P G M P P|H E A A J O A A A A|A A A A A A A A A A|A A f r r
A A A A A A A A A A|A A C A A A G J M F|A A A A A A A A A A|A A A A A A A A A A|A A A A A A A A B F|A A f r r
P P P P A A F H A A|A G A B A I A M P K|P M A B A A A A A A|A A A A A A A A A A|A A A A A A A A A B|H K f r r
M O A A B N A C P G|P P A B P P A B P G|A A P K A A A A A A|A A A A A A A A A A|A A A A B I A A P F|J O f r r
O O I G P P P F O O|A A A G P N A C O P|A A B F P P O L G N|D N F P B L E F P K|P N A C A A B P P L|A D f r r
B F P M O L A A O C|P P K J P P N K A F|A B P O A H O J D O|P N B F A E O L A A|A A P P A A A A A A|A A f r r
A A A A A A A A A A|A A A A A A A A A A|A A A A A A A A A A|A A A A A A N J A A|H H I N C N E G A A|E A f r r
C A A A A A A A A A|C A C A A A A A A A|A A C A A A A A A A|A A A A A A A A A A|P P A A P P P P L O|C I f r r
r r f f f f f f f f N N N N
```

10.11 Test Case 3. Look-angle file for high inclination satellitefrom Pacific Ocean Site

STATION LOOK-ANGLE FILE USING COEFFICIENT FILE fshi.cff
STATION LOCATION IN DEGREES AND KILOMETERS

LAT = 0.000
LON = -100.700
ALT = 0.000

YR	MO	DY	HR	MN	SEC	RANGE (MS)	RG RATE (Hz/GHz)	AZ (DEG)	ELV (DEG)
84	12	11	0	0	0.00	119.389	89.420	183.68	86.46
84	12	11	0	50	0.00	120.203	-620.936	309.67	72.41
84	12	11	1	40	0.00	122.968	-1186.453	315.95	53.46
84	12	11	2	30	0.00	127.060	-1492.778	320.74	36.04
84	12	11	3	20	0.00	131.626	-1502.151	326.64	20.93
84	12	11	4	10	0.00	135.801	-1241.004	334.30	8.80
84	12	11	5	0	0.00	138.866	-774.835	343.88	0.42
84	12	11	5	50	0.00	140.330	-188.188	354.92	-3.50
84	12	11	6	40	0.00	139.967	426.843	6.31	-2.53
84	12	11	7	30	0.00	137.834	976.744	16.68	3.23
84	12	11	8	20	0.00	134.262	1371.493	25.10	13.18
84	12	11	9	10	0.00	129.840	1532.292	31.24	26.57
84	12	11	10	0	0.00	125.357	1406.220	35.03	42.67
84	12	11	10	50	0.00	121.696	989.310	35.97	60.79
84	12	11	11	40	0.00	119.646	349.609	27.50	80.04
84	12	11	12	30	0.00	119.682	-372.764	236.27	79.40
84	12	11	13	20	0.00	121.794	-1006.993	225.83	60.16
84	12	11	14	10	0.00	125.495	-1414.909	221.07	42.09
84	12	11	15	0	0.00	129.989	-1531.051	215.67	26.07
84	12	11	15	50	0.00	134.394	-1361.427	208.69	12.79
84	12	11	16	40	0.00	137.925	-960.155	199.79	2.96
84	12	11	17	30	0.00	140.003	-406.606	189.18	-2.64
84	12	11	18	20	0.00	140.303	208.966	177.75	-3.45
84	12	11	19	10	0.00	138.780	793.000	166.87	0.63
84	12	11	20	0	0.00	135.669	1253.518	157.68	9.15
84	12	11	20	50	0.00	131.468	1506.375	150.71	21.39
84	12	11	21	40	0.00	126.904	1487.004	146.06	36.60
84	12	11	22	30	0.00	122.845	1170.749	143.93	54.08
84	12	11	23	20	0.00	120.139	597.929	146.62	73.07

10.12 Test Case 4. Look-angle file for high inclination satellite from Waldorf, Maryland

STATION LOOK-ANGLE FILE USING COEFFICIENT FILE fshi.cff

STATION LOCATION IN DEGREES AND KILOMETERS

LAT = 38.637
LON = -77.004
ALT = 0.089

YR	MO	DY	HR	MN	SEC	RANGE (MS)	RG RATE (Hz/GHz)	AZ (DEG)	ELV (DEG)
84	12	11	0	0	0.00	127.080	629.001	213.52	35.87
84	12	11	0	50	0.00	125.895	171.685	236.80	40.42
84	12	11	1	40	0.00	125.938	-175.043	261.19	40.33
84	12	11	2	30	0.00	126.768	-346.682	283.53	37.23
84	12	11	3	20	0.00	127.826	-328.108	303.08	33.47
84	12	11	4	10	0.00	128.575	-148.678	320.48	30.92
84	12	11	5	0	0.00	128.617	131.345	336.38	30.82
84	12	11	5	50	0.00	127.764	434.514	351.09	33.79
84	12	11	6	40	0.00	126.071	677.472	4.76	40.07
84	12	11	7	30	0.00	123.838	781.644	17.75	49.55
84	12	11	8	20	0.00	121.581	686.819	31.43	61.84
84	12	11	9	10	0.00	119.942	369.430	53.59	76.06
84	12	11	10	0	0.00	119.558	-139.170	159.03	82.28
84	12	11	10	50	0.00	120.879	-748.355	203.66	66.56
84	12	11	11	40	0.00	124.021	-1331.093	214.93	48.38
84	12	11	12	30	0.00	128.717	-1766.948	220.73	30.19
84	12	11	13	20	0.00	134.396	-1978.179	223.84	12.69
84	12	11	14	10	0.00	140.336	-1940.360	224.62	-3.64
84	12	11	15	0	0.00	145.808	-1672.546	222.69	-18.29
84	12	11	15	50	0.00	150.188	-1221.544	217.15	-30.53
84	12	11	16	40	0.00	153.016	-649.134	207.11	-39.10
84	12	11	17	30	0.00	154.030	-23.880	193.41	-42.40
84	12	11	18	20	0.00	153.177	583.983	180.06	-39.64
84	12	11	19	10	0.00	150.611	1106.535	171.14	-31.83
84	12	11	20	0	0.00	146.684	1482.660	167.64	-20.76
84	12	11	20	50	0.00	141.911	1664.496	168.92	-7.93
84	12	11	21	40	0.00	136.918	1626.918	174.47	5.52
84	12	11	22	30	0.00	132.362	1378.4[illegible]6	184.42	18.53
84	12	11	23	20	0.00	128.808	971.073	199.39	29.78