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PHILCO CORPORATION Western Development Laboratories

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(c) AFSSD Exhibit 61-27A, Paragraph 1.2.1.2

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TECHNICAL NOTE

WDL-TN62-14
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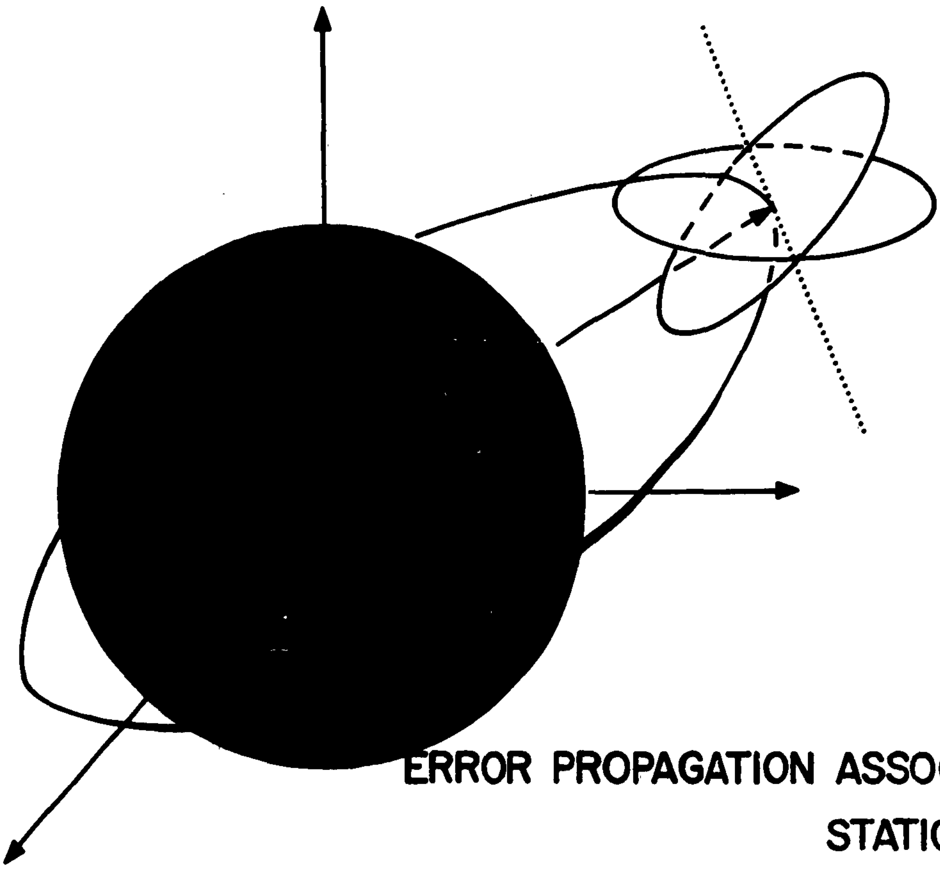

ERROR PROPAGATION ASSOCIATED WITH STATION LOCATION

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MATHEMATICAL ANALYSIS DEPARTMENT

CONTRACT AF04(695)-113

PHILCO
A SUBSIDIARY OF Ford Motor Company

WESTERN DEVELOPMENT LABORATORIES

WDL-TN62-14

TECHNICAL NOTE

ERROR PROPAGATION ASSOCIATED WITH STATION LOCATION

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Definitive Contract AF04(695)-113
AFBM Exhibit 58-1, Paragraph 4.2.1

Prepared for

SPACE SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Inglewood, California

ABSTRACT

PHILCO WDL-TN62-14 UNCLASSIFIED
ERROR PROPAGATION
ASSOCIATED WITH STATION LOCATION 33 pages
28 February 1963 Contract AF04(695)-113

This Technical Note presents a method using a satellite orbit and tracking data to determine errors in station location. It also documents a Philco 2000 Computer program which, given the standard deviations in the tracking data, calculates the covariance matrix for the station coordinates

FOREWORD

Technical Note WDL-TN62-14 has been prepared by the Philco WDL Mathematical Analysis Department for submittal to AFSSD for information purposes. This Technical Note is within the scope defined by Paragraph 4.2.1, AFBM Exhibit 58-1, "Contractor Reports Exhibit," dated 1 October 1959, as revised and amended.

The material presented in the Technical Note was developed in conjunction with Tracking Simulation and Evaluation and Advanced Trajectory Analysis Studies conducted by Philco WDL under Exhibit "A" of Definitive Contract AF04(695)-113, and Paragraph 1.2.1.2 of AFSSD Exhibit 61-27A, "Satellite Control Subsystem Work Statement," dated 15 February 1962.

TABLE OF CONTENTS

SECTION 1

INTRODUCTION

Current and projected mission requirements place a severe demand on the ability to accurately determine the position of a satellite. Since the equations of motion for a satellite are formulated in inertial space and the tracking information is given in local coordinates, it is necessary to know the location of the tracking stations to an accuracy compatible with the inherent noise level of the tracking equipment.

The existence of tracking data, and hence an orbit for a satellite, can be used to determine the location of a station in relation to other stations.

The observational data available from a satellite which is used for the purpose of locating a station on the geoid are the elevation (E), azimuth (A), slant range (S), and range rate ($\dot{S}$). Not all of these quantities will necessarily be available.

A camera at the site would give angular data about the orbit; an antenna might give range data in addition to giving angular data. A computer program has been written which indicates the errors in station location resulting from errors in the camera or antenna data. It is assumed the errors in azimuth and elevation (and range as a possible option) are randomly distributed with zero mean and specific variances. As a prediction of a survey's accuracy, the expected variances in the data can be used to find the resulting covariance matrix in station coordinates. The eigenvalues of the matrix are also calculated.

SECTION 2

EQUATIONS

An elliptical orbit is assumed in the computations. The orbit is defined by the elliptic elements t_o, η_o, ω, e, a, i, and Ω.

Over each pass η is obtained by an iterative process from[1]

$$t(\eta) - t(\eta_o) = \frac{1}{(1-e^2)^{3/2}\sqrt{\mu L^3}} \Bigg[\Delta - 2\tan^{-1}\left(\frac{e \sin \Delta}{1+\sqrt{1-e^2} + e \cos \Delta}\right) - \frac{e\sqrt{1-e^2}\sin \Delta}{1 + e \cos \Delta} \Bigg] \Bigg|_{\Delta = \eta_o - \omega_o}^{\Delta = \eta - \omega_o}$$

In this equation

$t(\eta)$ = time

e = eccentricity

$\mu = n^2 a^3 = 62625.53$

$L = \dfrac{1}{a(1-e^2)}$

These elliptic elements are then transformed to inertial cartesian coordinates and thence to local polar coordinates by standard transformation equations[2]. The local polar coordinates are then used to compute the elements of the covariance matrix.

---

1. E. D. Callender, "A Solution of the Equations of Motion for a Near-Earth Satellite," to be published.

2. "Program I Simulation and Evaluation Study Report," Philco Corporation, WDL-TR1596, 1 October 1961.

