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Look-Angle-Prediction Technique for Artificial Earth Satellites

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ABSTRACT

This report is concerned with the investigation of a method for obtaining look-angle predictions for artificial earth satellites relative to a given point on the earth. The input to the problem consists of the most-recently-determined elliptical orbital elements of the satellite, the spherical coordinates of a station on the earth, and a desired time of search. The results to be obtained for the satellite trajectory are azimuth, elevation, range, range rate (i.e., velocity), and the doppler frequency shift as a function of time.

The problem has been programmed for use on digital electronic computers in both NELIAC and FORTRAN compiler languages and is available for use at both NRL and the David Taylor Model Basin in the Washington, D.C., area. As part of the checking out procedure, a comparison of the results was made with data obtained at the Radio Research Establishment (RRE) in Malvern, England. It was concluded that the major portion of those discrepancies that exist between the NRL and the RRE data is due to differences in the models used. Examples of both NELIAC and FORTRAN input, an example of the FORTRAN output, and the FORTRAN source program for this problem are included in the appendices.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem R02-41
Project RT 7043014/652-1/F019-03-03

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LOOK-ANGLE-PREDICTION TECHNIQUE FOR ARTIFICIAL EARTH SATELLITES

GENERAL SCHEME

The problem of obtaining minute vectors along the trajectory of a satellite pass relative to an observing station on earth can be divided into two main parts. The first of these is called the search mode and is concerned with that portion of the satellite orbit which is below the horizon of the observing station. Its main function is to determine the time at which the satellite will cross the horizon of the station. When this time has been determined, the second main part of the computational scheme is entered–the look-angle mode. In this portion of the problem, positions of the satellite along its path are predicted. These positions are separated by a specified interval of time and are computed in an earth-fixed coordinate system, to be described below. Starting with the time of horizon crossing, the corresponding position of the satellite is used to compute the elevation angle, azimuth angle (measured east of north), and range relative to the observing station. The range-rate and doppler frequency shift are also calculated using the transmitting frequency of the station. The time is then increased by the specified time interval and the new position of the satellite is computed. Then the above-mentioned parameters are again computed for the observing station. This process is repeated until the satellite descends beyond the horizon of the station, at which time the search mode is re-entered.

COMPUTATIONAL SCHEME

Model Used

Successive values of satellite position are computed by updating the six classical elliptical elements describing the orbit of the satellite. These six elements are: right ascension of the ascending node Ω, argument of perigee ω, eccentricity e, semimajor axis a, mean anomaly M, and inclination i. In the orbit model chosen, corrections are made for the first-order secular perturbations, the motion of the node $\dot{\Omega}$, and the motion of perigee $\dot{\omega}$. The updated values of eccentricity and semimajor axis are obtained from the formulas

$$e = e_o + \dot{e}t$$

and

$$a = a_o + \dot{a}t + \ddot{a}t^2$$

where e_o and a_o refer to the values of a and e at epoch, and t is the time that has elapsed since epoch. The orbital elements at epoch and the time derivatives of a and e are the given input parameters. The updated value of the mean anomaly is obtained from the expression

$$M = M_o + \frac{120\pi}{\dot{P}}\left[\ln\left(1 + \frac{\dot{P}t}{P_o}\right)\right] \tag{1}$$

where M_o and P_o refer to the epoch values of the mean anomaly and anomalistic period, respectively, and $\dot{P}$ is the rate of change of period expressed in minutes per revolution

per hour. For stable satellites and for t less than 1000 hr the term $\dot{P}t/P_o$ is less than 10^{-2}. Hence, Eq. (1) can be expressed in series form by

$$M = M_o + \frac{120\pi}{\dot{P}} \left[\frac{\dot{P}t}{P_o} - \frac{1}{2}\left(\frac{\dot{P}t}{P_o}\right)^2 + \frac{1}{3}\left(\frac{\dot{P}t}{P_o}\right)^3 - \frac{1}{4}\left(\frac{\dot{P}t}{P_o}\right)^4 + \cdots \right]$$

The sixth classical element, inclination, which is the angle between the orbital plane of the satellite and the equatorial plane of the earth, is assumed constant.

Therefore, for the orbital model chosen, in addition to the six classical elements the following five elements are also included as input: regression (the motion of the node), rotation of perigee (the motion of perigee), the first time derivative of the semimajor axis, the first time derivative of eccentricity, and the first time derivative of the period. Although the rate of change of semimajor axis is optional, if the rate of change of period is given, the rate of change of semimajor axis is automatically calculated from it. (Refer to Appendix D for additional equations and constants used.)

Calculation of Satellite Position

The position of the satellite is computed in a right-handed Cartesian coordinate system which is earth-fixed and which has its origin at the center of the earth. The z axis points towards the geographic North pole, the x axis points towards zero degrees longitude, and the y axis points toward 90 degrees east longitude.

In order to calculate the position of the satellite at a time t hours after epoch, the orbital elements at epoch must first be updated to the time in question. This updating procedure has been discussed above. The equations expressing the coordinates of a satellite in terms of the elliptical elements contain the true anomaly f. Hence, the updated mean anomaly must be converted to true anomaly. This is done in two parts; first, the eccentric anomaly E is calculated from Kepler's equation

$$E - e \sin E = M.$$

This is done by the iterative procedure described by the equation $E_{N+1} = M + e \sin E_N$. The mean anomaly is used as a first guess at E, i.e., $E_o = M$. This process is repeated until the expression $|E_{N+1} - E_N|$ is within a specified tolerance. Second, the true anomaly is then calculated by use of the expression

$$f = \cos^{-1}\left(\frac{\cos E - e}{1 - e \cos E}\right).$$

The coordinates of the satellite can now be computed from the formulas

$$x = \frac{a(1-e^2)}{1+e\cos f} \cos\left\{\sin^{-1}\left[(\sin i)(\sin(f+\omega))\right]\right\} \cos\left[2\pi - \lambda_N + \sin^{-1}\left(\frac{\cos i \sin(f+\omega)}{\sqrt{1-(\sin^2 i)(\sin^2(f+\omega))}}\right)\right] \tag{2}$$

$$y = \frac{a(1-e^2)}{1+e\cos f} \cos\left\{\sin^{-1}\left[(\sin i)(\sin(f+\omega))\right]\right\} \sin\left[2\pi - \lambda_N + \sin^{-1}\left(\frac{\cos i \sin(f+\omega)}{\sqrt{1-(\sin^2 i)(\sin^2(f+\omega))}}\right)\right] \tag{3}$$

$$z = \frac{a(1-e^2)}{1+e\cos f} (\sin i)(\sin(f+\omega)) \tag{4}$$

where λ_N is the updated longitude of the ascending node. The right-ascension angle Ω of the orbital plane is implicitly contained in Eqs. (2) - (4) through the quantity λ_N. The geodetic latitude, longitude, and height above sea level of the receiver station are used to calculate the coordinates of the station, and this information, together with the results of Eqs. (2) - (4), is used to compute the vector from the station to the satellite for the specified time t after epoch.

Search Mode

Calculation of Maximum Elevation Point – The search mode begins by updating the input orbital elements for the time span given in the input as the initial time after epoch. If the resulting updated satellite position is below the horizon of the observing station, the satellite is advanced in its orbit by a predetermined fraction of its period. This process is repeated until the satellite passes through the maximum elevation point relative to the observing station. This is done by comparing the consecutive scalar (dot) products of the position vector to the satellite and the local zenith vector of the observing station. At this point in the process the maximum elevation point is calculated as described below.

If the initial updated position of the satellite is above the horizon of the station, the satellite is either advanced or moved back in its orbit until the point of maximum elevation is passed. This is again done by comparing successive dot products. The point of maximum elevation is now computed.

When it has been established that the satellite passed through the point of maximum elevation relative to the receiving station, an iterative procedure is performed to calculate the point of maximum elevation. A parabolic fit is made at the three points along the satellite trajectory which have the largest dot products when their position vectors are dotted with the local zenith vector of the receiving station. This is used as a first guess in the iterative process. This fit yields a value of time after epoch corresponding to the point on the parabola having maximum elevation relative to the station. This value of time is then used to update the orbital elements and compute the satellite position components. This position and its associated time after epoch then replace the corresponding values for the point of the original three points which has the highest elevation, and the parabolic fit is then repeated. This process continues until the elevation angles associated with two successive iterations are within a specified tolerance.

Calculation of Zero-Elevation Point – The original three points mentioned above are used to construct a parabola, and the intersection of this parabola with the plane tangent to the earth and passing through the observing station is computed. This results in a first guess at the point on the satellite trajectory at which the satellite crosses the station horizon. The corresponding time after epoch is also obtained. This point and the point of the original three which is closest to it in time are used in a straight-line fit to determine the next guess of the position and time of the zero-elevation crossing. A check is made to see which of the two points used in the straight-line fit is the greater distance from the zero elevation point. This is done by dotting the position vectors of the points with the station zenith vector and determining which dot product is larger. This point is then replaced by the new guess and the process is repeated until the values of time after epoch associated with two successive iterations differ by less than a specified tolerance.

Look-Angle Mode

Using the values of time after epoch and satellite position corresponding to zero evaluation, the following parameters are computed relative to the observing station: azimuth angle (measured in degrees east of north), elevation angle, and range. The

components of satellite velocity in fixed star space are now computed using the updated orbital elements. These velocity components are then used together with the transmitting frequency of the observing station to compute the rate of change of range and the doppler frequency shift.

To facilitate the calculation of azimuth and elevation angles, the following unit vectors are constructed in the earth-fixed coordinate system mentioned above: a vector **N**, lying in the plane tangent to the earth at the observing station S and pointing towards the North pole; a vector **Z** normal to and pointing outward from this tangent plane; and a vector **A** which is the vector (cross) product of **Z** and **N**, and hence lies in the tangent plane. These vectors are illustrated in Fig. 1 for a receiving station located at S and are given by the following formulas:

$$\mathbf{N} = -\,\mathbf{i}\,(\sin L)(\cos\lambda) + \mathbf{j}\,(\sin L)(\sin\lambda) + \mathbf{k}\,\cos L,$$

$$\mathbf{Z} = \mathbf{i}\,(\cos L)(\cos\lambda) - \mathbf{j}\,(\cos L)(\sin\lambda) + \mathbf{k}\,\sin L,$$

and

$$\mathbf{A} = \mathbf{Z} \times \mathbf{N} = -\,\mathbf{i}\,\sin\lambda - \mathbf{j}\,\cos\lambda,$$

where L is the geocentric latitude and λ is the longitude measured in degrees west.

The equation for obtaining the azimuth angle θ is

$$\theta = \cos^{-1}\left(\frac{\mathbf{R}'\cdot\mathbf{N}}{|\mathbf{R}'|}\right)$$

where $\mathbf{R}'$ is the projection of the vector **R**, drawn from the observing station to the satellite, onto the plane formed by the vectors **N** and **A**, i.e.,

$$\mathbf{R}' = (\mathbf{R}\cdot\mathbf{N})\mathbf{N} + (\mathbf{R}\cdot\mathbf{A})\mathbf{A}.$$

This is illustrated in Fig. 2.

The elevation angle ϕ is obtained from the expression

$$\phi = 90^\circ - \cos^{-1}\left(\frac{\mathbf{R}\cdot\mathbf{Z}}{|\mathbf{R}|}\right).$$

The slant range from the station to the satellite is the magnitude of the vector **R**.

