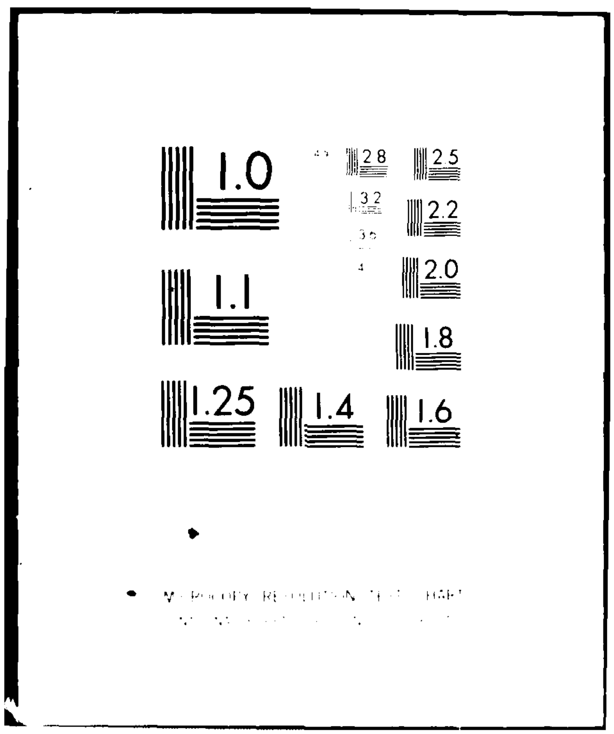
AD-A088 263 NAVAL SURFACE WEAPONS CENTER DAHLGREN LAB VA F/G 17/7
NSWC SATRACK MULTIPLE SATELLITE PROCESSOR (SAMSAP).(U)
MAR 78 J E JOHNSON
UNCLASSIFIED NSWC/DL-TR-3939 GIDEP-E162-0420 NL

1 OF 1
AD
A088263

END
DATE
FILMED
10-80
DTIC


1.0
2.8
2.5
3.2
2.2
2.0
1.1
1.8
1.25
1.4
1.6

NSWC/DL-TR-3939

NSWC SATRACK MULTIPLE SATELLITE PROCESSOR (SAMSAP)

bu
J. EDWIN JOHNSON
Strategic Systems Department

MARCH 1978

NAVAL SURFACE WEAPONS CENTER
Dahlgren, Virginia 22448
Silver Spring, Maryland 20910

1 79

OMB NO. 22-R0336

GOVERNMENT-INDUSTRY DATA EXCHANGE PROGRAM

GENERAL DOCUMENT SUMMARY SHEET

1 OF 1

Please Type All Information – See Instructions on Reverse

1. ACCESS NUMBER E162-0420	2. COMPONENT/PART NAME PER GIDEP SUBJECT THESAURUS Computers, Program, Tape	
3. APPLICATION Ground	4. MFR NOTIFICATION ☐ NOTIFIED ☒ NOT APPLICABLE	5. DOCUMENT ISSUE (Month/Year) March 1978
6. ORIGINATOR'S DOCUMENT TITLE NSWC SATRACK Multiple Satellite Processor (SAMSAP)		7. DOCUMENT TYPE ☒ GEN RPT ☐ NONSTD PART ☐ SPEC
8. ORIGINATOR'S DOCUMENT NUMBER TR-3939	9. ORIGINATOR'S PART NAME/IDENTIFICATION N/A	
10. DOCUMENT (SUPERSEDES) (SUPPLEMENTS) ACCESS NO. None	11. ENVIRONMENTAL EXPOSURE CODES N/A	
12. MANUFACTURER N/A	13. MANUFACTURER PART NUMBER ----	14. INDUSTRY/GOVERNMENT STANDARD NUMBER

15. OUTLINE, TABLE OF CONTENTS, SUMMARY, OR EQUIVALENT DESCRIPTION

Relates to performance evaluation of fleet ballistic missile systems, using the satellites of the Global Positioning System for error analysis. The SAMSAP computer program combines the pass normal matrices for the individual satellites into one system of simultaneous equations. The normal equations may be expanded to include the parameters of the station and satellite clock, gravity, and polar motion. The equations are solved for the parameter corrections and the systems covariance matrix at epoch. The corrected system state vector and the system covariance matrix are then propagated through the trajectory fit span and output to a tracked ephemeris data tape that is used by Johns Hopkins University in their Post-Flight Processor.

80 5 101

16. KEY WORDS FOR INDEXING

Ballistic Missile; Multiple Satellite Processor; Global Positioning; System Error Analysis; Ephemeris Data (Doc Des--M)

17. GIDEP REPRESENTATIVE B. A. Howard, Jr.	18. PARTICIPANT ACTIVITY AND CODE U.S. Navy, Naval Surface Weapons Center, Dahlgren VA (W4)

85

DD FORM 1 NOV 78 2000

INSTRUCTIONS FOR COMPLETING THE GIDEP GENERAL DOCUMENT SUMMARY SHEET

NOTE: Completion of a Summary Sheet by the participant is not mandatory for document acceptance into GIDEP. A Summary Sheet will be prepared by the GIDEP Operations Center for document submittals received.

PAGE 1 OF Enter the total number of summary sheet pages

BOX

1 Leave blank--entry will be completed by GIDEP Operations Center.

2 Enter standard nomenclature associated with GIDEP Subject Thesaurus selected from Section 12, Policies and Procedures Manual.

3 Indicate application which the device was used (e.g., ground, missile, shipboard, spacecraft; refer to P & P Manual, Section 13).