If the station coordinates are found by a differential corrections technique using least squares, the covariance matrix will be given by

$$\left(\sum_{t} A^T A \right)^{-1}$$

where A is the weighted Jacobian matrix and the summation is over all times at which data is provided[3]. The use of A for both azimuth and for the Jacobian matrix is standard notation and should cause no confusion. The elements of A are as follows (notation is ϕ_o = longitude, θ = latitude, h = height above the geoid, and R_s = radius to station):

a. $$\frac{\partial S}{\partial \phi} = \frac{R_s}{S} \cos\theta \, (x \sin\phi - y \cos\phi)$$

$$\frac{\partial S}{\partial \theta} = \frac{R_s}{S} (x \sin\theta \, \cos\phi + y \sin\theta \sin\phi - z \cos\theta)$$

$$\frac{\partial S}{\partial h} = \frac{1}{S} (R_s - x \cos\theta \cos\phi - y \cos\theta \sin\phi - z \sin\theta)$$

b. $$\frac{\partial \dot{S}}{\partial \phi} = - \frac{\partial S}{\partial \phi} \frac{\dot{S}}{S} + \frac{R_s}{S} \cos\theta \left[(\dot{x} \sin\phi - \dot{y} \cos\phi) + \dot{\phi} (y \sin\phi + x \cos\phi) \right]$$

$$\frac{\partial \dot{S}}{\partial \theta} = - \frac{\partial S}{\partial \theta} \frac{\dot{S}}{S} + \frac{R_s}{S} \left\{ \sin\theta \left[(\dot{x} \cos\phi + \dot{y} \sin\phi) + \dot{\phi} (y \cos\phi - x \sin\phi) \right] - \dot{z} \cos\theta \right\}$$

$$\frac{\partial \dot{S}}{\partial h} = - \frac{\partial S}{\partial h} \frac{\dot{S}}{S} - \frac{1}{S} \left[\cos\theta \, (\dot{x} \cos\phi + \dot{y} \sin\phi) + \dot{z} \sin\theta + \dot{\phi} \cos\theta \, (y \cos\phi - x \sin\phi) \right]$$

3. "A User's Manual for Three Tracking Simulators," Philco Corporation, WDL-TN62-1.

c. $$\frac{\partial E}{\partial \phi} = \frac{1}{S \cos E} \left[(y \cos \phi - x \sin \phi) \cos \theta - \frac{\partial S}{\partial \phi} \sin E \right]$$

$$\frac{\partial E}{\partial \theta} = \frac{1}{S \cos E} \left[z \cos \theta - (x \cos \phi + y \sin \phi) \sin \theta - \frac{\partial S}{\partial \theta} \sin E \right]$$

$$\frac{\partial E}{\partial h} = - \frac{1}{S} \frac{\partial S}{\partial h} \tan E - \frac{1}{S} \frac{1}{\cos E}$$

d. $$A = \tan^{-1} \frac{N}{D}$$

So, in general,

$$\frac{\partial A}{\partial \alpha} = \frac{1}{1 + \left[\frac{N}{D}\right]^2} \frac{D \frac{\partial N}{\partial \alpha} - N \frac{\partial D}{\partial \alpha}}{D^2}$$

$$N = - x \sin \phi + y \cos \phi$$

$$D = - \sin \theta (x \cos \phi + y \sin \phi) + z \cos \theta$$

(1) $$\frac{\partial N}{\partial \phi} = - x \cos \phi - y \sin \phi$$

$$\frac{\partial D}{\partial \phi} = - \sin \theta (y \cos \phi - x \sin \phi)$$

(2) $$\frac{\partial N}{\partial \theta} = 0$$

$$\frac{\partial D}{\partial \theta} = - \cos \theta (x \cos \phi + y \sin \phi) - z \sin \theta$$

(3) $$\frac{\partial A}{\partial h} = 0$$

In the preceding equations, $\phi = \Omega t + \phi_o + \Delta\phi$, where Ω is the rate of the earth's diurnal rotation, ϕ_o is the longitude from Greenwich, and $\Delta\phi$ is the phase angle. However, we have

$$\frac{\partial S}{\partial \phi} = \frac{\partial S}{\partial \phi_o}, \quad \frac{\partial E}{\partial \phi} = \frac{\partial E}{\partial \phi_o}, \quad \text{etc.,}$$

so that the preceding expressions can be used directly in the covariance matrix.

SECTION 3

COMPUTER RESULTS

Two orbits were used as test cases for the program: 61δ1 and 61αδ1 the first having an eccentricity of approximately 0.1 and a perigee of 469 statute miles and the second having an eccentricity of 0.01 and a perigee of 2180 statute miles. Palo Alto was used as the observation station.

For the 61δ1 orbit, three passes were observed, two overhead and one at a maximum elevation of approximately 41°. The time interval for the two overhead passes were approximately 30 minutes duration, while the pass at the lower elevation angle was about 24 minutes in length. With a 10-second interval between observations, this allowed about 180 observations for the 30-minute pass and about 144 observations for the 24-minute pass.

These passes were used in combinations of two to obtain four sets of results using a standard error for azimuth and elevation of 5 milliradians for 3 sets and 3 milliradians for the remaining set.

For the 61αδ1 orbit, two passes were used both singly and in combinations with equal errors in elevation and azimuth of 2 milliradians and 5 milliradians, thus obtaining 6 sets of results for the covariance matrix.

The listing of the orbit and computer results is given in Appendix A, and a description of the Computer Program and ALTAC Listing is given in Appendix B.

APPENDIX A

ORBIT AND COMPUTER RESULTS

61α51; ONE PASS OF 5 MINUTES

$\sigma_A = \sigma_E = 5$ MILLIRADIANS; $\Delta T = 2$ SECONDS

T ZERO	ETA ZERO	SMALL OMEGA	ECCENTRICITY	A	INCLINATION	OMEGA
0.454380+003	0.000000+000	0.635420+002	0.128900-001	0.539698+004	0.958600+002	0.617800+001

NUMBER OF OBSERVATIONAL PASSES IS 1

LATITUDE	LONGITUDE	ALTITUDE	DELTA PHI ZERO
0.374260+002	0.237898+003	0.200000+002	0.110324+003

DIMENSION OF COVARIANCE MATRIX IS 3

SIGS N MILES	SIGSD F/S	CONTROL	SIGA	SIGE	TIME IN	TIME OUT	TIME STEP
0.000000+000	0.000000+000	0	0.500000+001	0.500000+001	0.472000+003	0.477000+003	0.200000+001

COVARIANCE MATRIX FOR LATITUDE LONGITUDE ALTITUDE

EIGENVALUES FOR 3 BY 3

0.212356-012	0.575767-012	0.269458-003

UNITS ARE IN RADIANS AND N MILES

0.212356-012	0.242056-032	0.237010-047
0.242056-032	0.575767-012	0.000000+000
0.237010-047	0.000000+000	0.269458-003

UNITS ARE IN DEGREES AND N MILES

COVARIANCE MATRIX FOR LATITUDE AND LONGITUDE

1 1	1 2	2 1	2 2

UNITS ARE RADIANS SQUARED

0.347053-012	0.175520-012	0.175520-012	0.441070-012

UNITS ARE DEGREES SQUARED

0.113930-008	0.576196-009	0.576196-009	0.144795-008

SQUARE ROOT OF EIGEN VALUES IN RADIANS

0.758793-006	0.460821-006

61α81; ONE PASS OF 5 MINUTES

$\sigma_A = \sigma_E$ = 5 MILLIRADIANS; ΔT = 2 SECONDS

```
T ZERO         ETA ZERO       SMALL OMEGA    ECCENTRICITY   A              INCLINATION    OMEGA

 0.454380+003   0.000000+000   0.635420+002   0.128900-001   0.539698+004   0.958600+002   0.617808+001
NUMBER OF OBSERVATIONAL PASSES IS          1
LATITUDE            LONGITUDE          ALTITUDE          DELTA PHI ZERO
 0.374260+002        0.237898+003        0.200000+002        0.110324+003
DIMENSION OF COVARIANCE MATRIX IS          3
SIGS N MILES   SIGSD F/S      CONTROL        SIGA           SIGE           TIME IN        TIME OUT       TIME STEP
0.000000+000   0.000000+000          0       0.500000+001   0.500000+001   0.196700+004   0.197200+004   0.200000+001
COVARIANCE MATRIX FOR LATITUDE  LONGITUDE   ALTITUDE
EIGENVALUES FOR 3 BY 3
 0.418111-012        0.750578-012        0.101194-002
UNITS ARE  IN RADIANS AND N MILES
 0.418111-012        0.168220-038       -0.716564-058
 0.168220-038        0.750578-012        0.000000+000
-0.716564-058        0.000000+000        0.101194-002
UNITS  ARE  IN DEGREES AND N  MILES
COVARIANCE MATRIX FOR  LATITUDE AND LONGITUDE
1  1                1  2                2  1                2  2
UNITS ARE RADIANS SQUARED
 0.700701-012       -0.118722-012       -0.118722-012        0.467989-012
UNITS ARE  DEGREES SQUARED
 0.230026-008       -0.389740-009       -0.389740-009        0.153631-008
SQUARE ROOT OF EIGEN VALUES IN RADIANS
 0.866359-006        0.646615-006
```