The velocity components of the satellite (i.e., $\dot{x}$, $\dot{y}$, and $\dot{z}$) are computed by taking the partial derivatives of Eqs. (2)-(4) with respect to Ω, ω, and f, respectively, and then substituting the results into the formulas

$$\dot{x} = \frac{dx}{dt} = \frac{\partial x}{\partial \Omega}\frac{d\Omega}{dt} + \frac{\partial x}{\partial \omega}\frac{d\omega}{dt} + \frac{\partial x}{\partial f}\frac{df}{dt},$$

$$\dot{y} = \frac{dy}{dt} = \frac{\partial y}{\partial \Omega}\frac{d\Omega}{dt} + \frac{\partial y}{\partial \omega}\frac{d\omega}{dt} + \frac{\partial y}{\partial f}\frac{df}{dt},$$

and

$$\dot{z} = \frac{dz}{dt} = \frac{\partial z}{\partial \Omega}\frac{d\Omega}{\partial t} + \frac{\partial z}{\partial \omega}\frac{d\omega}{dt} + \frac{\partial z}{\partial f}\frac{df}{dt}.$$

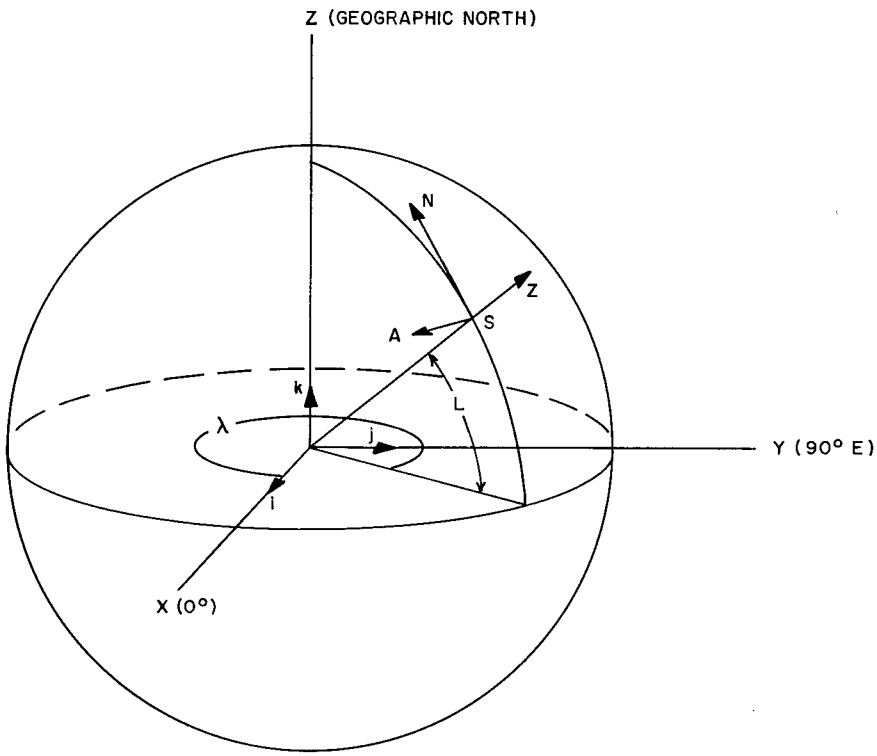

Fig. 1 - Relationship of unit vectors **N**, **Z**, and **A**, located at the station S, to unit vectors **i**, **j**, and **k** located at the center of the earth. The vector **N** points north of the station and lies in the plane tangent to the earth at S; **Z** is normal to, and directed outward from, this tangent plane; and **A** = **Z** × **N**. The geocentric latitude L is measured above the equator, and the longitude λ is measured west of 0°.

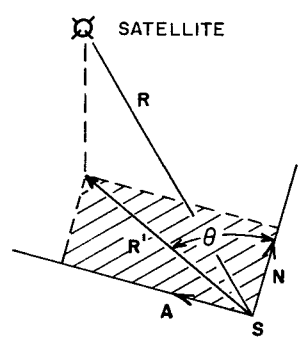

Fig. 2 - Geometry of station-fixed coordinate system used to obtain the azimuth angle θ from the projection **R**′ of the range vector **R** to the satellite

(Remember that Ω is implicitly contained in the quantity λ_N.) The terms $d\Omega/dt$ and $d\omega/dt$ are the input to the problem, and the term df/dt is given by the expression

$$\frac{df}{dt} = 120\pi \frac{(1 + e \cos f)^2}{(1 - e^2)^{3/2}} \frac{1}{\left(P_o + \dot{P} \frac{t}{24.0}\right)}.$$

The terms depending on di/dt, da/dt, and de/dt were neglected because they are small compared to the other terms.

Both the satellite velocity components (i.e., $\dot{x}$, $\dot{y}$, and $\dot{z}$) and the station velocity components are expressed in fixed star space. The relative velocity $\mathbf{v}$ between the satellite and the station is then computed by subtracting the station velocity vector from the satellite velocity vector. The range rate $\dot{R}$ is obtained by computing the component of the relative velocity vector along the vector connecting the station and satellite, i.e.,

$$\dot{R} = \frac{\mathbf{R} \cdot \mathbf{v}}{|\mathbf{R}|} .$$

The doppler frequency shift D is now calculated from the expression

$$D = -\left(\frac{2F}{c}\right)\dot{R}$$

where F is the transmitted frequency and c is the velocity of light.

The current value of time is now increased by an arbitrary time increment which is specified in the input data, and the position of the satellite corresponding to this new time is calculated. The above parameters are then calculated for this new value of satellite position. This process is repeated until the satellite descends below the horizon of the receiving station, at which time the search mode is re-entered.

COMPUTER PROGRAMS FOR DETERMINING LOOK ANGLES

Fortran Version

The look-angle problem was originally adapted for use on the Naval Research Laboratory's electronic digital computer (NAREC). NAREC has a NELIAC compiler associated with it but does not have the capability of using the Fortran compiler. Later it became necessary to use this program at an installation which had an IBM 7044 computer. The problem was then programmed using the Fortran language.

For the Fortran version of the program the twenty-four input parameters are as follows:

1. satellite identification code—This is the number given a satellite by North American Air Defense (NORAD).

2. the month, day, and year part of the epoch of the elements (expressed in modified Julian days)—Although written as a floating point word this input should be a whole number of days. To obtain modified Julian days subtract 2,400,000.5 from the Julian day.

3. fractions of modified Julian day—This allows the hours, minutes, and seconds part of the epoch to be included with the month, day, and year part of the epoch when

combined internally in the program. This double input yields a pseudodouble precision entry of the epoch of the elements.

(The following thirteen input parameters are orbital elements of the satellite at the particular epoch being used.)

4. semimajor axis (in earth radii)

5. first time derivative of semimajor axis (in earth radii per day)

6. second time derivative of semimajor axis (in earth radii per day per day)

7. inclination (in degrees)

8. argument of perigee (in degrees)

9. right ascension of the ascending node (in degrees)

10. eccentricity

11. anomalistic period (in minutes)

12. mean longitude—If the satellite is in direct motion, this term is the sum of the argument of perigee, the mean anomaly, and the right ascension of the ascending node (in degrees, between 0 and 360); if the satellite is retrograde, this term is the sum of the mean anomaly and the argument of perigee minus the right ascension of the ascending node (in degrees, between 0 and 360).

13. first time derivative of argument of perigee (in degrees per day)

14. first time derivative of right ascension of the ascending node (in degrees per day)

15. first time derivative of eccentricity (in ratio per day)

16. first time derivative of period (in minutes per revolution per day).

(The next four input parameters pertain to the observing station.)

17. longitude (in degrees west)

18. geodetic latitude (in degrees)

19. height above sea level (in statute miles)

20. transmitting frequency (in megacycles per second).

(The next three parameters give the interval of time that the program is to search for passes above the horizon of the station and the time increment used to step the satellite along its path when above the horizon of the observing station.)

21. initial time after epoch to start the search mode (in hours)

22. time increment (in hours)

23. time after epoch to end computation (in hours)

24. either zero, one, or two in floating point mode—"two" cycles the program to read another complete set of data, i.e., both satellite elements and station coordinates

along with a new set of times; "one" cycles the program to read only the new initial time, increment, and final time, retaining the original set of satellite orbital elements and station coordinates; and "zero" tells the program that all input data has been processed and the problem is completed.

To use the Fortran version, type four words of data per card using sixteen spaces per word of data starting in column one and skipping four spaces between words. Appendix A contains the Fortran input data used to obtain look angles for satellite 36, a Russian capsule, from 63.6 to 64.2 hr after epoch with an increment of 30 sec, and from 87.7 to 88.3 hr after epoch with an increment of 1 sec. Appendix A also shows the output for this example. For brevity, the 30-sec increment was used and only the answers for the first time span are shown. In the output the azimuth and elevation are expressed in degrees, the range in statute miles, the range rate in statute miles per second, and the doppler frequency shift in kilocycles per second. Refer to Appendix B for the entire Fortran source program.

NELIAC Version

In the NELIAC version the order of the input data is the same as that of the Fortran version. Fortran uses eight-digit accuracy in floating point mode, whereas normal accuracy of the NELIAC compiler when used with the NAREC computer is ten digits. In the NELIAC input, if another time interval is to be processed, the new time, increment, and final time are placed directly after the first group of times. This means that for one satellite many passes may be observed. The number of inputs in the list is, therefore, a variable with a minimum of twenty four. After the last final time input, a dummy input (9999.0) is used to tell the computer to continue and either to call in data for another satellite or that the problem is completed. If another satellite is to be used, then another set of orbital elements, as described above, is required. The dummy input 8888.0 is used to signify the end of the data and the conclusion of the problem. The input data for the same example used to illustrate the Fortran version is shown in Appendix C written in the NELIAC format. The output formats in both versions are identical. A sample operator's instruction sheet is also included in Appendix C.

The object program tapes, in bioctal form, are on file at the NRL Research Computation Center and are labeled B5539 and B5541.

COMPARISON OF RESULTS WITH OBSERVATION

A check on the accuracy of the method described in the above section was made by comparing the azimuth angle, elevation angle, and range obtained by this method with similar results obtained at the Radio Research Establishment (RRE) in Malvern, England. A set of look angles was observed at Malvern on a given satellite. These were used by the RRE to obtain a set of orbital elements. These elements were then used as input to the minute-vector (Minvec) program, and the two sets of look angles were compared. The look angles for points close to the horizons and for the point of maximum elevation appear in Table 1 for satellite trajectories on three different days. It was concluded that the major portion of the discrepancy appearing in the results was due to the difference in the models used by the Malvern group and by NRL.

A second accuracy check was performed by comparing the calculated minute vectors with observed data from the Space Surveillance System. This was not as extensive a check as the preceding one since only one point per satellite pass is observed by the surveillance system. The predicted time of the detection "fence" crossing was obtained from the Minvec program by computing the time that the azimuth angle from station to satellite equals the azimuth angle of the detection fence at the station in question. The time differences obtained can again be attributed, in large part, both to approximations made in the orbital model and to inaccuracies of the input orbital elements.

Table 1
Comparison of NRL and RRE Look Angles and Ranges Derived from Minvec Program for Three Earth-Satellite Trajectories

12-11-64	RRE	NRL	Diff	12-14-64	RRE	NRL	Diff
15 50 30 Z				16 47 00 Z			
Range (stat mi)	1489.1	1489.0	+0.1	Range	1343.6	1343.7	-0.1
Azim. (deg)	35.04	35.00	+0.04	Azim.	25.31	25.32	-0.01
Elev. (deg)	7.36	7.29	+0.07	Elev.	9.52	9.44	+0.08
15 53 30 Z				16 49 30 Z			
Range (stat mi)	531.1	530.7	+0.4	Range	753.5	753.4	+0.1
Azim. (deg)	321.93	321.97	-0.04	Azim.	322.54	322.57	-0.03
Elev. (deg)	39.86	39.84	+0.02	Elev.	24.92	24.87	+0.05
15 57 00 Z				16 53 00 Z			
Range (stat mi)	1696.7	1696.0	+0.7	Range	1823.6	1822.2	+1.4
Azim. (deg)	245.51	245.48	+0.03	Azim.	258.36	258.31	+0.05
Elev. (deg)	4.57	4.56	+0.01	Elev.	3.11	3.13	-0.02
12-17-64							
17 42 00 Z				17 47 30 Z			
Range (stat mi)	1527.0	1526.0	+1.0	Range	1662.9	1662.0	+0.9
Azim. (deg)	24.30	24.32	-0.02	Azim.	274.71	274.67	+0.04
Elev. (deg)	6.81	6.71	+0.10	Elev.	5.05	4.94	+0.11
17 44 30 Z							
Range (stat mi)	961.7	960.1	+1.6				
Azim. (deg)	333.20	333.23	-0.03				
Elev. (deg)	17.58	17.48	+0.10				

CONCLUSIONS

The primary reason for splitting the satellite trajectory look-angle problem into two main parts (i.e., the search mode and the look-angle mode) was to reduce computation time on the computer. The time increments used in the search mode were originally an order of magnitude larger than the increment used in the look-angle mode. This resulted in a faster stepping up process of the satellite in that portion of its orbit which is beneath the horizon of the receiving station. However, because of the magnitude of the search mode increment, it is possible that a satellite pass will be missed, i.e., it is possible that before advancing, the satellite is below the ascending horizon, and after being advanced, the satellite is below the descending horizon. For this reason a parabolic fit was made to obtain the maximum elevation point and to determine whether or not this point was above the horizon of the observing station. This added a great deal to the complexity of the problem. When this method is employed, the computation time on the NAREC computer is still large. For example, using a 1-sec time interval above the horizon, a 1000-mi-high satellite passing directly over an observing station will require approximately 2 hr of computation time. When this problem was run on the IBM 7090 and 7044 computers the computation time was reduced by two orders of magnitude.

If it is desired to generate look angles at time intervals of 1 min or greater, and if satellite passes that are above the horizon for less than this time interval can be ignored, then a modification could be made in the existing program such that the search mode could be eliminated. The problem would then consist only of the look-angle mode, with printout occurring only when the satellite is above the horizon of the observing station. When the time interval is less than 1 min, the reduction in computation time caused by the presence of the search mode is significant.