61α81; TWO PASSES OF 5 MINUTES

$\sigma_A = \sigma_E$ = 5 MILLIRADIANS ΔT = 2 SECONDS

T ZERO	ETA ZERO	SMALL OMEGA	ECCENTRICITY	A	INCLINATION	OMEGA
0.454380+003	0.000000+000	0.635420+002	0.128900-001	0.539698+004	0.958600+002	0.617800+001

NUMBER OF OBSERVATIONAL PASSES IS 2

LATITUDE	LONGITUDE	ALTITUDE	DELTA PHI ZERO
0.374260+002	0.237898+003	0.200000+002	0.110324+003

DIMENSION OF COVARIANCE MATRIX IS 3

SIGS N MILES	SIGSD F/S	CONTROL	SIGA	SIGE	TIME IN	TIME OUT	TIME STEP
0.000000+000	0.000000+000	0	0.500000+001	0.500000+001	0.472000+003	0.477000+003	0.200000+001
0.000000+000	0.000000+000	0	0.500000+001	0.500000+001	0.196700+004	0.197200+004	0.200000+001

COVARIANCE MATRIX FOR LATITUDE LONGITUDE ALTITUDE

EIGENVALUES FOR 3 BY 3

0.162806-012	0.248285-012	0.604345-004

UNITS ARE IN RADIANS AND N MILES

0.162806-012	-0.193333-032	-0.108643-046
-0.193333-032	0.248285-012	0.000000+000
-0.108643-046	0.000000+000	0.604345-004

UNITS ARE IN DEGREES AND N MILES

COVARIANCE MATRIX FOR LATITUDE AND LONGITUDE

1 1	1 2	2 1	2 2
UNITS ARE RADIANS SQUARED			
0.204991-012	0.427357-013	0.427357-013	0.206099-012
UNITS ARE DEGREES SQUARED			
0.672945-009	0.140293-009	0.140293-009	0.676583-009

SQUARE ROOT OF EIGEN VALUES IN RADIANS

0.498282-006	0.403492-006

61α δ1; ONE PASS AT 5 MINUTES

$\sigma_A = \sigma_E = 2$ MILLIRADIANS $\Delta T = 2$ SECONDS

```
T ZERO         ETA ZERO        SMALL OMEGA     ECCENTRICITY    A               INCLINATION     OMEGA

0,454380+003   0,000000+000    0,635420+002    0,128900-001    0,539698+004    0,958600+002    0,617800+001
NUMBER OF OBSERVATIONAL PASSES IS       1
LATITUDE            LONGITUDE           ALTITUDE            DELTA PHI ZERO
0,374260+002        0,237898+003        0,200000+002        0,110324+003
DIMENSION OF COVARIANCE MATRIX IS       3
SIGS N MILES   SIGSD F/S       CONTROL         SIGA            SIGE            TIME IN         TIME OUT        TIME STEP
0,000000+000   0,000000+000          0         0,200000+001    0,200000+001    0,472000+003    0,477000+003    0,200000+001
COVARIANCE MATRIX FOR LATITUDE  LONGITUDE   ALTITUDE
EIGENVALUES FOR 3 BY 3
0,339769-013        0,921227-013        0,431133-004
UNITS ARE  IN RADIANS AND N MILES
0,339769-013        0,387290-033        0,379216-048
0,387290-033        0,921227-013        0,000000+000
0,379216-048        0,000000+000        0,431133-004
UNITS  ARE  IN DEGREES AND N  MILES
COVARIANCE MATRIX FOR  LATITUDE AND LONGITUDE
1  1                1  2                2  1                2  2
UNITS ARE RADIANS SQUARED
0,555284-013        0,280831-013        0,280831-013        0,705713-013
UNITS ARE. DEGREES SQUARED
0,182289-009        0,921913-010        0,921913-010        0,231671-009
SQUARE ROOT OF EIGEN VALUES IN RADIANS
0,303517-006        0,184328-006
```

61α δ1; ONE PASS OF 5 MINUTES

$\sigma_A = \sigma_E = 2$ MILLIRADIANS $\Delta T = 2$ SECONDS

```
T ZERO          ETA ZERO        SMALL OMEGA     ECCENTRICITY    A               INCLINATION     OMEGA

 0.454380+003   0.000000+000    0.635420+002    0.128900-001    0.539698+004    0.958600+002    0.617800+001
NUMBER OF OBSERVATIONAL PASSES IS       1
LATITUDE            LONGITUDE           ALTITUDE            DELTA PHI ZERO
 0.374260+002        0.237898+003        0.200000+002        0.110324+003
DIMENSION OF COVARIANCE MATRIX IS       3
SIGS N MILES   SIGSD F/S      CONTROL        SIGA           SIGE           TIME IN        TIME OUT       TIME STEP
0.000000+000   0.000000+000          0       0.200000+001   0.200000+001   0.196700+004   0.197200+004   0.200000+001
COVARIANCE MATRIX FOR LATITUDE  LONGITUDE   ALTITUDE
EIGENVALUES FOR 3 BY 3
 0.668978-013        0.120093-012        0.161910-003
UNITS ARE  IN RADIANS AND N MILES
 0.668978-013        0.269150-039       -0.114649-058
 0.269150-039        0.120093-012        0.000000+000
-0.114649-058        0.000000+000        0.161910-003
UNITS  ARE  IN DEGREES AND N  MILES
COVARIANCE MATRIX FOR  LATITUDE AND LONGITUDE
1 1                 1 2                 2 1                 2 2
UNITS ARE RADIANS SQUARED
 0.112112-012       -0.189955-013       -0.189955-013        0.748782-013
UNITS ARE  DEGREES SQUARED
 0.368042-009       -0.623585-010       -0.623585-010        0.245810-009
SQUARE ROOT OF EIGEN VALUES IN RADIANS
 0.346544-006        0.258546-006
```

61α δ1; TWO PASSES OF 5 MINUTES

$\sigma_A = \sigma_E$ = 2 MILLIRADIANS ΔT = 2 SECONDS

```
T ZERO        ETA ZERO       SMALL OMEGA   ECCENTRICITY   A              INCLINATION   OMEGA

 0,454380+003  0,000000+000  0,635420+002  0.128900-001  0.539698+004  0,958600+002  0,617800+001
NUMBER OF OBSERVATIONAL PASSES IS         2
LATITUDE          LONGITUDE         ALTITUDE          DELTA PHI ZERO
 0,374260+002      0,237898+003      0,200000+002      0.110324+003
DIMENSION OF COVARIANCE MATRIX IS          3
SIGS N MILES  SIGSD F/S     CONTROL       SIGA          SIGE          TIME IN       TIME OUT      TIME STEP
0,000000+000  0,000000+000        0       0,200000+001  0,200000+001  0,472000+003  0,477000+003  0,200000+001
0,000000+000  0,000000+000        0       0,200000+001  0,200000+001  0,196700+004  0,197200+004  0,200000+001
COVARIANCE MATRIX FOR LATITUDE  LONGITUDE   ALTITUDE
EIGENVALUES FOR 3 BY 3
 0,260490-013      0,397255-013      0,966951-005
UNITS ARE  IN RADIANS AND N MILES
 0,260490-013     -0,309333-033     -0,173829-047
-0,309333-033      0,397255-013      0,000000+000
-0,173829-047      0,000000+000      0,966951-005
UNITS  ARE  IN DEGREES AND N  MILES
COVARIANCE MATRIX FOR  LATITUDE AND LONGITUDE
1  1              1  2              2  1              2  2
UNITS ARE RADIANS SQUARED
 0,327986-013      0,683771-014      0,683771-014      0.329759-013
UNITS ARE  DEGREES SQUARED
 0,107671-009      0,224468-010      0,224468-010      0.108253-009
SQUARE ROOT OF EIGEN VALUES IN RADIANS
 0,199313-006      0,161397-006
```

6181; TWO PASSES OF 30 MINUTES

$\sigma_A = \sigma_E$ = 5 MILLIRADIANS ΔT = 10 SECONDS

T ZERO	ETA ZERO	SMALL OMEGA	ECCENTRICITY	A	INCLINATION	OMEGA
0.438960+003	0.000000+000	0.270978+003	0.105650+000	0.430106+004	0.388200+002	0.199332+003

NUMBER OF OBSERVATIONAL PASSES TS 2

LATITUDE	LONGITUDE	ALTITUDE	DELTA PHI ZERO
0.374260+002	0.237898+003	0.900000+002	0.167480+002

DIMENSION OF COVARIANCE MATRIX TS 2

SIGS N MILES	SIGSD F/S	CONTROL	SIGA	SIGE	TIME IN	TIME OUT	TIME STEP
0.000000+000	0.000000+000	0	0.500000+001	0.500000+001	0.450000+003	0.480000+003	0.100000+002
0.000000+000	0.000000+000	0	0.500000+001	0.500000+001	0.576000+003	0.607200+003	0.100000+002

COVARIANCE MATRIX FOR LATITUDE AND LONGITUDE

1 1	1 2	2 1	2 2

UNITS ARE RADIANS SQUARED

0.257871-013	-0.110774-014	-0.110774-014	0.508815-013

UNITS ARE DEGREES SQUARED

0.846538-010	-0.363648-011	-0.363648-011	0.167034-009

SQUARE ROOT OF EIGEN VALUES IN RADIANS

0.225678-006	0.160432-006

6161; TWO PASSES OF 30 MINUTES

$\sigma_A = \sigma_E = 5$ MILLIRADIANS $\Delta T = 10$ SECONDS

T ZERO	ETA ZERO	SMALL OMEGA	ECCENTRICITY	A	INCLINATION	OMEGA
0.438960+003	0.000000+000	0.270978+003	0.105650+000	0.430106+004	0.388200+002	0.199332+003

NUMBER OF OBSERVATIONAL PASSES TS 2

LATITUDE	LONGITUDE	ALTITUDE	DELTA PHI ZERO
0.374260+002	0.237898+003	0.200000+002	0.167680+002

DIMENSION OF COVARIANCE MATRIX TS 2

SIGS N MILES	SIGSD F/S	CONTROL	SIGA	SIGE	TIME IN	TIME OUT	TIME STEP
0.000000+000	0.000000+000	0	0.500000+001	0.500000+001	0.576000+003	0.607200+003	0.100000+002
0.000000+000	0.000000+000	0	0.500000+001	0.500000+001	0.174000+004	0.176400+004	0.100000+002

COVARIANCE MATRIX FOR LATITUDE AND LONGITUDE

1 1	1 2	2 1	2 2
UNITS ARE RADIANS SQUARED			
0.403280-013	-0.982482-015	-0.982482-015	0.798397-013
UNITS ARE DEGREES SQUARED			
0.132389-009	-0.322529-011	-0.322529-011	0.262098-009

SQUARE ROOT OF EIGEN VALUES IN RADIANS

0.282602-006 0.200758-006

6181; TWO PASSES OF 30 MINUTES

$\sigma_A = \sigma_E = 3$ MILLIRADIANS $\Delta T = 10$ SECONDS

T ZERO	ETA ZERO	SMALL OMEGA	ECCENTRICITY	A	INCLINATION	OMEGA
0.438960+003	0.000000+000	0.270978+003	0.105650+000	0.430106+004	0.388200+002	0.199332+003

NUMBER OF OBSERVATIONAL PASSES IS 2

LATITUDE	LONGITUDE	ALTITUDE	DELTA PHI ZERO
0.374260+002	0.237898+003	0.200000+002	0.167680+002

DIMENSION OF COVARIANCE MATRIX IS 2

SIGS N MILES	SIGSD F/S	CONTROL	SIGA	SIGF	TIME IN	TIME OUT	TIME STEP
0.100000+000	0.000000+000	1	0.300000+001	0.300000+001	0.576000+003	0.607200+003	0.100000+002
0.100000+000	0.000000+000	1	0.300000+001	0.300000+001	0.174000+004	0.176400+004	0.100000+002

COVARIANCE MATRIX FOR LATITUDE AND LONGITUDE

1 1	1 2	2 1	2 2
UNITS ARE RADIANS SQUARED			
0.137337-010	0.532483-012	0.532483-012	0.802017-011
UNITS ARE DEGREES SQUARED			
0.450849-007	0.174803-008	0.174803-008	0.263286-007

SQUARE ROOT OF EIGEN VALUES IN RADIANS

0.371253-005	0.282329-005

6181; TWO PASSES AT 30 MINUTES

$\sigma_A = \sigma_E = 5$ MILLIRADIANS $\Delta T = 10$ SECONDS

```
T ZERO        ETA ZERO      SMALL OMEGA   ECCENTRICITY  A             INCLINATION   OMEGA

0.438960+003  0.000000+000  0.270978+003  0.105650+000  0.430106+004  0.388200+002  0.199332+003
NUMBER OF OBSERVATIONAL PASSES IS          2
LATITUDE          LONGITUDE          ALTITUDE          DELTA PHI ZERO
 0.374260+002      0.237898+003       0.200000+002      0.167680+002
DIMENSION OF COVARIANCE MATRIX IS           3
SIGS N MILES  SIGSD F/S     CONTROL       SIGA          SIGE          TIME IN       TIME OUT      TIME STEP
0.000000+000  0.000000+000             0  0.500000+001  0.500000+001  0.450000+003  0.480000+003  0.100000+002
0.000000+000  0.000000+000             0  0.500000+001  0.500000+001  0.576000+003  0.607200+003  0.100000+002
COVARIANCE MATRIX FOR LATITUDE  LONGITUDE   ALTITUDE
EIGENVALUES FOR 3 BY 3
 0.257383-013      0.509384-013       0.107791-004
UNITS ARE  IN RADIANS AND N MILES
 0.257383-013      0.611403-038       0.305638-055
 0.611403-038      0.509384-013       0.000000+000
 0.305638-055      0.000000+000       0.107791-004
UNITS  ARE  IN DEGREES AND N  MILES
COVARIANCE MATRIX FOR  LATITUDE AND LONGITUDE
1  1              1  2               2  1              2  2
UNITS ARE RADIANS SQUARED
 0.257871-013     -0.110774-014      -0.110774-014      0.508615-013
UNITS ARE  DEGREES SQUARED
 0.846538-010     -0.363648-011      -0.363648-011      0.167034-009
SQUARE ROOT OF EIGEN VALUES IN RADIANS
 0.225678-006      0.160432-006
```

APPENDIX B

DESCRIPTION OF COMPUTER PROGRAM AND ALTAC LISTING

INPUT FOR DC11 PROGRAM
(GEODETIC SURVEY)

One complete set of data consists of at least 6 data cards. Each card is divided into 8 fields, 10 slots long.