ACKNOWLEDGMENTS

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APPENDIX A

EXAMPLE OF FORTRAN INPUT DATA USED TO OBTAIN SATELLITE LOOK ANGLES

5230/4550(Test)12/63

NELIAC-N CODING SHEET:

PROGRAMMER _____ DATE _____

TITLE _____

7

(:Page f DATA - 1)

```
DATA , # 0000 , . .

7
DATAWORD 1 ( 27 ) = 36.0, 38841.0, , 1.046373, , ,
64.97, 31.076, 331.806, 0.0082224, 90.465,
273.574, -0.454, -3.589, , -0.00427,
81.5094, 31.9767, 0.00745645, 108.015,
63.6, 0.00833333333, 64.2,
87.7, 0.00027777777, 88.3, 9999.0,

DATAWORD N = 8888.0; . .

5 . .
```

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INPUT ORBITAL ELEMENTS

SATNO 36 MOD JULIAN DAY 38841.000

EPOCH 3/22/65 0 HR 0 MIN 0. SEC

SEMIAXIS 1.0463730 EARTH RADII DA/DT-0.32926271E-04 EARTH RADII/DAY

D(DA/DT)DT 0. EARTH RADII/DAY/DAY INCL 64.9700 DEG.

ARGPER 31.0760 DEG. RTASC 331.8060 DEG. ECCEN 0.00822239

PERIOD 90.46500 MIN. MEANLONG273.5740 DEG. ROTPER-0.4540 DEG/DAY

REG -3.5890 DEG/DAY DE/DT 0. RATIO/DAY

D(PER)/DT-0.42699999E-02 MIN/DAY

STATION PARAMETERS

WLONG 81.509398 DEG. GEODLAT 31.9766996 DEG.

SEA LEVEL HT 0.00745644 MILES FREQ 108.0150 MCS

NUMBER OF ITERATIONS ON MAX. ELEVATION FIT 8

NUMBER OF ITERATIONS ON ZERO ELEVATION FIT 6

DATE	HR	MIN	SECONDS	AZIMUTH	ELEV	RANGE	RANGERT	DOPPLER
32465.	15	39	0.0	196.9783	0.1392	1758.259	-7.241	5.218
32465.	15	39	30.0	195.7826	2.2556	1541.433	-7.210	5.196
32465.	15	40	0.0	194.1781	4.7365	1325.906	-7.153	5.155
32465.	15	40	30.0	191.9179	7.7829	1112.706	-7.049	5.079
32465.	15	41	0.0	188.5180	11.7582	903.893	-6.851	4.937
32465.	15	41	30.0	182.8972	17.3635	703.677	-6.444	4.644
32465.	15	42	0.0	172.2204	25.8814	522.451	-5.495	3.960
32465.	15	42	30.0	148.1807	37.8790	388.178	-3.102	2.235
32465.	15	43	0.0	101.9337	42.2181	358.423	1.294	-0.932
32465.	15	43	30.0	67.2098	31.2388	454.227	4.692	-3.381
32465.	15	44	0.0	52.1002	21.0400	619.777	6.124	-4.413
32465.	15	44	30.0	44.7559	14.3566	813.441	6.706	-4.833
32465.	15	45	0.0	40.5660	9.7824	1019.117	6.975	-5.026
32465.	15	45	30.0	37.8952	6.3872	1230.664	7.112	-5.125
32465.	15	46	0.0	36.0610	3.6901	1445.230	7.186	-5.178
32465.	15	46	30.0	34.7330	1.4320	1661.484	7.226	-5.207

APPENDIX B

FORTRAN SOURCE PROGRAM

```
      FOR
C     MAIN PROGRAM STARTS HERE                                          STX40002
C     MINVEC  PROGRAM USING SPASUR ORBITAL ELEMENTS                     STX40003
     0COMMON SEMIAX,DADT,DADTSQ,ECCEN,DEDT,GHA,RTASC,REG,ARGPER,ROTPER,
     1AINCL,XSTAT,YSTAT,ZSTAT,ALOZNX,ALOZNY,ALOZNZ,ANOMEP,CSEMIA,CECCEN,
     2ANOM,CARGPE,ALONGN,AITER2 ,PER,DPERDT ,ALONGE
     0READ 1, RE,PIE,TWOPI,GHADAY,AJDREF,AJDRGH,EQRAD,ANGLET,RADIAN,
     1ROTEAR,AMAXIM,VLIGHT,ZTOLER,PJDCON,AMONCO,DAYCON,YRCONS
    1 FORMAT (E16.10,3E20.10)
 2540READ1,SATNO,AJD,FRJD,SEMIAX,DADT,DADTSQ,AINCL,ARGPER,RTASC,ECCEN,
     1PER,AMEANL,ROTPER,REG,DEDT,DPERDT,WLONG,GEODLA,SEAHT,FREQ
      AINCL = AINCL * RADIAN                                            STX40024
      RTASC = RTASC * RADIAN                                            STX40025
      ARGPER = ARGPER * RADIAN                                          STX40026
      AMEANL = AMEANL * RADIAN                                          STX40027
      WLONG = WLONG * RADIAN                                            STX40028
      GEODLA = GEODLA *RADIAN                                           STX40029
      CINCL = COSF(AINCL)
      IF (DADT)65,66,65                                                 STX40031
   66 DADT = (2.0 *SEMIAX/(3.0*PER))*DPERDT                             STX40032
   65 IF(CINCL)51,50,50                                                 STX40033
   50 AMEANA = AMEANL - ARGPER - RTASC                                  STX40034
      GO TO 52                                                          STX40035
   51 AMEANA = AMEANL - ARGPER + RTASC                                  STX40036
   52 IF(AMEANA)53,53,54                                                STX40037
   53 AMEANA = TWOPI + AMEANA                                           STX40038
      GO TO 52                                                          STX40039
   54 IF(AMEANA - TWOPI)56,56,55                                        STX40040
   55 AMEANA = AMEANA - TWOPI                                           STX40041
      GO TO 54                                                          STX40042
   56 ANOMEP = AMEANA                                                   STX40043
      IF (AJD +FRJD - AJDREF)57,58,58                                   STX40044
   57 DELTIM = AJDREF - AJD - FRJD                                      STX40045
      BACKGH = DELTIM * GHADAY                                          STX40046
      ANEWGH = AJDRGH - BACKGH                                          STX40047
   61 IF( ANEWGH)59,60,60                                               STX40048
   59 ANEWGH = ANEWGH + 360.0                                           STX40049
      GO TO 61                                                          STX40050
   58 DELTIM = AJD - AJDREF + FRJD                                      STX40051
      UPGHA = DELTIM * GHADAY                                           STX40052
      ANEWGH = AJDRGH + UPGHA                                           STX40053
   63 IF( ANEWGH -360.0)60,60,62                                        STX40054
   62 ANEWGH = ANEWGH -360.0                                            STX40055
      GO TO 63                                                          STX40056
   60 GHA = ANEWGH * RADIAN                                             STX40057
      CGEODL = COSF(GEODLA)
      GEODL2 =GEODLA*2.0                                                STX40059
      CGEOD2 = COSF(GEODL2)
      GEODL4 = GEODLA * 4.0                                             STX40061
      CGEOD4 = COSF(GEODL4)
      GEODL6 = GEODLA * 6.0                                             STX40063
      CGEOD6 = COSF(GEODL6)
     0SLRAD =((0.998320047 + 0.1683494E-2 * CGEOD2 -0.3549E-5*CGEOD4    STX40065
     1+0.8E-8 * CGEOD6)* EQRAD)/1609.344                                STX40066
      TANLPR = (SINF(GEODLA) / COSF ( GEODLA)) * 0. 9933074743
      ALPR = ATANF(TANLPR)
      BET = PIE -(GEODLA - ALPR)                                        STX40069
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      CBET =COSF(BET)
      SBET = SINF (BET)
      RHO = SLRAD * SLRAD + SEAHT * SEAHT - 2.0 * SLRAD * SEAHT * CBET  STX40072
      RHO = SQRTF(RHO)
      SDELTA = SEAHT * SBET / RHO                                       STX40074
 4002 IF ( SDELTA) 5001, 5002, 5002                                     STX40075
 5001 SDELTA = ABSF(SDELTA)
      DELTAL = TWOPI - ASINF ( SDELTA )
      GO TO 5003                                                        STX40078
 5002 DELTAL = ASINF ( SDELTA )
 5003 GEOCLA = DELTAL + ALPR                                            STX40080
      CGEOCL = COSF (GEOCLA)
      SGEOCL = SINF (GEOCLA)
      RADHT = RHO                                                       STX40083
      CWLONG = COSF(WLONG)
      SGEODL = SINF(GEODLA)
      SWLONG = SINF(WLONG)
      XSTAT =( RADHT *CGEOCL *CWLONG)/RE                                STX40087
      YSTAT = -RADHT*CGEOCL*SWLONG/RE                                   STX40088
      ZSTAT = RADHT *SGEOCL /RE                                         STX40089
 4003 OUTINC = PER / 4320.                                              STX40090
      ALOZNX = CGEODL * CWLONG                                          STX40091
      ALOZNY = - CGEODL * SWLONG                                        STX40092
      ALOZNZ = SGEODL                                                   STX40093
  255 READ 1, TIME,AINCR,FTIME,TEST
      PASCOU = 0.0                                                      STX40096
      AITERA = 0.0                                                      STX40097
      ANUMBE = 0.0                                                      STX40098
      AITER1 = 0.0                                                      STX40099
      POSCT=0.0                                                         STX40100
      AIOCOU = 0.0                                                      STX40101
      AITER2 = 0.0                                                      STX40102
      AMON=AMONCO                                                       STX40103
      DAY=DAYCON                                                        STX40104
      YR=YRCONS                                                         STX40105
      AJDCON = PJDCON                                                   STX40106
    2 IF(AJDCON-AJD)4,3,3                                               STX40107
    3 W=56.0                                                            STX40108
    8 IF(YR - W)6,5,6                                                   STX40109
    6 IF(W-96.0)7,9,9                                                   STX40110
    7 W=W+4.0                                                           STX40111
      GO TO 8                                                           STX40112
    5 AJDCON = AJDCON - 366.0                                           STX40113
      GO TO 10                                                          STX40114
    9 AJDCON = AJDCON - 365.0                                           STX40115
   10 YR = YR -1.0                                                      STX40116
      GO TO 2                                                           STX40117
    4 YR = YR +1.0                                                      STX40118
      W=56.0                                                            STX40119
   15 IF(YR-W)12,11,12                                                  STX40120
   12 IF(W-96.0)13,14,13                                                STX40121
   13 W=W+4.0                                                           STX40122
      GO TO 15                                                          STX40123
   11 AJDCON = AJDCON + 366.0                                           STX40124
      GO TO 16                                                          STX40125
   14 AJDCON = AJDCON + 365.0                                           STX40126
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16 IF(AJDCON-AJD)4,17,17                                STX40127
17 W=56.0                                               STX40128
22 IF(YR-W)19,18,19                                     STX40129
19 IF(W-96.0)21,20,21                                   STX40130
21 W=W+4.0                                              STX40131
   GO TO 22                                             STX40132
18 AJDCON = AJDCON - 366.0                              STX40133
   FEB = 29.0                                           STX40134
   GO TO 23                                             STX40135
20 AJDCON =AJDCON - 365.0                               STX40136
   FEB = 28.0                                           STX40137
23 AJAN = AJDCON + 31.0                                 STX40138
   IF (AJAN-AJD)25,24,24                                STX40139
24 AMON = 1.0                                           STX40140
   AJAN = AJAN - 31.0                                   STX40141
   DAY = AJD - AJAN                                     STX40142
   GO TO 26                                             STX40143
25 DAYOFY = AJAN + FEB                                  STX40144
   IF (DAYOFY - AJD)28,27,27                            STX40145
27 AMON = 2.0                                           STX40146
   DAYOFY = DAYOFY - FEB                                STX40147
   DAY = AJD - DAYOFY                                   STX40148
   GO TO 26                                             STX40149
28 DAYOFY = DAYOFY + 31.0                               STX40150
   IF (DAYOFY - AJD)30,29,29                            STX40151
29 AMON = 3.0                                           STX40152
   DAYOFY = DAYOFY -31.0                                STX40153
   DAY = AJD - DAYOFY                                   STX40154
   GO TO 26                                             STX40155
30 DAYOFY = DAYOFY +30.0                                STX40156
   IF (DAYOFY - AJD)32,31,31                            STX40157
31 AMON = 4.0                                           STX40158
   DAYOFY = DAYOFY - 30.0
   DAY = AJD - DAYOFY                                   STX40160
   GO TO 26                                             STX40161
32 DAYOFY = DAYOFY + 31.0                               STX40162
   IF(DAYOFY - AJD) 34,33,33                            STX40163
33 AMON =5.0                                            STX40164
   DAYOFY = DAYOFY - 31.0                               STX40165
   DAY = AJD - DAYOFY                                   STX40166
   GO TO 26                                             STX40167
34 DAYOFY = DAYOFY +30.0                                STX40168
   IF(DAYOFY - AJD)36,35,35                             STX40169
35 AMON =6.0                                            STX40170
   DAYOFY = DAYOFY -30.0                                STX40171
   DAY = AJD - DAYOFY
   GO TO 26                                             STX40173
36 DAYOFY = DAYOFY +31.0                                STX40174
   IF(DAYOFY - AJD) 38,37,37                            STX40175
37 AMON =7.0                                            STX40176
   DAYOFY = DAYOFY - 31.0                               STX40177
   DAY = AJD - DAYOFY                                   STX40178
   GO TO 26                                             STX40179
38 DAYOFY = DAYOFY + 31.0                               STX40180
   IF(DAYOFY - AJD)40,39,39                             STX40181
39 AMON = 8.0                                           STX40182
   DAYOFY = DAYOFY -31.0                                STX40183
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      DAY = AJD -DAYOFY                                                 STX40184
      GO TO 26                                                          STX40185
   40 DAYOFY = DAYOFY +30.0                                             STX40186
      IF(DAYOFY-AJD)42,41,41                                            STX40187
   41 AMON=9.0                                                          STX40188
      DAYOFY=DAYOFY-30.0                                                STX40189
      DAY=AJD-DAYOFY                                                    STX40190
      GO TO 26                                                          STX40191
   42 DAYOFY = DAYOFY +31.0                                             STX40192
      IF(DAYOFY - AJD) 44,43,43                                         STX40193
   43 AMON =10.0                                                        STX40194
      DAYOFY = DAYOFY -31.0                                             STX40195
      DAY = AJD - DAYOFY                                                STX40196
      GO TO 26                                                          STX40197
   44 DAYOFY = DAYOFY +30.0                                             STX40198
      IF(DAYOFY -AJD)46,45,45                                           STX40199
   45 AMON =11.0                                                        STX40200
       DAYOFY = DAYOFY -30.0                                            STX40201
      DAY=AJD - DAYOFY                                                  STX40202
      GO TO 26                                                          STX40203
   46 DAYOFY = DAYOFY +31.0                                             STX40204
      IF(DAYOFY-AJD)48,47,47                                            STX40205
   47 AMON=12.0                                                         STX40206
      DAYOFY=DAYOFY-31.0                                                STX40207
      DAY= AJD -DAYOFY                                                  STX40208
      GO TO 26                                                          STX40209
   48 PRINT 49                                                          STX40210
   49 FORMAT(31H DID NOT BRACKET YEAR CORRECTLY)                        STX40211
      GO TO 157
   26 HRFR = FRJD * 24.0                                                STX40213
      CALL SPLIT(HRFR,HR,AMINFR)                                        STX40214
      AMINFR = AMINFR * 60.0                                            STX40215
      CALL SPLIT(AMINFR,AMIN,SEC)                                       STX40216
      SEC= SEC * 60.0                                                   STX40217
   64 TC = TIME                                                         STX40218
  229 CALL POSITI (TC,R3X1,R3Y1,R3Z1,AL1)                               STX40219
      AINAL1 = AL1                                                      STX40220
      T1 = TC                                                           STX40221
      IF(AL1)68,67,67                                                   STX40222
   67 COUN=1.0                                                          STX40223
   69 T2 = T1-(COUN*OUTINC)                                             STX40224
      CALL COMCUR (T1,ANOM1)                                            STX40225
      CALL COMCUR (T2,ANOM2)                                            STX40226
      CALL AMCK (ANOM2,ANOM1,ANOMST)                                    STX40227
      IF(ANOMST-1.309)71,70,70                                          STX40228
   70 COUN= 0.5*COUN                                                    STX40229
      GO TO 69                                                          STX40230
   71 COUN=1.0                                                          STX40231
      CALL POSITI(T2,R3X2,R3Y2,R3Z2,AL2)                                STX40232
      AINAL2 =AL2                                                       STX40233
      IF(AL2-AL1)73,72,72                                               STX40234
   72 T3= T2-(COUN*OUTINC)                                              STX40235
      CALL COMCUR(T3,ANOM3)                                             STX40236
      CALL AMCK(ANOM3,ANOM2,ANOMST)                                     STX40237
      IF(ANOMST-1.309)75,74,74                                          STX40238
   74 COUN=0.5*COUN                                                     STX40239
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      GO TO 72                                                          STX40240
   75 COUN = 1.0                                                        STX40241
      CALL POSITI (T3,R3X3,R3Y3,R3Z3,AL3)                               STX40242
      IF ( AL3 - AL2 ) 77,76,76                                         STX40243
   76 T1 = T2                                                           STX40244
      AL1 = AL2                                                         STX40245
      ANOM1 = ANOM2                                                     STX40246
      T2 = T3                                                           STX40247
      AL2 = AL3                                                         STX40248
      ANOM2 = ANOM3                                                     STX40249
      GO TO 72                                                          STX40250
   77 CALL SWITCH (T1, T2, T3, AL1, AL2, AL3)                           STX40251
  106 ORIGA1 = AL1                                                      STX40252
      ORIGT1 = T1                                                       STX40253
      ORIGA2 = AL2                                                      STX40254
      ORIGT2 = T2                                                       STX40255
      ORIGA3 = AL3                                                      STX40256
      ORIGT3 = T3                                                       STX40257
   83 CALL CALMAX(AL1,T1,AL2,T2,AL3,T3,AMAXAL,AMAXT,ACOE,BCOE,CCOE)     STX40258
      ALN = AMAXAL                                                      STX40259
      TN = AMAXT                                                        STX40260
      IF (ALN ) 5004, 5005, 5005                                        STX40261
 5004 ALN = ABSF(ALN)
      ANGLEN = PIE -ACOSF (ALN )
      GO TO 5006                                                        STX40264
 5005 ANGLEN = ACOSF ( ALN )
 5006 AITER1 = AITER1 + 1.0                                             STX40266
      IF(AITER1-1.0)79,78,79                                            STX40267
   78 ORIGAC = ACOE                                                     STX40268
      ORIGBC = BCOE                                                     STX40269
      ORIGCC = CCOE                                                     STX40270
      ABST1T = AL1                                                      STX40271
      ABST2T = AL2                                                      STX40272
      ABST3T = AL3                                                      STX40273
      IF(ABST1T-ABST2T)80,81,81                                         STX40274
   81 IF(ABST1T - ABST3T)80,82,82                                       STX40275
   82 ALNMN1=ALN                                                        STX40276
      AL1 = ALN                                                         STX40277
      TNMIN1 = TN                                                       STX40278
      T1 = TN                                                           STX40279
      ANGNM1 = ANGLEN                                                   STX40280
      GO TO 83                                                          STX40281
   80 IF(ABST2T-ABST1T)84,85,85                                         STX40282
   85 IF(ABST2T - ABST3T)84,86,86                                       STX40283
   86 ALNMN1 = ALN                                                      STX40284
      AL2 = ALN                                                         STX40285
      TNMIN1 = TN                                                       STX40286
      T2 = TN                                                           STX40287
      ANGNM1 = ANGLEN                                                   STX40288
      GO TO 83                                                          STX40289
   84 ALNMN1 = ALN                                                      STX40290
      AL3 = ALN                                                         STX40291
      TNMIN1 = TN                                                       STX40292
      T3 =TN                                                            STX40293
      ANGNM1 = ANGLEN                                                   STX40294
      GO TO 83                                                          STX40295
   79 IF (AITER1 -AMAXIM) 88,87,88                                      STX40296
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 87 PRINT 89                                                            STX40297
 890FORMAT(76H MAX NUMBER OF ITERATIONS ON PARABOLIC FIT ON INITIAL POSTX40298
   1INT HAS BEEN REACHED)                                               STX40299
    GO TO 157
 88 IF( ABSF(ANGLEN-ANGNM1) -ANGLET)90,90,91
 90 COUN = 1.0                                                          STX40302
    IMAXEL = AITER1
    AITER1 =0.0                                                         STX40303
    IF( ALN)93,93,92                                                    STX40304
 93 PRINT 94                                                            STX40305
 940FORMAT (78H INITIAL POINT ABOVE HORIZON BUT PARABOLIC FIT HOMED INSTX40306
   1 ON POINT BELOW HORIZON)                                            STX40307
    GO TO 157                                                           STX40308
 91 ABST1T = AL1                                                        STX40309
    ABST2T = AL2                                                        STX40310
    ABST3T = AL3                                                        STX40311
    IF (ABST1T -ABST2T)95,96,96                                         STX40312
 96 IF (ABST1T -ABST3T)95,97,97                                         STX40313
 97 ALNMN1 = ALN                                                        STX40314
    AL1 =ALN                                                            STX40315
    ANGNM1 =ANGLEN                                                      STX40316
    TNMIN1 =TN                                                          STX40317
    T1 =TN                                                              STX40318
    GO TO 83                                                            STX40319
 95 IF (ABST2T -ABST1T)98,99,99                                         STX40320
 99 IF (ABST2T -ABST3T)98,100,100                                       STX40321
100 ALNMN1 =ALN                                                         STX40322
    AL2 =ALN                                                            STX40323
    ANGNM1 = ANGLEN                                                     STX40324
    TNMIN1 = TN                                                         STX40325
    T2 =TN                                                              STX40326
    GO TO 83                                                            STX40327
 98 ALNMN1 =ALN                                                         STX40328
    AL3 = ALN                                                           STX40329
    ANGNM1 = ANGLEN                                                     STX40330
    TNMIN1 = TN                                                         STX40331
    T3 =TN                                                              STX40332
    GO TO 83                                                            STX40333
 73 T3=T1+(COUN*OUTINC)                                                 STX40334
    CALL COMCUR(T3,ANOM3)                                               STX40335
    CALL AMCK(ANOM1,ANOM3,ANOMST)                                       STX40336
    IF(ANOMST-1.309)102,101,101                                         STX40337
101 COUN= 0.5* COUN                                                     STX40338
    GO TO 73                                                            STX40339
102 IF(T3-FTIME)104,103,103                                             STX40340
103 GO TO 157                                                           STX40341
104 COUN =1.0                                                           STX40342
    CALL POSITI(T3,R3X3,R3Y3,R3Z3,AL3)                                  STX40343
    IF(AL3-AL1)105,252,252                                              STX40344
252 T2=T1                                                               STX40345
    AL2=AL1                                                             STX40346
    ANOM2 = ANOM1                                                       STX40347
    T1 = T3                                                             STX40348
    AL1 = AL3                                                           STX40349
    ANOM1 = ANOM3                                                       STX40350
    GO TO 73                                                            STX40351
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105 CALL SWITCH(T1,T2,T3,AL1,AL2,AL3)                                  STX40352
    GO TO 106                                                          STX40353
 68 COUN = 1.0                                                         STX40354
109 T2 = T1 +(COUN*OUTINC)                                             STX40355
    CALL COMCUR(T1,ANOM1)                                              STX40356
    CALL COMCUR(T2,ANOM2)                                              STX40357
    CALL AMCK(ANOM1,ANOM2,ANOMST)                                      STX40358
    IF(ANOMST-1.309)108,107,107                                        STX40359
107 COUN=0.5*COUN                                                      STX40360
    GO TO 109                                                          STX40361
108 IF(T2-FTIME)111,110,110                                            STX40362
110 GO TO 157                                                          STX40363
111 COUN= 1.0                                                          STX40364
119 CALL POSITI(T2,R3X2,R3Y2,R3Z2,AL2)                                 STX40365
    IF(AL2-AL1)112,113,113                                             STX40366
112 AL1= AL2                                                           STX40367
    T1=T2                                                              STX40368
    ANOM1=ANOM2                                                        STX40369
116 T2 = T1 +(COUN* OUTINC)                                            STX40370
    CALL COMCUR ( T2,ANOM2)                                            STX40371
    CALL AMCK (ANOM1,ANOM2,ANOMST)                                     STX40372
    IF (ANOMST-1.309)115,114,114                                       STX40373
114 COUN =0.5 * COUN                                                   STX40374
    GO TO 116                                                          STX40375
115 IF (T2 -FTIME)118,117,117                                          STX40376
117 GO TO 157                                                          STX40377
118 COUN = 1.0                                                         STX40378
    GO TO 119                                                          STX40379
113 B1 = AL1                                                           STX40380
    B2 = T1                                                            STX40381
    AL1 =AL2                                                           STX40382
    T1 =T2                                                             STX40383
    A1 =AL2                                                            STX40384
    A2 =T2                                                             STX40385
    ANOM1 =ANOM2                                                       STX40386
122 T2 =T1 +(COUN *OUTINC)                                             STX40387
    CALL COMCUR (T2,ANOM2)                                             STX40388
    CALL AMCK (ANOM1,ANOM2,ANOMST)                                     STX40389
    IF (ANOMST-1.309)121,120,120                                       STX40390
120 COUN =0.5 * COUN                                                   STX40391
    GO TO 122                                                          STX40392
121 IF (T2 - FTIME)124,123,123                                         STX40393
123 GO TO 157                                                          STX40394
124 COUN = 1.0                                                         STX40395
    CALL POSITI (T2,R3X2,R3Y2,R3Z2,AL2)                                STX40396
    IF(AL2-AL1)126,126,125                                             STX40397
125 ANUMBE = ANUMBE + 1.0                                              STX40398
    IF(ANUMBE - 1.0)128,127,128                                        STX40399
127 B1=AL2                                                             STX40400
    B2=T2                                                              STX40401
    AL1=AL2                                                            STX40402
    T1 = T2                                                            STX40403
    ANOM1 = ANOM2                                                      STX40404
    GO TO 122                                                          STX40405
128 A1=B1                                                              STX40406
    A2=B2                                                              STX40407
    B1=AL2                                                             STX40408
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      B2=T2                                                             STX40409
      AL1= AL2                                                          STX40410
      ANOM1 = ANOM2                                                     STX40411
      T1=T2                                                             STX40412
      GO TO 122                                                         STX40413
  126 IF(B2)130,129,130                                                 STX40414
  129 PRINT 131                                                         STX40415
 1310FORMAT(68H ANOMALY JUMP TO LARGE. SECOND POINT OMITTED BECAUSE MAXSTX40416
     1 ELEV PASSED)                                                     STX40417
      GO TO 157                                                         STX40418
  130 IF(ANUMBE) 133,132,133                                            STX40419
  132 A84 = B1                                                          STX40420
      T84 = B2                                                          STX40421
      B1 = A1                                                           STX40422
      B2 = A2                                                           STX40423
      A1 = A84                                                          STX40424
      A2 = T84                                                          STX40425
  133 C1 = AL2                                                          STX40426
      C2 = T2                                                           STX40427