SUMMARY OF DATA:

CARD 1	TO	t_o	(MIN)	INITIAL CONDITIONS OF THE SATELLITE (FLOATING POINT NUMBER, X·XXX±X)
	ATAO	η_o	(DEG)	
	OHL	ω	(DEG)	
	ECC		-	
	AX	a	(N.M.)	
	FI	i	(DEG)	
	OHB	Ω	(DEG)	
CARD 2	NOOBPASS			NO. OF OBSERVATIONAL PASSES (A FIXED POINT NUMBER)
CARD 3	FLAT	θ	(DEG)	STATION COORDINATES
	FLONO	ϕ_E	(DEG E)	
	ALT	h	(FT)	
	DELPHIO	$\Delta\phi$	(DEG)	
CARD 4	DIMEN			DIMENSION OF COVARIANCE MATRIX (2 = LAT & LONG, 3 = LAT, LONG, & ALT) (A FIXED POINT NUMBER)

CARD 5	SIGS	σ_s (N.M.)	REPEAT FOR EACH OBSERVATIONAL PASS
	SIGD	σ_D (FT/SEC)	
	JFLAG1		
	SIGA	σ_A (SEC) IF JFLAG1 = 0; (MI.RAD) IF JFLAG1 = 1	
	SIGE	σ_E (SEC) IF JFLAG1 = 0; (MI.RAD) IF JFLAG1 = 1	
	T1	t_1 (MIN)	
	T2	t_2 (MIN)	
	DELT	Δt (SEC)	
CARD 6	I	I = 0, NO MORE DATA CASES I = 1, ANOTHER COMPLETE SET OF DATA FOLLOWING STARTING WITH CARD 1	

SAMPLE SET OF DATA

FOR DC11

10	20	30	40	50	60	70	80
0.44+3	0.0+1	0.27+3	0.105+0	4.3+3	0.4+2	0.19+3	
1							
0.37+2	2.37+2	0.20+2	0.16+2				
2							
0.0+1	0.0+1	0	0.1+2	0.10+2	0.45+3	0.48+3	0.10+2
1							

CASE 1

10	20	30	40	50	60	70	80
0.44+3	0.0+1	0.27+3	0.1+0	4.3+3	0.4+2	0.2+3	
2							
0.37+2	2.37+2	0.2+2	0.16+2				
3							
0.1+1	0.2+1	1	0.01+1	0.02+1	0.4+3	0.5+3	0.1+2
0.08+1	0.1+1	1	0.01+1	0.17+1	0.4+3	0.6+3	0.2+2
0							

CASE 2,
2 PASSES

PROGRAM INPUT

VARIABLE		NAME & DESCRIPTION
t_o	TO	TIME OF INITIAL CONDITIONS (MIN)
η_o	ATAO	$\nu + \omega$ (DEG)
ω	OHL	ANGLE OF PERIGEE (DEG)
ϵ	ECC	ECCENTRICITY
a	AX	SEMI-MAJOR AXIS (N.M.)
i	FI	ANGLE OF INCLINATION (DEG)
Ω	OHB	OMEGA (DEG)
θ	FLAT	LATITUDE (DEG)
ϕ	FLONO	LONGITUDE (DEG)
h	ALT	ALTITUDE (FT)
$\delta\phi_o$	DELPHIO	ANGLE BETWEEN INITIAL X-AXIS AND GREENWICH AT T ZERO
σ_{SR}	SIGS	$\sigma_{\text{SLANT RANGE}}$ (N.M.)
σ_{SD}	SIGSD	σ_{DOPPLER} (FT/SEC)
σ_A	SIGA	σ_{AZIMUTH} (MILLIRAD OR SEC)
σ_E	SIGE	$\sigma_{\text{ELEVATION}}$ (MILLIRAD OR SEC)
t_1	T1	TIME IN (MIN)
t_2	T2	TIME OUT (MIN)
Δt	DELT	TIME STEP (SEC)

STANDARD DEVIATIONS OF NOISE IN THE TRACKING DATA

COMPUTED CONSTANTS

C200	90.0
C100	$2.0/\pi$
C2	$\pi/180$
C10	$180/\pi$
C11	$(C10)^2$
C101	1.0/C10
C3	$(180)3600/\pi$
C110	1.0/C100

SUMMARY OF EQUATIONS

ATAO	=	C2	*	ATAO
OHL	=	C2	*	OHL
V	=	ECC	*	cos (OHL)
WA	=	ECC	*	sin (OHL)
TO	=	60.0	*	TO
FL	=	1.0/(AX * (1.0 - ECC))		
ALT	=	ALT/6076.10333		
FLAT	=	C2 * FLAT		
FLONO	=	C2 * FLONO		
DELPHIO	=	C2 * DELPHIO		
COS 1	=	cos (FLAT)		
SIN 1	=	sin (FLAT)		
DELPHIQ	=	C100 * DELPHIO		

$$\text{FMEANMO} = \sqrt{\frac{62625.53}{\text{AX}^3}}$$

$$\text{C4} = \sqrt{1.0 - \text{ECC}^2}$$

$$\text{FATAO} = -\left[2.0 * \tan^{-1}\left(\frac{\text{ECC} * \sin(\text{ATAO-OHL})}{1.0 + \text{C4} + \text{ECC} * \cos(\text{ATAO-OHL})}\right) + \frac{\text{ECC} * \text{C4} * \sin(\text{ATAO-OHL})}{1.0 + \text{ECC} * \cos(\text{ATAO-OHL})}\right]$$

FLATA = C100 * FLAT

FLONA = C100 * (FLONO - .00007292*TO)

T1 = 60.0 * T1

T2 = 60.0 * T2

SUMMARY OF EQUATIONS (CONTINUED)

E = C110 * E

A = C110 * A

FI = C200 * FI

OHB = C200 * OHB

COSE = cos (E)

SINE = sin (E)

COSA = cos (A)

SINA = sin (A)

FLON = FLONO + DELPHIO + 0.00007292 * (T - TO)

COS2 = cos (FLON)

SIN2 = sin (FLON)

SLON = R * COS1 * (X * SIN2 - Y * COS2)/S

SLAT = R * (X * SIN1 * COS2 + Y * SIN1 * SIN2 - Z * COS1)/S

SALT = (R-X * COS1 * COS2 - Y * COS1 * SIN2 - Z * SIN1)/S

$$\text{SDLON} = -\text{SLON} * \frac{\text{SD}}{\text{S}} + \text{R} * \text{COS1} * \left[\text{XD} * \text{SIN2} - \text{YD} * \text{COS2} + \text{FLOND} * (\text{Y} * \text{SIN2} + \text{X} * \text{COS2})\right] / \text{S}$$

$$\text{SDLAT} = -\text{SLAT} * \frac{\text{SD}}{\text{S}} + \text{R} * \left[\text{SIN1} * \left\{\text{XD} * \text{COS2} - \text{YD} * \text{SIN2} + \text{FLOND} * (\text{Y} * \text{COS2} - \text{X} * \text{SIN2})\right\} - \text{ZD} * \text{COS1}\right] / \text{S}$$

$$\text{S DALT} = -\text{SDALT} * \frac{\text{SD}}{\text{S}} - \left[\text{XD} * \text{COS2} * \text{COS1} + \text{YD} * \text{SIN2} * \text{COS1} + \text{ZD} * \text{SIN1} + \text{FLOND} * \text{COS1} * (\text{Y} * \text{COS2} - \text{X} * \text{SIN2})\right] / \text{S}$$

SUMMARY OF EQUATIONS (CONTINUED)

$$ELON = \left[COS1 * (Y * COS2 - X * SIN2) - SINE * SLON\right] / (S * COSE)$$

$$TANE = SINE/COSE$$

$$ELAT = \left[Z + COS1 - SIN1 * (X * COS2 + Y * SIN2) - SLAT * SINE\right] / (S * COSE)$$

$$EALT = - SALT * \frac{TANE}{S} - \frac{1.0}{S} * COSE$$

$$C1 = 1.0/ (FN^2 + D^2)$$

$$ALON = C1 * \left[D * (-X * COS2 - Y * SIN2) + FN * SIN1 * (Y * COS2 - X * SIN2)\right]$$

$$ALAT = C1 * FN * \left[COS1 * (X * COS2 + Y * SIN2) - Z * SIN2\right]$$

$$AALT = 0.0$$

P MATRIX

$$\begin{bmatrix} SLAT & SLON & SALT \\ SDLAT & SDLON & SDALT \\ ALAT & ALON & AALT \\ ELAT & ELON & EALT \end{bmatrix}$$

SUMMARY OF EQUATIONS (CONTINUED)