      ORIGA1 = A1                                                       STX40428
      ORIGT1 = A2                                                       STX40429
      ORIGA2 = B1                                                       STX40430
      ORIGT2 = B2                                                       STX40431
      ORIGA3 = C1                                                       STX40432
      ORIGT3 = C2                                                       STX40433
  139 CALL CALMAX( A1,A2,B1,B2,C1,C2,AMAXAL,AMAXT,ACOE,BCOE,CCOE)       STX40434
      ALN = AMAXAL                                                      STX40435
      TN = AMAXT                                                        STX40436
      IF( ALN ) 5007,5008,5008                                          STX40437
 5007 ALN = ABSF(ALN)
      ANGLEN = PIE -ACOSF ( ALN )
      GO TO 5009                                                        STX40440
 5008 ANGLEN = ACOSF ( ALN )
 5009 AITERA = AITERA +1.0                                              STX40442
      IF(AITERA - 1.0)135,134,135                                       STX40443
  134 ORIGAC = ACOE                                                     STX40444
      ORIGBC = BCOE                                                     STX40445
      ORIGCC = CCOE                                                     STX40446
      ABST1T = ABSF(A2-TN)
      ABST2T = ABSF(B2-TN)
      ABST3T = ABSF(C2-TN)
      IF(ABST1T-ABST2T)136,136,138                                      STX40450
  136 IF(ABST1T-ABST3T)137,137,138                                      STX40451
  137 ALNMN1 = ALN                                                      STX40452
      A1 = ALN                                                          STX40453
      TNMIN1 = TN                                                       STX40454
      A2 = TN                                                           STX40455
      ANGNM1 = ANGLEN                                                   STX40456
      GO TO 139                                                         STX40457
  138 IF(ABST2T-ABST1T)140,140,141                                      STX40458
  140 IF(ABST2T-ABST3T)142,142,141                                      STX40459
  142 ALNMN1 = ALN                                                      STX40460
      B1 = ALN                                                          STX40461
      TNMIN1 = TN                                                       STX40462
      B2 = TN                                                           STX40463
      ANGNM1 = ANGLEN                                                   STX40464
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      GO TO 139                                                         STX40465
  141 ALNMN1 = ALN                                                      STX40466
      C1 = ALN                                                          STX40467
      TNMIN1 = TN                                                       STX40468
      C2 = TN                                                           STX40469
      ANGNM1 = ANGLEN                                                   STX40470
      GO TO 139                                                         STX40471
  135 IF(AITERA- AMAXIM)144,143,144                                     STX40472
  143 PRINT 145                                                         STX40473
  145 FORMAT(51H EXCEEDED MAX NUMBER OF ITERATIONS ON PARABOLIC FIT)    STX40474
      GO TO 157                                                         STX40475
  144 IF(ABSF(ANGLEN-ANGNM1)-ANGLET)146,146,147
  146 COUN= 1.0                                                         STX40477
      ANUMBE =0.0                                                       STX40478
      IMAXEL = AITERA
      AITERA = 0.0                                                      STX40479
      IF (AMAXAL) 149,149,92                                            STX40480
  149 T1 = TN                                                           STX40481
      AL1 =ALN                                                          STX40482
      GO TO 109                                                         STX40483
  147 ABST1T = ABSF(A2-TN)
      ABST2T = ABSF(B2-TN)
      ABST3T = ABSF(C2-TN)
      IF(ABST1T-ABST2T)150,150,151                                      STX40487
  150 IF(ABST1T-ABST3T)152,152,151                                      STX40488
  152 ALNMN1 = ALN                                                      STX40489
      A1 = ALN                                                          STX40490
      TNMIN1 = TN                                                       STX40491
      A2 = TN                                                           STX40492
      ANGNM1 = ANGLEN                                                   STX40493
      GO TO 139                                                         STX40494
  151 IF(ABST2T-ABST1T)153,153,156                                      STX40495
  153 IF(ABST2T-ABST3T)155,155,156                                      STX40496
  155 ALNMN1 = ALN                                                      STX40497
      B1 = ALN                                                          STX40498
      TNMIN1 = TN                                                       STX40499
      B2 =TN                                                            STX40500
      ANGNM1 =ANGLEN                                                    STX40501
      GO TO 139                                                         STX40502
  156 ALNMN1 =ALN                                                       STX40503
      C1 = ALN                                                          STX40504
      TNMIN1 = TN                                                       STX40505
      C2 =TN                                                            STX40506
      ANGNM1 = ANGLEN                                                   STX40507
      GO TO 139                                                         STX40508
  157 IF (TEST) 256,257,256
  256 IF (TEST - 1.0) 254,255,254                                       STX40515
  257 CALL ENDJOB
   92 AA = ORIGAC                                                       STX40516
      BB = ORIGBC                                                       STX40517
      CC = ORIGCC                                                       STX40518
      T = BB * BB - 4.0 *AA *CC                                         STX40519
      T = SQRTF(T)
      T = ABSF( T/ (2.0 * AA))
      T = -(BB/ (2.0 *AA))- T                                           STX40522
      TON = T                                                           STX40523
      CALL POSITI (TON,R3X,R3Y,R3Z,ALPHAO)                              STX40524
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      IF (ORIGT2 -AMAXT)148,154,154                                     STX40525
  154 CALL POSITI (ORIGT1,TR3X,TR3Y,TR3Z,ORIGA1)                        STX40526
      ZALPHA = ORIGA1                                                   STX40527
      ZTIME = ORIGT1                                                    STX40528
      GO TO 158                                                         STX40529
  148 ZTEMP1 = ABSF(ORIGA1)
      IF ( ABSF(ORIGA2) -ZTEMP1)159,159,154
  159 CALL POSITI ( ORIGT2,TR3X,TR3Y,TR3Z,ORIGA2)                       STX40532
      ZTIME =ORIGT2                                                     STX40533
      ZALPHA = ORIGA2                                                   STX40534
  158 IF( TON -ZTIME)160,161,161                                        STX40535
  160 CALL ALINHO ( R3X,R3Y,R3Z,TON,TR3X,TR3Y,TR3Z,ZTIME,ANEWTI ,ITEST) STX40536
  253 IF(ITEST) 157,168,157                                             STX40537
  168 ZTEMP1 = ABSF(ZALPHA)
      IF (ABSF(ALPHAO)-ZTEMP1)162,163,163
  162 IF (ABSF(TON -ANEWTI) - ZTOLER) 5050,5050,165
  165 ZTIME = ANEWTI                                                    STX40541
      CALL POSITI (ZTIME,TR3X,TR3Y,TR3Z,ZALPHA)                         STX40542
      GO TO 158                                                         STX40543
  163 IF (ABSF(ZTIME-ANEWTI)-ZTOLER)166,166,167
  166 TON =ZTIME                                                        STX40545
      ALPHAO = ZALPHA                                                   STX40546
      R3X =TR3X                                                         STX40547
      R3Y =TR3Y                                                         STX40548
      R3Z =TR3Z                                                         STX40549
      GO TO 5050
  167 TON =ANEWTI                                                       STX40551
      CALL POSITI (TON,R3X,R3Y,R3Z,ALPHAO)                              STX40552
      GO TO 158                                                         STX40553
  161 CALL ALINHO (TR3X,TR3Y,TR3Z,ZTIME,R3X,R3Y,R3Z,TON,ANEWTI ,ITEST)  STX40554
       GO TO 253                                                        STX40555
 5050 IZEROE = AITER2
  164 SINLGE = SINF(GEODLA)
      COSLGE = COSF(GEODLA)
      SINWLO = SINF(WLONG)
      COSWLO = COSF(WLONG)
      ANX = - SINLGE * COSWLO                                           STX40560
      ANY =   SINLGE * SINWLO                                           STX40561
      ANZ = COSLGE                                                      STX40562
      AAX = -SINWLO                                                     STX40563
      AAY = -COSWLO                                                     STX40564
      TC =TON                                                           STX40565
      IF (POSCT -1.0)169,170,169                                        STX40566
  169 POSCT = 1.0                                                       STX40567
      TE = FRJD*24.0
      ADJTP = (TC+TE)*60.0
      CALL SPLIT ( ADJTP, ADJTP, ADJTP1)                                STX40569
      TC = (ADJTP/60.0)-TE
  170 CALL POSITI(TC,R3X,R3Y,R3Z,ALPHAO)                                STX40571
  230 RPRIMN = R3X* ANX +R3Y* ANY +R3Z*ANZ                              STX40572
      RPRIMA = R3X*AAX+R3Y*AAY                                          STX40573
      RPRIMX = RPRIMN * ANX +RPRIMA *AAX                                STX40574
      RPRIMY = RPRIMN * ANY +RPRIMA *AAY                                STX40575
      RPRIMZ = RPRIMN * ANZ                                             STX40576
      TEMP = RPRIMX **2 +RPRIMY **2 + RPRIMZ **2                        STX40577
      TEMP = SQRTF(TEMP)
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      RPRIMX = RPRIMX /TEMP                                             STX40579
      RPRIMY = RPRIMY / TEMP                                            STX40580
      RPRIMZ = RPRIMZ / TEMP                                            STX40581
      AZANGL = RPRIMX * ANX +RPRIMY *ANY +RPRIMZ *ANZ                   STX40582
      IF ( AZANGL ) 5010, 5011, 5011                                    STX40583
 5010 AZANGL = ABSF ( AZANGL)
      AZANGL = PIE - ACOSF ( AZANGL )
      GO TO 5012                                                        STX40586
 5011 AZANGL = ACOSF (AZANGL )
 5012 IF (RPRIMA ) 172, 171, 171                                        STX40588
  171 AZANGL = TWOPI - AZANGL                                           STX40589
  172 TEMP= R3X ** 2 + R3Y**2 + R3Z **2                                 STX40590
      R3MAG = SQRTF(TEMP)
      TEMP = (R3X * ALOZNX +R3Y*ALOZNY +R3Z * ALOZNZ) /R3MAG            STX40592
      IF ( TEMP) 5013, 5014, 5014                                       STX40593
 5013 TEMP =ABSF (TEMP)
      TEMP = PIE- ACOSF (TEMP)
      GO TO 5015                                                        STX40596
 5014 TEMP = ACOSF ( TEMP)
 5015 ELEVAN = TWOPI / 4.0 - TEMP                                       STX40598
      TEMP = 60.0* TWOPI / (PER +DPERDT *TC / 24.0)                     STX40599
      TEMPVL = 1.0 - CECCEN * CECCEN                                    STX40600
      COSINE = COSF(ANOM)
      TEMPVL = TEMPVL * TEMPVL * TEMPVL                                 STX40602
      TEMPVL = SQRTF(TEMPVL)
      ANDOT =(1.0+ CECCEN* COSINE)*(1.0 + CECCEN * COSINE)*TEMP/TEMPVL  STX40604
      RPRAD = ROTPER * RADIAN/24.0                                      STX40605
      REGRAD = REG * RADIAN/24.0                                        STX40606
     0CALL VELOCI (CSEMIA,CECCEN,AINCL,ANOM,CARGPE,ALONGE,RPRAD,REGRAD, STX40607
     1ANDOT,RHO,CGEOCL,SWLONG,CWLONG,VX,VY,VZ)                          STX40608
      VX = VX * RE/3600.0                                               STX40609
      VY = VY*RE/3600.0                                                 STX40610
      VZ = VZ* RE/3600.0                                                STX40611
      RANGER = (R3X *VX + R3Y* VY +R3Z* VZ)/ R3MAG                      STX40612
      DOPPLE = -2.0 * FREQ * 1000.0 * RANGER/VLIGHT                     STX40613
      IF(AIOCOU)174,173,174                                             STX40614
  173 AINCL = AINCL/ RADIAN                                             STX40615
      ARGPER = ARGPER/RADIAN                                            STX40616
      RTASC = RTASC/RADIAN                                              STX40617
      AMEANL = AMEANL/RADIAN                                            STX40618
      WLONG = WLONG/RADIAN                                              STX40619
      GEODLA = GEODLA/RADIAN                                            STX40620
      AIOCOU = AIOCOU + 1.0                                             STX40621
      OU1 = AJD + FRJD                                                  STX40622
      MON = AMON                                                        STX40623
      ISATNO = SATNO                                                    STX40624
      IDAY = DAY                                                        STX40625
      IYR = YR                                                          STX40626
      IHR = HR                                                          STX40627
      MIN = AMIN                                                        STX40628
      PRINT 175,ISATNO,OU1,MON,IDAY,IYR,IHR,MIN,SEC                     STX40631
 1750FORMAT(1H1,19X,31H INPUT     ORBITAL     ELEMENTS,///,10X,6H SATNOSTX40632
     1,I4, 16H  MOD JULIAN DAY,2X,F9.3,//,11X,5HEPOCH,2X,I2,1H/,I2,1H/, STX40633
     2I2,3X,I2,3H HR,I3,4H MIN,F9.6,4H SEC,//)                          STX40634
     0PRINT 176, SEMIAX,DADT,DADTSQ,AINCL,ARGPER,RTASC,ECCEN,PER,AMEANL,STX40635
     1ROTPER,REG,DEDT,DPERDT                                            STX40636
  176 FORMAT(2X,8HSEMIAXIS,F10.7,20H EARTH RADII   DA/DT,E15.8,16H EARTHSTX40637
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    1 RADII/DAY,//,2X,11HD(DA/DT)DT ,E14.8,31H EARTH RADII/DAY/DAY      STX40638
    2INCL  ,F8.4,5H DEG.,//,2X,7HARGPER ,F8.4,18H DEG.      RTASC    ,F8.STX40639
    34,16H DEG.     ECCEN  ,F10.8,//,2X,6HPERIOD,F10.5,17H MIN.     MEANLSTX40640
    4ONG,F8.4,15H DEG.     ROTPER,F7.4,8H DEG/DAY,//,2X,5HREG  ,F7.4,21HSTX40641
    5 DEG/DAY      DE/DT    ,E14.8,10H RATIO/DAY,//,2X,9HD(PER)/DT,E15.8,STX40642
    68H MIN/DAY,//////)                                                  STX40643
     PRINT 177,WLONG,GEODLA,SEAHT,FREQ                                   STX40644
 1770FORMAT(20X,22HSTATION      PARAMETERS,//,2X,10HWLONG      ,F10.6,  STX40645
    119H DEG.        GEODLAT,F11.7,5H DEG.,//,2X,12HSEA LEVEL HT,F11.8, STX40646
    214H MILES     FREQ,F11.4,4H MCS,////)                               STX40647
     PRINT 5060 , IMAXEL , IZEROE
50600FORMAT (2X,42HNUMBER OF ITERATIONS ON MAX. ELEVATION FIT,I2,//,2X,
    142HNUMBER OF ITERATIONS ON ZERO ELEVATION FIT,I2,//)
     AINCL = AINCL * RADIAN                                              STX40648
     ARGPER = ARGPER * RADIAN                                            STX40649
     RTASC = RTASC * RADIAN                                              STX40650
     AMEANL = AMEANL * RADIAN                                            STX40651
     WLONG = WLONG * RADIAN                                              STX40652
     GEODLA = GEODLA * RADIAN                                            STX40653
     PRINT 178                                                           STX40654
 178 FORMAT(68H   DATE  HR MIN SECONDS  AZIMUTH  ELEV     RANGE    RANGSTX40655
    1ERT  DOPPLER,//)                                                    STX40656
 174 OU26 = AZANGL/RADIAN                                                STX40657
     OU27 = ELEVAN/RADIAN                                                STX40658
     OU28 = 1.609344 * R3MAG * RE                                        STX40659
     OU29 = 1.609344 * RANGER                                            STX40660
     OU30 = DOPPLE                                                       STX40661
     TDAYS = TC/24.0                                                     STX40664
     CALL SPLIT (TDAYS,DAYS,THRS)                                        STX40665
     THRS = THRS * 24.0                                                  STX40666
     CALL SPLIT (THRS,HRS,TMINS)                                         STX40667
     TMINS = TMINS * 60.0                                                STX40668
     CALL SPLIT ( TMINS, AMINS, TSECS)                                   STX40669
     SECS = TSECS * 60.0                                                 STX40670
     STLSEC = (SECS+0.05)*10.0
     STLSE1 = 0.0
     STLSE2 = 0.0
     CALL SPLIT (STLSEC,STLSE1,STLSE2)
     STLSEC = STLSE1/10.0
     TC = STLSEC/3600.0+AMINS/60.0+HRS+DAYS*24.0
     FDAY = DAYS + DAY                                                   STX40671
     FHR = HRS + HR                                                      STX40672
     FMIN = AMINS + AMIN                                                 STX40673
     FSEC = SECS + SEC                                                   STX40674
     TEMPSE = FSEC + 0.05                                                STX40675
     SECCOU = 0.0                                                        STX40676
 183 IF(TEMPSE - 60.0)182,181,181                                        STX40677
 181 FSEC = ABSF(FSEC - 60.0)
     TEMPSE = TEMPSE - 60.0                                              STX40679
     SECCOU = SECCOU + 1.0                                               STX40680
     GO TO 183                                                           STX40681
 182 FMIN = SECCOU + FMIN                                                STX40682
     SECCOU = 0.0                                                        STX40683
     AMINCO = 0.0                                                        STX40684
 186 IF(FMIN - 60.0)185,184,184                                          STX40685
 184 FMIN = FMIN - 60.0                                                  STX40686
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      AMINCO = AMINCO + 1.0                                             STX40687
      GO TO 186                                                         STX40688
  185 FHR = AMINCO + FHR                                                STX40689
      AMINCO = 0.0                                                      STX40690
      HRCOU = 0.0                                                       STX40691
  189 IF(FHR - 24.0)188,187,187                                         STX40692
  187 FHR = FHR - 24.0                                                  STX40693
      HRCOU = HRCOU + 1.0                                               STX40694
      GO TO 189                                                         STX40695
  188 FDAY = HRCOU + FDAY                                               STX40696
      HRCOU = 0.0                                                       STX40697
      FMON = AMON                                                       STX40698
      FYR = YR                                                          STX40699
  198 IF(FMON - 2.0)191,190,191                                         STX40700
  190 W = 60.0                                                          STX40701
  195 IF(FYR - W)194,193,192                                            STX40702
  192 W = W + 4.0                                                       STX40703
      IF(W - 96.0)195,195,194                                           STX40704
  193 IF(FDAY - 29.0)197,197,196                                        STX40705
  196 FMON = FMON + 1.0                                                 STX40706
      FDAY = FDAY - 29.0                                                STX40707
      GO TO 198                                                         STX40708
  194 IF(FDAY - 28.0)197,197,199                                        STX40709
  199 FMON = FMON + 1.0                                                 STX40710
      FDAY = FDAY - 28.0                                                STX40711
      GO TO 198                                                         STX40712
  191 WW = 1.0                                                          STX40713
      WWW = 8.0                                                         STX40714
  202 IF(FMON - WW)205,200,201                                          STX40715
  201 WW = WW + 2.0                                                     STX40716
      IF(WW - 7.0)202,202,203                                           STX40717
  203 IF(FMON - WWW)205,200,204                                         STX40718
  204 IF(FMON - 10.0)205,200,205                                        STX40719
  200 IF(FDAY - 31.0)207,207,206                                        STX40720
  207 IF(FMON - 12.0)197,197,208                                        STX40721
  205 IF(FMON - 12.0)210,209,210                                        STX40722
  209 IF(FDAY - 31.0)197,197,211                                        STX40723
  206 FMON = FMON + 1.0                                                 STX40724
      FDAY = FDAY - 31.0                                                STX40725
      GO TO 198                                                         STX40726
  211 FYR = FYR + 1.0                                                   STX40727
      FMON = 1.0                                                        STX40728
      FDAY = FDAY - 31.0                                                STX40729
      GO TO 191                                                         STX40730
  210 W4 = 4.0                                                          STX40731
      W5 = 9.0                                                          STX40732
  216 IF(FMON - W4)214,213,215                                          STX40733
  215 W4 = W4 + 2.0                                                     STX40734
      IF(W4 - 6.0)216,216,217                                           STX40735
  217 IF(FMON - W5) 214,213,218                                         STX40736
  218 IF(FMON - 11.0)214,213,214                                        STX40737
  213 IF(FDAY - 30.0)207,207,219                                        STX40738
  219 FMON = FMON + 1.0                                                 STX40739
      FDAY = FDAY - 30.0                                                STX40740
      GO TO 198                                                         STX40741
  214 PRINT 220                                                         STX40742
  220 FORMAT ( 18H MONTH INPUT ERROR)                                   STX40743
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      GO TO 157
  208 FYR = FYR + 1.0                                                   STX40745
      FMON = FMON -12.0                                                 STX40746
      GO TO 198                                                         STX40747
  197 IF(OU27) 5021,5020,5020
 5020 OU38 = FMON * 10000.0 + FDAY * 100.0 + FYR
      IOU34 = FHR                                                       STX40749
      IOU35 = FMIN                                                      STX40750
      OU36 = FSEC                                                       STX40751
      PRINT 212, OU38,IOU34,IOU35,OU36,OU26,OU27,OU28,OU29,OU30         STX40752
 2120FORMAT(F8.0,1X,I2,2X,I2,2X,F6.1,3X,F8.4,1X,F7.4,1X,F9.3,2X,F6.3,   STX40753
     11X,F9.3)                                                          STX40754
 5021 TC = TC + AINCR
      CALL POSITI(TC,ANR3X,ANR3Y,ANR3Z,ALC)                             STX40776
      TCP = TC                                                          STX40777
      IF(TC - AMAXT)221,221,222                                         STX40778
  222 IF(ALC)223,221,221                                                STX40779
  223 PRINT 224                                                         STX40780
  224 FORMAT (1H1)                                                      STX40781
      TC = TCP - AINCR                                                  STX40782
      COUN = 1.0                                                        STX40783
      AITER1 = 0.0                                                      STX40784
      PASCOU = 0.0                                                      STX40785
      AITER2 = 0.0                                                      STX40786
      ANUMBE = 0.0                                                      STX40787
      AITERA = 0.0                                                      STX40788
      POSCT = 0.0                                                       STX40789
  227 TC = TCP +(COUN * OUTINC)                                         STX40790
      CALL COMCUR(TCP,ALP)                                              STX40791
      CALL COMCUR(TC,ALC)                                               STX40792
      CALL AMCK(ALC,ALP,ANOMST)                                         STX40793
      IF(ANOMST - 1.309)226,225,225                                     STX40794
  225 COUN = 0.5 * COUN                                                 STX40795
      GO TO 227                                                         STX40796
  226 IF(TC - FTIME)228,228,157                                         STX40797
  228 COUN = 1.0                                                        STX40798
      B2 = 0.0                                                          STX40799
      GO TO 229                                                         STX40800
  221 R3X = ANR3X                                                       STX40801
      R3Y = ANR3Y                                                       STX40802
      R3Z = ANR3Z                                                       STX40803
      GO TO 230                                                         STX40804
      END                                                               STX40859
       FOR
      SUBROUTINE POSITI (CURRTI,R3X,R3Y,R3Z,AL)                         POSI0003
     0COMMON SEMIAX,DADT,DADTSQ,ECCEN,DEDT,GHA,RTASC,REG,ARGPER,ROTPER,
     1AINCL,XSTAT,YSTAT,ZSTAT,ALOZNX,ALOZNY,ALOZNZ,ANOMEP,CSEMIA,CECCEN,
     2ANOM,CARGPE,ALONGN,AITER2 ,PER,DPERDT ,ALONGE
      PIE = 3.14159265                                                  POSI0013
      TWOPI = 6.2831852                                                 POSI0014
      ROTEAR = 0.26251617                                               POSI0015
      RADIAN = 0.174532925E-1                                           POSI0016
      TIMED = CURRTI/24.0                                               POSI0017
      CSEMIA = SEMIAX + (DADT * TIMED) + (DADTSQ * TIMED * TIMED)       POSI0018
      CECCEN = ECCEN + (DEDT * TIMED)                                   POSI0019
      CALL COMCUR(CURRTI,ANOM)                                          POSI0020
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      IF(GHA - RTASC)3006,3006,3007                                     POSI0021
 3006 ALONGN = 2.0 * PIE + GHA -RTASC                                   POSI0022
      GO TO 4000                                                        POSI0023
 3007 ALONGN = GHA - RTASC                                              POSI0024
 4000 ALONGE = ALONGN + ROTEAR* CURRTI - (REG * RADIAN /24.0)* CURRTI   POSI0025
      CARGPE = ARGPER + (ROTPER * RADIAN/24.0) * CURRTI                 POSI0026
      SUM =CARGPE +ANOM                                                 POSI0027
      SINSUM = SINF(SUM)
      COSSUM = COSF(SUM)
      SININC = SINF(AINCL)
      COSINC = COSF(AINCL)
      SINWSI = SINSUM * SININC                                          POSI0032
      IF ( SINWSI) 5016, 5017, 5017                                     POSI0033
 5016 SINWSI = ABSF (SINWSI)
      A = TWOPI - ASINF ( SINWSI)
      GO TO 5018                                                        POSI0036
 5017 A = ASINF ( SINWSI)
 5018 D = 1.0- SINSUM * SINSUM * SININC ** 2                            POSI0038
      E = SQRTF(D)
      F = SINSUM * COSINC/E                                             POSI0040
 4005 IF (F) 5019,5020,5020                                             POSI0041
 5019 F =ABSF (F)
      G = TWOPI - ASINF (F)
      GO TO 5021                                                        POSI0044
 5020 G = ASINF (F)
 5021 IF ( COSSUM ) 3008,3031, 3031                                     POSI0046
 3008 G = PIE -G                                                        POSI0047
 3031 B = PIE * 2.0 - ALONGE + G                                        POSI0048
      COSANO = COSF(ANOM)
      C= CSEMIA * (1.0 - CECCEN * CECCEN)/(1.0 + CECCEN * COSANO)       POSI0050
 4006 COSA = COSF(A)
      COSB = COSF(B)
      SINB = SINF(B)
      X = C* COSA * COSB                                                POSI0054
      R3X = X - XSTAT                                                   POSI0055
      Y= C* COSA * SINB                                                 POSI0056
      R3Y = Y - YSTAT                                                   POSI0057
      Z = C * SINSUM * SININC                                           POSI0058
      R3Z = Z - ZSTAT                                                   POSI0059
      R = X**2 + Y**2 + Z**2                                            POSI0060
      SQR = SQRTF(R)
      ARCLAT = Z/SQR                                                    POSI0062
 4007 IF( ARCLAT) 5022,5023,5023                                        POSI0063
 5022 ARCLAT = ABSF( ARCLAT)
      ALAT1 = TWOPI - ASINF (ARCLAT)
      GO TO 5024                                                        POSI0066
 5023 ALAT1 = ASINF ( ARCLAT)
 5024 XSRY = X**2 +Y**2                                                 POSI0068
      SQRXY = SQRTF(XSRY)
      ARCLON = X/SQRXY                                                  POSI0070
 4008 IF (ARCLON) 5025, 5026, 5026                                      POSI0071
 5025 ARCLON = ABSF( ARCLON)
      ALONG1 = PIE - ACOSF(ARCLON)
      GO TO 5027                                                        POSI0074
 5026 ALONG1 = ACOSF (ARCLON)
 5027 R3SQ = R3 X**2 +R3Y**2 +R3Z**2                                    POSI0076
      AMAGR3  = SQRTF(R3SQ)
```

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      RZ = R3X * ALOZNX + R3Y * ALOZNY + R3Z * ALOZNZ                    POSI0078
      AL = RZ/AMAGR3                                                    POSI0079
 4009 RETURN                                                            POSI0080
      END                                                               POSI0081
       FOR
      SUBROUTINE COMCUR (CTIME,CANOM)                                   COMC0003
     0COMMON SEMIAX,DADT,DADTSQ,ECCEN,DEDT,GHA,RTASC,REG,ARGPER,ROTPER,
     1AINCL,XSTAT,YSTAT,ZSTAT,ALOZNX,ALOZNY,ALOZNZ,ANOMEP,CSEMIA,CECCEN,
     2ANOM,CARGPE,ALONGN,AITER2 ,PER,DPERDT ,ALONGE
      AMENAN = ANOMEP                                                   COMC0013
      TIMEC = CTIME                                                     COMC0014
      CALL CMPNMN(DPERDT,AMENAN,TIMEC,PER,ANEWME)                       COMC0015
      PIE = 3.14159265                                                  COMC0016
 3009 IF((2.0* PIE)- ANEWME)3010,3010,3011                              COMC0017
 3010 ANEWME = ANEWME - 2.0 * PIE                                       COMC0018
      GO TO 3009                                                        COMC0019
 3011 AMENAN = ANEWME                                                   COMC0020
      SINMEA = SINF(AMENAN)
      CECCEN = ECCEN +(DEDT * CTIME/24.0)                               COMC0022
      E1 = AMENAN +(CECCEN * SINMEA)                                    COMC0023
 3014 SINE1 = SINF(E1)
      E2 = AMENAN +(CECCEN * SINE1)                                     COMC0025
      IF(ABSF(E2 - E1)-0.1745329252E-6)3013,3013,3012
 3012 E1 = E2                                                           COMC0027
      GO TO 3014                                                        COMC0028
 3013 COSE2 = COSF(E2)
      E3 = (COSE2 - CECCEN)/(1.0 - CECCEN * COSE2)                      COMC0030
 4010 IF( E3) 5028, 5029,5029                                           COMC0031
 5028 E3 = ABSF( E3 )
      CANOM = PIE - ACOSF( E3)
      GO TO 5030                                                        COMC0034
 5029 CANOM = ACOSF( E3)
 5030 DELTAT = AMENAN / (2.0*PIE)                                       COMC0036
      IF(DELTAT - 0.5)3016,3015,3015                                    COMC0037
 3015 CANOM = 2.0 * PIE - CANOM                                         COMC0038
 3016 RETURN                                                            COMC0039
      END                                                               COMC0040
       FOR
     0SUBROUTINE VELOCI(SEMIMA,ECCENT,AINCLI,TRANOM,ARGPRE,BLONGN,DWDT, VELO0003
     1DRTASC,DVDT,RHO,CGEOCL,SWLONG,CWLONG,XDOT,YDOT,ZDOT)              VELO0004
      ROTEAR = 0.26251617                                               VELO0005
      RE = 3963.338                                                     VELO0006
      PIE = 3.14159265                                                  VELO0007
      TWOPI = 6.28318531                                                VELO0008
      SINI = SINF(AINCLI)
      COSI = COSF(AINCLI)
      SINV = SINF(TRANOM)
      COSV = COSF(TRANOM)
      TEMP1 = TRANOM + ARGPRE                                           VELO0013
      SINARG = SINF(TEMP1)
      COSARG = COSF(TEMP1)
      TEMP2 = 1.0 - (SINARG * SINARG * SINI * SINI)                     VELO0016
      SQUARE = SQRTF(TEMP2)
      BETA = COSARG/SQUARE                                              VELO0018
 4019 IF (BETA) 5031, 5032, 5032                                        VELO0019
 5031 BETA = ABSF(BETA)
```