FOR 2 DIMENSIONAL PROBLEM:

$$COMAT_{11} = W_1^2 P_{11} P_{11} + W_2^2 P_{21} P_{21}$$

$$COMAT_{12} = W_1^2 P_{11} P_{12} + W_2^2 P_{21} P_{22}$$

$$COMAT_{21} = W_1^2 P_{12} P_{11} + W_2^2 P_{22} P_{21}$$

$$COMAT_{22} = W_1^2 P_{12} P_{12} + W_2^2 P_{22} P_{22}$$

$$C5 = COMAT_{11}\ COMAT_{22} - COMAT_{12}\ COMAT_{21}$$

$$C5 = 1.0/C5$$

$$CM_{11} = C5 * COMAT_{22}$$

$$CM_{12} = -C5 * COMAT_{21}$$

$$CM_{21} = -C5 * COMAT_{12}$$

$$CM_{22} = C5 * COMAT_{11}$$

$$C51 = \sqrt{(CM_{11} + CM_{22})^2 - (4.0*C5)}$$

$$EIGEN1 = \sqrt{\left[(CM_{11} + CM_{22}) + C51\right] * 0.5}$$

$$EIGEN2 = \sqrt{\left[(CM_{11} + CM_{22}) - C51\right] * 0.5}$$

CONVERT CM ARRAY TO DEGREES SQUARED:

$$CM_{11} = C11\ (CM_{11})$$

$$CM_{12} = C11\ (CM_{12})$$

$$CM_{21} = C11\ (CM_{21})$$

$$CM_{22} = C11\ (CM_{22})$$

SUMMARY OF EQUATIONS (CONTINUED)

FOR 3 DIMENSIONAL PROBLEM:

$$COMAT_{11} = W_1^2\ P_{11}\ P_{11} + W_2^2\ P_{21}\ P_{21} + W_3^2\ P_{31}\ P_{31} + W_4^2\ P_{41}\ P_{41}$$

$$COMAT_{12} = W_1^2\ P_{11}\ P_{12} + W_2^2\ P_{21}\ P_{22} + W_3^2\ P_{31}\ P_{32} + W_4^2\ P_{41}\ P_{42}$$

$$COMAT_{13} = W_1^2\ P_{11}\ P_{13} + W_2^2\ P_{21}\ P_{23} + W_3^2\ P_{31}\ P_{33} + W_4^2\ P_{41}\ P_{43}$$

$$COMAT_{21} = W_1^2\ P_{12}\ P_{11} + W_2^2\ P_{22}\ P_{21} + W_3^2\ P_{32}\ P_{31} + W_4^2\ P_{42}\ P_{41}$$

$$COMAT_{22} = W_1^2\ P_{12}\ P_{12} + W_2^2\ P_{22}\ P_{22} + W_3^2\ P_{32}\ P_{32} + W_4^2\ P_{42}\ P_{42}$$

$$COMAT_{23} = W_1^2\ P_{12}\ P_{13} + W_2^2\ P_{22}\ P_{23} + W_3^2\ P_{32}\ P_{33} + W_4^2\ P_{42}\ P_{43}$$

$$COMAT_{31} = W_1^2\ P_{13}\ P_{11} + W_2^2\ P_{23}\ P_{21} + W_3^2\ P_{33}\ P_{31} + W_4^2\ P_{43}\ P_{41}$$

$$COMAT_{32} = W_1^2\ P_{13}\ P_{12} + W_2^2\ P_{23}\ P_{22} + W_3^2\ P_{33}\ P_{32} + W_4^2\ P_{43}\ P_{42}$$

$$COMAT_{33} = W_1^2\ P_{13}\ P_{13} + W_2^2\ P_{23}\ P_{23} + W_3^2\ P_{33}\ P_{33} + W_4^2\ P_{43}\ P_{43}$$

$$\begin{aligned} C20 = {} & COMAT_{11}*COMAT_{22}*COMAT_{33} + 2.0 * COMAT_{12}*COMAT_{23}*COMAT_{31} \\ & -COMAT_{13}^2*COMAT_{22} - COMAT_{23}^2*COMAT_{11} \\ & -COMAT_{12}^2*COMAT_{33} \end{aligned}$$

$$C21 = 1.0/C20$$

$$CM_{11} = C21*(COMAT_{22}\ COMAT_{33} - COMAT_{23}^2)$$

$$CM_{12} = -C21*(COMAT_{21}\ COMAT_{33} - COMAT_{23}\ COMAT_{31})$$

$$CM_{21} = CM_{12}$$

$$CM_{13} = C21*(COMAT_{21}\ COMAT_{32} - COMAT_{31}\ COMAT_{22})$$

$$CM_{31} = CM_{13}$$

$$CM_{22} = C21*(COMAT_{11}\ COMAT_{33} - COMAT_{13}^2)$$

SUMMARY OF EQUATIONS (CONTINUED)

FOR 3 DIMENSIONAL PROBLEM (CONT'D.):

$$CM_{33} = C21*(COMAT_{11}\ COMAT_{22} - COMAT_{12}^{2})$$

$$CM_{23} = -C21*(COMAT_{11}\ COMAT_{32} - COMAT_{12}\ COMAT_{31})$$

$$CM_{32} = CM_{23}$$

AFTER GOING TO SUBROUTINE FOR EIGEN VECTOR AND MATRIX:

$$CM_{11} = C11\ (CM_{11})$$

$$CM_{12} = C11\ (CM_{12})$$

$$CM_{13} = C10\ (CM_{13})$$

$$CM_{21} = C11\ (CM_{21})$$

$$CM_{22} = C11\ (CM_{22})$$

$$CM_{23} = C10\ (CM_{23})$$

$$CM_{31} = C10\ (CM_{31})$$

$$CM_{32} = C10\ (CM_{32})$$

$$CM_{33} \quad CM_{33}$$

$$C5 = COMAT_{11}\ COMAT_{22} - COMAT_{12}\ COMAT_{21}$$

$$C5 = 1.0/C5$$

$$CM_{11} = C5 * COMAT_{22}$$

$$CM_{12} = -C5 * COMAT_{21}$$

$$CM_{21} = -C5 * COMAT_{12}$$

$$CM_{22} = C5 * COMAT_{11}$$

SUMMARY OF EQUATIONS (CONTINUED)

AFTER GOING TO SUBROUTINE FOR EIGEN VECTOR AND MATRIX (CONT'D.):

$$C51 = \sqrt{(CM_{11} + CM_{22})^2 - 4.0*C5}$$

$$EIGEN1 = \sqrt{(CM_{11} + CM_{22} + C51) * 0,5}$$

$$EIGEN2 = \sqrt{(CM_{11} + CM_{22} - C51) * 0.5)}$$

$$CM_{11} = C11\ (CM_{11})$$

$$CM_{12} = C11\ (CM_{12})$$

$$CM_{21} = C11\ (CM_{21})$$

$$CM_{22} = C11\ (CM_{22})$$

407 LISTING

```
C                   ALTAC   ABS, SUBR.
 110003 I           DC11
 110004             IOUNITS  DTI, 5UT, 12, 10, ERRORI, BUFFI, BUFFI-  DTO ,6UT,..
 110005              ERRORO,BUFFO,    BUFFO    $
 110006             DIMENSION   COMAT(3,3)   , P(4,3) ,  W(4), CM(3,3), EVAL(3),
 110007                EVVEC(3,3) $
                    C200= 90.0$
 110008             C100 = 2.0/3.1415962 $
 110009             C2 =3.1415962/180.0 $
 110010             C10 = 180.0/3.1415962    -   C11 =C10**2        $
 110011             C101 = 1.0/C10$
 110012             C3 = 180.0* 3600.0/3.1415962  $
 110013             C110   = 1.0/  C100$
 110014  START      DO (L1) I=1,3 $
 110015             DO (L1) I1=1,3 $
 110016  L1         COMAT(I,I1)= 0.0  - CM(I,I1)=0.0 $
 110017             READ INPUT TAPE 5UT ,FORI1, TO,ATAO, OHL,ECC,AX,FI , OHB  $
 110018  FORI1      FORMAT  ( 8E10 ) $
 110019             WRITE OUTPUT TAPE 6UT, FORO1$
 110020  FORO1      FORMAT  (2H70,S5,  6HT ZERO,S9, 8HETA ZERO, S7,11HSMALL OMEGA,
 110021               S4,12HECCENTRICITY,S3, 1HA, S14,11HINCLINATION,S4,5HOMEGA)$
 110022             WRITE OUTPUT TAPE 6UT, FORO2, TO,ATAO,OHL,ECC, AX, FI ,OHB  $
 110023             ATAO =C2*ATAO $
 110024              OHL  = OHL * C2      $
 110025             V = ECC* COS(OHL) - WA=ECC* SIN(OHL)  - TO =TO* 60.0 $
 110026             FL = 1.0/(AX *(1.0 - ECC**2) )    $
 110027             READ  INPUT  TAPE 5UT,  FORI2 , NOOBPAS $
 110028  FORI2      FORMAT  (8I10)    $
 110029             WRITE OUTPUT TAPE 6UT , FORO3, NOOBPAS $
 110030  FORO3      FORMAT  (2H20,S5, 34HNUMBER OF OBSERVATIONAL PASSES IS , I10)$
 110031  FORO2      FORMAT  (2H20 , S5 , 7(E13.6, S2) )$
 110032             READ INPUT TAPE 5UT, FORI1, FLAT, FLONO,ALT, DELPHIO  $
 110033             WRITE OUTPUT TAPE 6UT, FORO4     $
 110034  FORO4      FORMAT  (2H20,S5, 8HLATITUDE, S12, 9HLONGITUDE, S11, 8HALTITUDE,
 110035               S12, 14HDELTA PHI ZERO ) $
 110036             WRITE OUTPUT TAPE 6UT, FORO5, FLAT,FLONO,ALT,DELPHIO  $
 110037  FORO5      FORMAT  (2H20, S5, 4(E13.6, S7 ) ) $
 110038             ALT =  ALT/6076.10333  - FLAT=C2*FLAT-FLONO=C2*FLONO$
 110039             DELPHIO= C2*DELPHIO $
 110040             READ INPUT TAPE 5UT, FORI2, NODIM   $
 110041             WRITE OUTPUT TAPE 6UT, FORO6, NODIM  $
 110042             COS1= COS(FLAT) - SIN1 = SIN(FLAT)  $
 110043             DELPHIO  = DELPHIO * C100$
 110044             START TACS
 110045             TMD      DELPHIO$
 110046             TDM      TRF11,DELPHI $
 110047             END TACS
 110048  FORO6      FORMAT (2H20, S5,35HDIMENSION OF COVARIANCE MATRIX IS  ,I10)$
 110049             WRITE OUTPUT TAPE 6UT, FORO7 $
 110050  FORO7      FORMAT  (2H20, S5,12HSIGS N MILES,S3, 9HSIGSD F/S,S6, 7HCONTROL,
 110051             S8, 4HSIGA, S11, 4HSIGE, S11, 7HTIME IN, S8, 8HTIME OUT, S7 ,
 110052               9HTIME STEP)  $
 110053  FORO8      FORMAT  (2H20, S3, 2(E13.6,S2), I10,S2, 5(E13.6,S2)  ) $
```

407 LISTING (CONT'D)

```
          R=ALTS
110055         IF(ECC) LL1, LL1, LL2  $
110056  LL1    JFLAG2=0  -  GO TO LL3  $
110057  LL2    JFLAG2 =1  $
110058  LL3    FMEANMO = SQRT(62625.5300/AX**3 )                    $
110059         C4= SQRT(1.0-ECC**2)    $
110060         FATAO = -( 2.0*ATAN( ECC*SIN(ATAO-OHL)/(1.0 + C4+ ECC*COS(
110061               ATAO -OHL)) )  + ECC*C4* SIN(ATAO-OHL)/(1.0+ ECC*COS(ATAO
110062               -OHL) )   )   $
110063         FLATA =  C100*FLAT   $
110064         FLONA = C100*(FLONO-.729211584E-4*(TO) ) $
               START TACS
               TMA     C/HLTL,STATABS
               JMP     COMSTAS
               END TACS
110065         DO (L2) I10 =1, NOOBPAS  $
110066         READ INPUT TAPE  5UT,  FORI3, SIGS, SIGSD, JFLAG1, SIGA, SIGE,
110067          T1, T2, DELT  $
110068  FORI3  FORMAT ( 2(E10), I10, 5(E10) )  $
110069         WRITE OUTPUT  TAPE 6UT, FOR08, SIGS,SIGSD,JFLAG1, SIGA, SIGE,
110070           T1, T2, DELT  $
110071         T1 = T1*60.0  -  T2 = T2*60.0$
110072         IF (SIGS  ) L3, L3, L4   $
110073  L3     W(1)= 0.0   $
110074         GO TO L5    $
110075  L4     W(1) =1.0/ SIGS  $
110076  L5     IF( SIGSD) L6, L6, L7  $
110077  L6     W(2)=0.0   $
110078         GO TO  L8   $
110079  L7     W(2) =  6076.10333 / SIGSD    $
110080  L8     IF( SIGA)  L9, L9, L10   $
110081  L9     W(3) =0.0 -  GO TO L15  $
110082  L10    IF( JFLAG1) L11,L11,L12   $
110083  L11    W(3) =C3/SIGA       -GO TO L15$
110084  L12    W(3) = 1000.0/SIGA                  - GO TO L15  $
110085  L15    IF(SIGE) L16,L16, L17  $
110086  L16    W(4)=0.0  -  GO TO L20  $
110087  L17    IF (JFLAG1) L18,L18,L19  $
110088  L18    W(4) = C3/SIGE                     - GO TO L20 $
110089  L19    W(4) = 1000.0/ SIGE                - GO TO L20  $
110090  L20    T = T1-DELT $
110091  L21    T= T + DELT $
110092         IF( JFLAG2)  L22, L22, L23 $
110093  L22    ATA1= ATAO  +FMEANMO *(T-TO)   - GO TO L25 $
        L23    ATA2 = ATAO + FMEANMO*(T -TO)$
110095  L24    ATA1  =  ATAO  +FMEANMO*(T-TO) +FATAO
110096          +2.0*ATAN( ECC*SIN(ATA2-OHL)/(1.0+C4+ECC*COS(ATA2-OHL)) )
110097          +ECC*C4*SIN(ATA2 -OHL)/(1.0+ECC*COS(ATA2-OHL))  $
110098         IF( ABS( ATA2- ATA1) -.0001 )  L25, L25, L24A  $
110099  L24A   ATA2 =ATA1  $
110100         GO TO L24   $
        L25    ATA1=C10*ATA1  -TT=T- TTT=TS
110102         START TAC $
```