```
      BETA =PIE - ACOSF(BETA)
      GO TO 5033                                                        VEL00022
 5032 BETA = ACOSF(BETA)
 5033 IF( SINARG* COSI) 3024, 3024, 3023                                VEL00024
 3024 BETA = TWOPI - BETA                                               VEL00025
 3023 ALPHA = TWOPI - BLONGN + BETA                                     VEL00026
      COSALP = COSF(ALPHA)
      SINALP = SINF(ALPHA)
      TEMP1 = SEMIMA * (1.0 - ECCENT * ECCENT) * SQUARE                 VEL00029
      AX = TEMP1/(1.0 + ECCENT * COSV)                                  VEL00030
 4020 AY = TEMP1/(1.0 + ECCENT * COSV)                                  VEL00031
      BX = TEMP1 * COSALP                                               VEL00032
      BY = TEMP1 * SINALP                                               VEL00033
      TEMP2 = TEMP1/SQUARE                                              VEL00034
      CX = TEMP2 * COSALP/(1.0 + ECCENT * COSV)                         VEL00035
      CY = TEMP2 * SINALP/(1.0 + ECCENT * COSV)                         VEL00036
      DXDRTA =  -AX * SINALP                                            VEL00037
      TEMP1 = AX * SINALP * COSI/(SQUARE * SQUARE)                      VEL00038
      TEMP2 = CX * SINI * SINI * SINARG * COSARG /SQUARE                VEL00039
      DXDW = -(TEMP1 + TEMP2)                                           VEL00040
     0DXDV  = BX * ECCENT * SINV/((1.0 + ECCENT * COSV)* (1.0 + ECCENT *VEL00041
     1COSV))                                                            VEL00042
      DXDV = DXDV - TEMP1 - TEMP2                                       VEL00043
      DYDRTA = AY * COSALP                                              VEL00044
      TEMP1 = AY * COSALP * COSI/(SQUARE * SQUARE)                      VEL00045
      TEMP2 = CY * SINI * SINI * SINARG * COSARG /SQUARE                VEL00046
      DYDW = TEMP1 - TEMP2                                              VEL00047
     0DYDV = BY * ECCENT * SINV/((1.0 + ECCENT * COSV) * (1.0 + ECCENT  VEL00048
     1* COSV))                                                          VEL00049
      DYDV = DYDV + TEMP1 - TEMP2                                       VEL00050
      TEMP1 = SEMIMA * (1.0 - ECCENT ** 2) * SINI                       VEL00051
      TEMP2 = TEMP1 * COSARG/(1.0 + ECCENT * COSV)                      VEL00052
      DZDW = TEMP2                                                      VEL00053
      DZDV = TEMP1 * ECCENT * SINARG * SINV/ (1.0 + ECCENT * COSV)**2   VEL00054
      DZDV = DZDV + TEMP2                                               VEL00055
      XDOT = DXDRTA * DRTASC + DXDW * DWDT + DXDV * DVDT                VEL00056
      YDOT = DYDRTA * DRTASC + DYDW * DWDT + DYDV * DVDT                VEL00057
      ZDOT = DZDW * DWDT + DZDV * DVDT                                  VEL00058
      XDOTST = ROTEAR * RHO * CGEOCL * SWLONG/RE                        VEL00059
      YDOTST = ROTEAR * RHO * CGEOCL * CWLONG /RE                       VEL00060
      XDOT = XDOT - XDOTST                                              VEL00061
      YDOT = YDOT - YDOTST                                              VEL00062
      RETURN                                                            VEL00063
      END                                                               VEL00064
       FOR
      SUBROUTINE ALINHO(ZX1,ZY1,ZZ1,ZT1,ZX2,ZY2,ZZ2,ZT2,ZTO ,ITEST)     ALIN0003
     0COMMON SEMIAX,DADT,DADTSQ,ECCEN,DEDT,GHA,RTASC,REG,ARGPER,ROTPER,
     1AINCL,XSTAT,YSTAT,ZSTAT,ALOZNX,ALOZNY,ALOZNZ,ANOMEP,CSEMIA,CECCEN,
     2ANOM,CARGPE,ALONGN,AITER2 ,PER,DPERDT ,ALONGE
      ZD1 = ZX1 * ALOZNX + ZY1 * ALOZNY + ZZ1 * ALOZNZ                  ALIN0013
      ZD2 = ZX2 * ALOZNX + ZY2 * ALOZNY + ZZ2 * ALOZNZ                  ALIN0014
      ZTO = ZT1 - (ZD1/(ZD1 - ZD2)) * (ZT1 - ZT2)                       ALIN0015
 4018 AITER2 = 1.0 + AITER2                                             ALIN0016
      ITEST = 0                                                         ALIN0017
      IF(AITER2- 10.0  )3021,3020,3021                                  ALIN0018
 3020 PRINT 3022                                                        ALIN0019
 30220FORMAT(64H MAXIMUM NUMBER OF ITERATIONS ON ZERO ELEVATION HAS BEENALIN0020
```

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```
    1 REACHED)                                                          ALIN0021
     ITEST = 1                                                          ALIN0022
3021 RETURN                                                             ALIN0023
     END                                                                ALIN0024
      FOR
     SUBROUTINE CMPNMN(DPERDT,AMENAN,TIMEC,PER,ANEWME)                  CMPN0003
     PIE =3.14159265                                                    CMPN0004
     PDOT = DPERDT/24.0                                                 CMPN0005
     IF(PDOT)3018,3017,3018                                             CMPN0006
3017 ANEWME = AMENAN +(120.0 * PIE * TIMEC)/PER                         CMPN0007
     GO TO 3019                                                         CMPN0008
3018 AMANTE = PDOT * TIMEC/PER                                          CMPN0009
40110AMANTE = AMANTE -(AMANTE * AMANTE)/2.0 + AMANTE * AMANTE * AMANTE/CMPN0010
    13.0 -AMANTE * AMANTE * AMANTE * AMANTE/4.0 + AMANTE * AMANTE *     CMPN0011
    2AMANTE * AMANTE * AMANTE/5.0                                       CMPN0012
     ANEWME = AMENAN + 120.0 * PIE *AMANTE/PDOT                         CMPN0013
3019 RETURN                                                             CMPN0014
     END                                                                CMPN0015
      FOR
    0SUBROUTINE CALMAX(ALPHAO,TIMEON,ALPHTW,TIMETW,ALPHTH,TIMETH,AMAXALCALM0003
    1,AMAXTI,ACOEFF,BCOEFF,CCOEFF)                                      CALM0004
     ACOEFF = (ALPHTH - ALPHAO)/((TIMETH - TIMEON) * (TIMETH - TIMETW))CALM0005
40120ACOEFF = ACOEFF - (ALPHTW  - ALPHAO)/((TIMETW -TIMEON) * (TIMETH -CALM0006
    1TIMETW))                                                           CALM0007
4013 BCOEFF =(ALPHTW - ALPHAO)/(TIMETW - TIMEON)                        CALM0008
40140BCOEFF = BCOEFF - (ALPHTH - ALPHAO)*(TIMETW + TIMEON)/((TIMETH -   CALM0009
    1TIMEON) * (TIMETH - TIMETW))                                       CALM0010
40150BCOEFF = BCOEFF + (ALPHTW - ALPHAO) * (TIMETW + TIMEON)/           CALM0011
    1((TIMETW - TIMEON) * (TIMETH - TIMETW))                            CALM0012
4016 CCOEFF = ALPHAO - (ACOEFF * TIMEON**2 + BCOEFF * TIMEON)           CALM0013
     AMAXTI = -0.5 *(BCOEFF/ACOEFF)                                     CALM0014
4017 CALL    POSITI(AMAXTI,R3XMAX,R3YMAX,R3ZMAX,AMAXAL)                 CALM0015
     RETURN                                                             CALM0016
     END                                                                CALM0017
      FOR
     SUBROUTINE SPLIT (A,B,C)                                           SPLI0004
     AI=0.0                                                             SPLI0005
3004 IF(A-AI)3001,3002,3003                                             SPLI0006
3001 B = AI - 1.0                                                       SPLI0007
     GO TO 3005                                                         SPLI0008
3002 B = AI                                                             SPLI0009
     GO TO 3005                                                         SPLI0010
3003 AI =AI + 1.0                                                       SPLI0011
     GO TO 3004                                                         SPLI0012
3005 C = A - B                                                          SPLI0013
     RETURN                                                             SPLI0014
     END                                                                SPLI0015
      FOR
     SUBROUTINE AMCK(V1,V2,ANS)                                         AMCK0003
     TWOPI = 6.28328531                                                 AMCK0004
     ANS = V2 - V1                                                      AMCK0005
     IF(ANS)3032,3033,3033                                              AMCK0006
3032 ANS = ANS + TWOPI                                                  AMCK0007
3033 RETURN                                                             AMCK0008
     END                                                                AMCK0009
      FOR
```

```
      SUBROUTINE SWITCH(T1,T2,T3,AL1,AL2,AL3)                    SWIT0003
      IF(T1 - T2)3025,3025,3026                                  SWIT0004
 3025 IF(T2-T3)3027,3027,3028                                    SWIT0005
 3028 IF(T1-T3)3029,3029,3030                                    SWIT0006
 3029 T84 = T2                                                   SWIT0007
      T2 = T3                                                    SWIT0008
      T3 = T84                                                   SWIT0009
      A84 = AL2                                                  SWIT0010
      AL2 = AL3                                                  SWIT0011
      AL3 = A84                                                  SWIT0012
      GO TO 3027                                                 SWIT0013
 3030 T84 = T1                                                   SWIT0014
      T1 = T3                                                    SWIT0015
      T3 = T84                                                   SWIT0016
      A84 = AL1                                                  SWIT0017
      AL1 = AL3                                                  SWIT0018
      AL3 = A84                                                  SWIT0019
      GO TO 3029                                                 SWIT0020
 3026 T84 = T1                                                   SWIT0021
      T1 = T2                                                    SWIT0022
      T2 = T84                                                   SWIT0023
      A84 = AL1                                                  SWIT0024
      AL1 = AL2                                                  SWIT0025
      AL2 = A84                                                  SWIT0026
      GO TO 3025                                                 SWIT0027
 3027 RETURN                                                     SWIT0028
      END
                                                          1044     15
```