407 LISTING (CONT'D)

```
110103          TMA     C/HLT,T-C/HLT,TT$
110104          JMP     TRF11 $
110105          TMA     C/HLT,TT-C/HLT,TTT $
110106          TMQ     C/HLT,STATAB       $
                JMP     TRF21$
110107          JMP     L25A    $
110108 LSTATAB  SET     (P)+2    $
110109  R       SET     (P)+1    $
110110          SET     (P)+2    $
110111  FLATA   SET     (P)+1    $
110112          SET     (P)+14   $
110113  FLONA   SET     (P)+1    $
110114          SET     (P)+16   $
110115  T       SET     (P)+1    $
110116  FI      SET     (P)+1    $
110117  OHB     SET     (P)+1    $
110118  ATA1    SET     (P)+1    $
110119  V       SET     (P)+1    $
110120  WA      SET     (P)+1    $
110121  FL      SET     (P)+1    $
                SET     (P)+20$
110122  TT      SET     (P)+1    $
110123  X       SET     (P)+1    $
110124  Y       SET     (P)+1    $
110125  Z       SET     (P)+1    $
110126  XD      SET     (P)+1    $
110127  YD      SET     (P)+1    $
110128  ZD      SET     (P)+1    $
110129  TTT     SET     (P)+1    $
110130  S       SET     (P)+1    $
110131  A       SET     (P)+1    $
110132  E       SET     (P)+1    $
110133  SD      SET     (P)+1    $
110134          END TACS
110135  L25A    E = E*C110$
110136          A =    A*C110$
                FI=C200*FI-OHB=C200*OHB$
110137          COSE =COS(E) - SINE=SIN(E)- COSA=COS(A)-  SINA= SIN(A)$
1101371         TANE = SINE / COSE                                     $
110138          FLON= FLONO + DELPHIO +0.729211584E-4 *(T-TO) $
110139          COS2= COS(FLON) - SIN2 = SIN(FLON)  $
110140          SLON =    R*COS1     *(X*SIN2      -Y* COS2      )/S $
110141          SLAT =    R*(X* SIN1     *COS2      +Y* SIN1      * SIN2
110142                        -Z *COS1      )/S    $
110143          SALT   = ( R -X*COS1       *COS2      -Y* COS1       * SIN2
110144                        -Z*SIN1       )/ S  $
110145          SDLON  = -SLON* SD/S  + R* COS1     *((XD * SIN2       -YD *
110146            COS2)      + FLOND* ( Y* SIN2      + X* COS2    )  )/S  $
110147          SDLAT  = -SLAT* SD/ S  +R *( SIN1      *( XD* COS2       -YD *
110148            SIN2       + FLOND *( Y* COS2      -X* SIN2       ) )
110149            - ZD * COS1        ) / S  $
110150          SDALT   = -SALT * SD/ S  -( XD* COS2      *COS1       +YD *SIN2 ,
110151                      *COS1       +ZD * SIN1       + FLOND *COS1      *(
```

407 LISTING (CONT'D)

```
110152          Y* COS2       -X* SIN2        ))/ S  $
110153          ELON =  ( COS1 * (Y*COS2  -X* SIN2 ) - SINE * SLON )/( S* COSE)$
110154          ELAT = (Z*COS1 -SIN1*( X*COS2 +Y*SIN2 ) -SLAT* SINE)/(S*COSE) $
110155          EALT =-SALT*TANE/ S -1.0/(S*COSE)    $
                START TAC            $
                TMD      TRF11.KCOM+2  $
                TDM      DS
                TMD      TRF11.KCOM+3  $
                TDM      FNS
                END TAC            $
                C1=1.0/(FN  **2 +D  **2)    $
110157          ALON =C1*(D*(-X*COS2-Y*SIN2)+FN* SIN1*(Y*COS2 -X*SIN2) )  $
110158          ALAT =C1*FN* ( COS1*(X*COS2 +Y*SIN2) -Z *SIN2  ) $
110159          AALT =0.0  $
110160          P(1,1) = SLAT - P(2,1) =SDLAT- P(3,1) =ALAT-  P(4,1)= ELAT  $
110161          P(1,2) = SLON - P(2,2) =SDLON- P(3,2) =ALON-  P(4,2)= ELON  $
110162          P(1,3) = SALT - P(2,3) =SDALT- P(3,3) =AALT-  P(4,3) =EALT  $
110163          DO (L30) I=1, NODIM  $
110164          DO (L30) J=1, NODIM  $
110165          DO (L30) K=1,4  $
110166  L30     COMAT(I,J) = COMAT(I,J)+ W(K)**2*P(K,I)*P(K,J)    $
110167          IF ( T2 -T)  L2 , L21, L21      $
110168  L2      CONTINUE $
110169          IF( NODIM -2)  L50,L50,L51Q$
110170  L50     C5 = COMAT(1,1)*COMAT(2,2) -COMAT(1,2)*COMAT(2,1)    $
110171          C5 = 1.0/C5  $
110172          CM(1,1)=C5    * COMAT(2,2) - CM(1,2)=-C5*COMAT(2,1)  $
110173          CM(2,1)  = -C5* COMAT(1,2)- CM(2,2)= C5*COMAT(1,1)  $
110174          WRITE OUTPUT TAPE 6UT, FOR020  $
110175  FOR020  FORMAT  (2H20,S5, 45HCOVARIANCE MATRIX FOR  LATITUDE AND LONGITU
110176          DE ) $
1101765         WRITE OUTPUT TAPE 6UT,FF1$
110177  FF1     FORMAT (2H20,           S5, 4H1  1, S16, 4H1  2, S16, 4H2  1,
110178          S16, 4H2  2  )  $
110179          WRITE OUTPUT  TAPE  6UT, FOR021 $
110180  FOR021  FORMAT  (2H20, S5,25HUNITS ARE RADIANS SQUARED )$
110181          WRITE OUTPUT TAPE 6UT, FOR022, CM(1,1), CM(1,2), CM(2,1),CM(2,2)
110182            $
110183  FOR022  FORMAT  (2H20,S5, 6(E13.6, S7)  ) $
110184          WRITE OUTPUT TAPE 6UT, FOR023  $
110185  FOR023  FORMAT  (2H20, S5, 26HUNITS ARE  DEGREES SQUARED ) $
110186          C51= SQRT((CM(1,1)+CM(2,2))**2 -4.0*C5)        $
110187          EIGEN1=
110188            SQRT((CM(1,1)+ CM(2,2) +C51 )*0.5)  $
110189          EIGEN2=
110190            SQRT((CM(1,1)+CM(2,2) -C51 )*0.5 ) $
110191          DO (L51) I=1,2  $
110192          DO (L51) J=1,2  $
110193  L51     CM(I,J) = C11*CM(I,J)    $
110194          WRITE OUTPUT TAPE 6UT,FOR022, CM(1,1), CM(1,2), CM(2,1), CM(2,2)
110195            $
110196          WRITE OUTPUT TAPE 6UT, FOR024  $
110197  FOR024  FORMAT (2H20, S5, 38HSQUARE ROOT OF EIGEN VALUES IN RADIANS )$
```

407 LISTING (CONCL.)

```
110198          WRITE OUTPUT TAPE 6UT, FOR022, EIGEN1,EIGEN2    $
110199          GO TO L100  $
110204  L51Q    C20 = COMAT(1,1) *COMAT(2,2)*COMAT(3,3)+2.0*COMAT(1,2)*
110205            COMAT(2,3)* COMAT(3,1) -COMAT(1,3)**2 *COMAT(2,2)
110206           -COMAT(2,3)**2 *COMAT(1,1) -COMAT(1,2)**2 *COMAT(3,3) $
110207          C21 = 1.0/C20  $
110208          CM(1,1) =C21*(COMAT(2,2)*COMAT(3,3)-COMAT(2,3)**2)      $
110209          CM(1,2) =-C21*(COMAT(2,1)*COMAT(3,3)-COMAT(2,3)*COMAT(3,1) )$
110210          CM(2,1)= CM(1,2) $
110211          CM(1,3) = C21* (COMAT(2,1)*COMAT(3,2) -COMAT(3,1)*COMAT(2,2))$
110212          CM(3,1) = CM(1,3)  $
110213          CM(2,2) = C21* (COMAT(1,1)*COMAT(3,3)-COMAT(1,3)**2 )  $
110214          CM(3,3) =C21 * (COMAT(1,1)*COMAT(2,2)-COMAT(1,2)**2 )  $
110215          CM(2,3) =-C21*( COMAT(1,1)*COMAT(3,2)-COMAT(1,2)*COMAT(3,1))$
110216          CM(3,2) = CM(2,3)                          $
110217          WRITE OUTPUT TAPE 6UT , FOR025  $
110218  FOR025  FORMAT  (2H20,S5,54HCOVARIANCE MATRIX FOR LATITUDE  LONGITUDE
110219          ALTITUDE   ) $
110220          START TAC $
1102205         ICCZ              $
110221 S        WDEIGJ  LLL10-LLL11$
110222          JMP     LLL12         $
110223  LLL10   C/HLTL,3-C/HLTL,CM  $
110224  LLL11   C/HLTL,EVAL-C/HLTL,EVVEC  $
```

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