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APPENDIX C

EXAMPLE OF NELIAC INPUT DATA USED TO OBTAIN SATELLITE LOOK ANGLES

IBM

Form X28-7327-4
Printed in U.S.A.

FORTRAN CODING FORM

Program		Punching Instructions: Graphic / Punch	Card Form # *
Programmer	Date		Page of / Identification (73–80)

C FOR COMMENT

STATEMENT NUMBER (1–5)	Cont. (6)	FORTRAN STATEMENT (7–72)			
+36.0		+38841.0	+.0	+1.046373	
+.0		+.0	+64.97	+31.076	
+331.806		+0.008222 4	+90.465	+273.574	
-0.454		-3.589	+.0	-0.00427	
+81.5094		+31.9767	+0.00745645	+108.015	
+63.6		+.0083333333	+64.2	+1.0	
+87.7		+.00027777778	+88.3	+.0	

* A standard card form, IBM electro 888157, is available for punching source statements from this form.

NELIAC-N OPERATOR INSTRUCTION SHEET (6/16/64) Date √ _____

RCC Problem Number √ _____ NRL Account Number √ _____

Problem Title √ _____ Programmer √ _____

Sweep _____ Telephone √ _____

Printer only (except reloadable dumps) unless otherwise specified.

1. Compile

   Flowchart Tapes:

   (1) F-DATA (3) F- (5) F-

   (2) F- (4) F- (6) F-

NORMAL COMPILATION L0 c00 (Name List Dump). R0 c00 (no Name List Dump).

Reset the Bias: L0 c01 (Name List Dump). R0 c01 (no Name List Dump).

Stop on bad compilation unless otherwise specified. CIRCLE DUMPS DESIRED.

2. Name List Dump L0 c05.

3. OP Dump L0 c09 (4-column). R0 c09 (single-column).

4. Dump Location (if desired);

   L0 c0a (4-column) or R0 c0a (single-column) (if needed) Box and Transfer.

5. Bioctal Dump and Comparison Load
   LABEL B-DATA

   L0 c06, Load Tape, L0 c07.

6. NAREC Dump

   L0 c08.

7. Other Information:

   Symbol String Dump: L0 c0e before compilation.

   Run Information Extra Copy L0 c0d

   Remove Sym. Str. Dump: L0c c0f.

   Printer Code L0 c0b. Punch Code L0 c0c. Load Flowchart: L0 c10.

8. Special Instructions:

   1. Load B 5541
   2. Load B 5539
   3. Load B-DATA
   4. L.O. 2800

√ Indicates spaces to be filled in by user.

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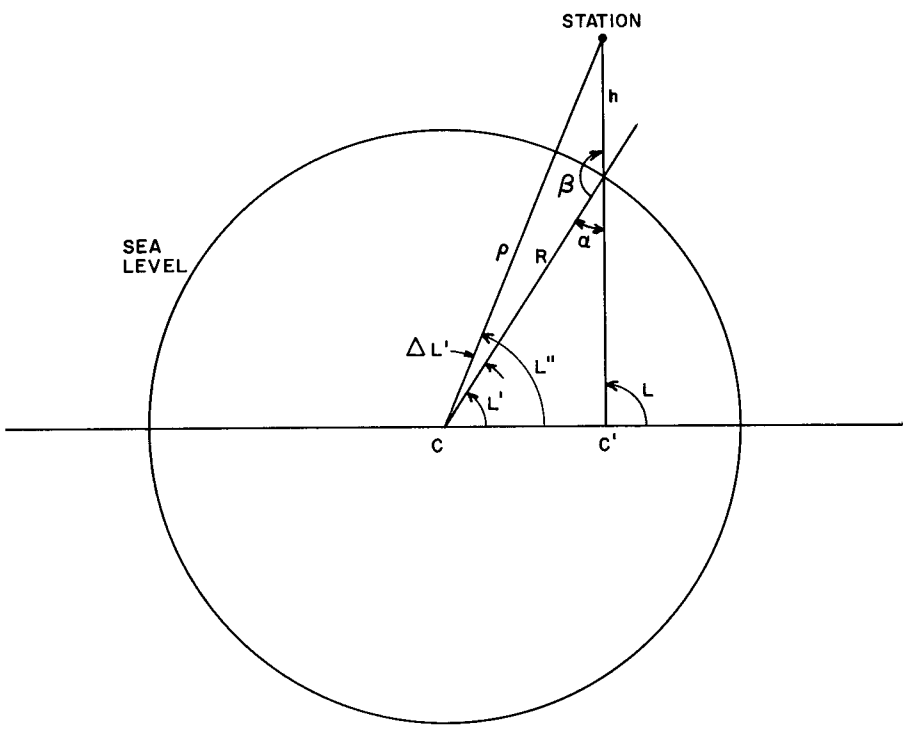
APPENDIX D

CONSTANTS AND EQUATIONS

1. To convert geodetic latitude to geocentric latitude the following diagram was used:



where

h = height of the station above sea level

L = geodetic latitude

R = radius of earth (see item 2 below)

L'' = geocentric latitude

A flattening factor f' due to the oblateness of the earth was taken to be 1/298.34

$$\tan L' = (1-f')^2 \tan L$$

$$\alpha = L - L'$$

$$\beta = \pi - \alpha$$

$$\rho^2 = R^2 + h^2 - 2Rh \cos \beta$$

$$\sin \Delta L' = \frac{h \sin \beta}{\rho}$$

and

$$L'' = L' + \Delta L'.$$

2. To determine the sea-level radius R as a function of geodetic latitude L the following equation was used:

$$R = a(0.998320047 + 0.001683493 \cos 2L - 0.000003549 \cos 4L + 0.000000008 \cos 6L),$$

where a = 6,378,165 meters.

3. Some of the constants used were:

1 stat mi = 1609.344 meters

π = 3.14159265

earth's rotation = 15.041067 deg/hr = 0.26251614 rad/hr

and

velocity of light = 186,283 mi/sec.

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* U.S. Naval Research Laboratory Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

LOOK-ANGLE-PREDICTION TECHNIQUE FOR ARTIFICIAL EARTH SATELLITES

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

An interim report on the problem.

5. AUTHOR(S) *(Last name, first name, initial)*

Buisson, J.A., III, and deVezin, H.G., Jr.

6. REPORT DATE December 30, 1965	7a. TOTAL NO. OF PAGES 44	7b. NO. OF REFS None

8a. CONTRACT OR GRANT NO. NRL Problem R02-41 b. PROJECT NO. RT 7043014/652-1/F019-03-03 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NRL Report 6351 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* None

10. AVAILABILITY/LIMITATION NOTICES

Unlimited availability. Available from Clearinghouse for Scientific and Technical Information, Springfield, Va. 22151 - $2.00.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Dept. of Navy (Bureau of Naval Weapons)

13. ABSTRACT

This report is concerned with the investigation of a method for obtaining look-angle predictions for aritifical earth satellites relative to a given point on the earth. The input to the problem consists of the most-recently-determined elliptical orbital elements of the satellite, the spherical coordinates of a station on the earth, and a desired time of search. The results to be obtained for the satellite trajectory are azimuth, elevation, range, range rate (i.e., velocity), and the doppler frequency shift as a function of time.

The problem has been programmed for use on digital electronic computers in both NELIAC and FORTRAN compiler languages and is available for use at both NRL and the David Taylor Model Basin in the Washington, D.C., area. As part of the checking out procedure, a comparison of the results was made with data obtained at the Radio Research Establishment (RRE) in Malvern, England. It was concluded that the major portion of those discrepancies that exist between the NRL and the RRE data is due to differences in the models used. Examples of both NELIAC and FORTRAN input, an example of the FORTRAN output, and the FORTRAN source program for this problem are included in the appendices.

DD FORM 1 JAN 64 1473

Security Classification

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Satellites (artificial)						
Azimuth angle						
Declination angle						
Altitude						
Prediction						
Orbital trajectories						
Programming (computers)						
Programming languages						
NELIAC (computer language)						

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