4 Device manufacturer must be notified of test results. Manufacturer approval of report is not required--include pertinent manufacturer correspondence with document submittal to GIDEP; check NOTIFIED entry. If document is for a nonstandard part or of a general nature and a manufacturer is not identified, check NOT APPLICABLE.

5 Enter month and year of document issue.

6 Enter complete document title exactly as it appears on originator document.

7 Identify document type by inserting letter X by appropriate descriptor.

8 Enter document number exactly as it appears on originator document.

9 Enter part name and identification as assigned by organization/agency originating the report; if not specified, enter N/A (Not Applicable).

10 Delete either SUPERSEDES or SUPPLEMENTS. If document supersedes/supplements an existing GIDEP document, enter GIDEP microfilm access number of appropriate document. If document neither supersedes nor supplements an existing GIDEP document, enter the word NONE.

11 Enter the single symbol coding for environmental exposure as defined in Subject Thesaurus, Section 12, P&P Manual (e.g., C – Salt Spray; V – Vibration; % – Shelf Life); if not specified, enter N/A (Not Applicable).

12 Enter manufacturer abbreviation and H-4 Code number listed in GIDEP Manufacturer List. If manufacturer is not listed, enter the phrase, SEE BOX 15; enter manufacturer's full name and division (if any) in Box 15. If more than one manufacturer, enter phrase, SEE BOX 15; enter additional manufacturers as appropriate. If manufacturer is not specified, enter N/A (Not Applicable).

13 Enter complete part number. Use open O for alpha letter O, and use Ø for numeric zero. If more than one part number, enter phrase, SEE BOX 15; enter additional part number(s). If a part number is not specified, enter four dashes (----).

14 Enter standard part number such as the 1N or 2N--diode and transistor designators. For GIDEP purposes, any military assigned number is considered as a government standard part number. If more than one standard number, enter phrase SEE BOX 15; enter additional standard number(s).

15 If subject matter in document can be categorized into more than one major subject category, enter additional subject categories in upper right-hand corner. Briefly summarize test results or material detailed in text of document. Include any pertinent details or comments required for proper interpretation of material presented (e.g., peculiar environmental capabilities, unique electrical characteristics that may be "state-of-the-art," or characteristics that restrict part usage to particular applications or any other details that may aid a prospective user of the part).

16 Enter appropriate words or phrases that enhance information retrieval on subject matter(s) contained in document. As a secondary data retrieval technique within each applicable Major Category (entry 2), the document is referenced in the computer data bank and Report Index according to each key word. Do not use abbreviations or words that are part of the subject category listed in Box 2. Key word phrases are limited to 60 total characters and blank spaces. Separate key words and/or phrases with commas.

17 Enter signature or name of GIDEP Representative.

18 Enter name, city, and state of participant activity or corporation and division submitting the document and GIDEP two-character code (e.g., X1).

FOREWORD

The formulation for the Naval Surface Weapons Center SATRACK Multiple Satellite Processor (SAMSAP) was conducted in support of the Johns Hopkins University/Applied Physics Laboratory (JHU/APL) program to evaluate the accuracy of U.S. Navy fleet ballistic missile systems.

This report has been reviewed and approved by S. J. Smith, Head, Satellite Geodesy Branch, and R. J. Anderle, Head, Astronautics and Geodesy Division.

Released by:

Ralph A. Niemann

R. A. NIEMANN, Head
Strategic Systems Department

3

CONTENTS

4

INTRODUCTION

This report presents the formulation for the Naval Surface Weapons Center (NSWC) SATRACK Multiple Satellite Processor (SAMSAP). SATRACK is a Johns Hopkins University/Applied Physics Laboratory (JHU/APL) program to evaluate the accuracy of U.S. Navy fleet ballistic missile systems. The program uses data from the Global Positioning System (GPS) satellites in conjunction with an APL-developed tracking system. The satellite data and missile telemetry data are combined to obtain an accurate estimation of the missile's trajectory.

SAMSAP is an orbit determination program designed to meet the special requirements for generating satellite orbital data for use in the APL Post-Flight Processor (PFP) computer program. SAMSAP computes a multiple satellite solution for the GPS satellites using single satellite pass matricies (range and range difference) and perturbed trajectories from the single satellite orbit determination program CELEST.* The multiple satellite solution contains solutions for station and satellite clock timing, drift, and aging errors. It may also contain solutions for up to 20 gravity parameters, four polar motion parameters, and station positions (as well as the standard orbit constants). Once the solution is obtained, the ephemeris for each satellite and the system covariance matrix are propagated as required for the SATRACK tracked ephemeris data (TED) tape. These results are written on a file that is reformatted and output on magnetic tape for transmittal to JHU/APL.

The CELEST files used by the program are

1. Pass Matrix Files – One for each data class for each satellite. This file contains the pass normal equations which are expanded by the SAMSAP program, combined with pass matrices of other satellites, and solved.

2. Perturbed Trajectory Files – One for each satellite. The perturbed trajectory file contains the partial derivatives which constitute the state transition matrix for the satellite. The partials are used in expanding the pass matrices for gravity parameters and for propagating the state vector and covariance matrix.

3. Polar Motion File – One per run. This file contains the polar motion parameters needed to expand the pass matrices for polar motion.

4. ABCD File – One per run. This file contains the Greenwich hour angles and the inertial-to-earth fixed transformation matrices for each time step in the integration. It is used by the SAMSAP program to output the required values for APL's use.

---

*James W. O'Toole, *CELEST Computer Program for Computing Satellite Orbits*, Naval Surface Weapons Center, Dahlgren Laboratory Technical Report NSWC/DL TR-3565, Dahlgren, Virginia, October 1976.

Figure 1 is a flowchart designed to illustrate the following discussion of the program's logic.

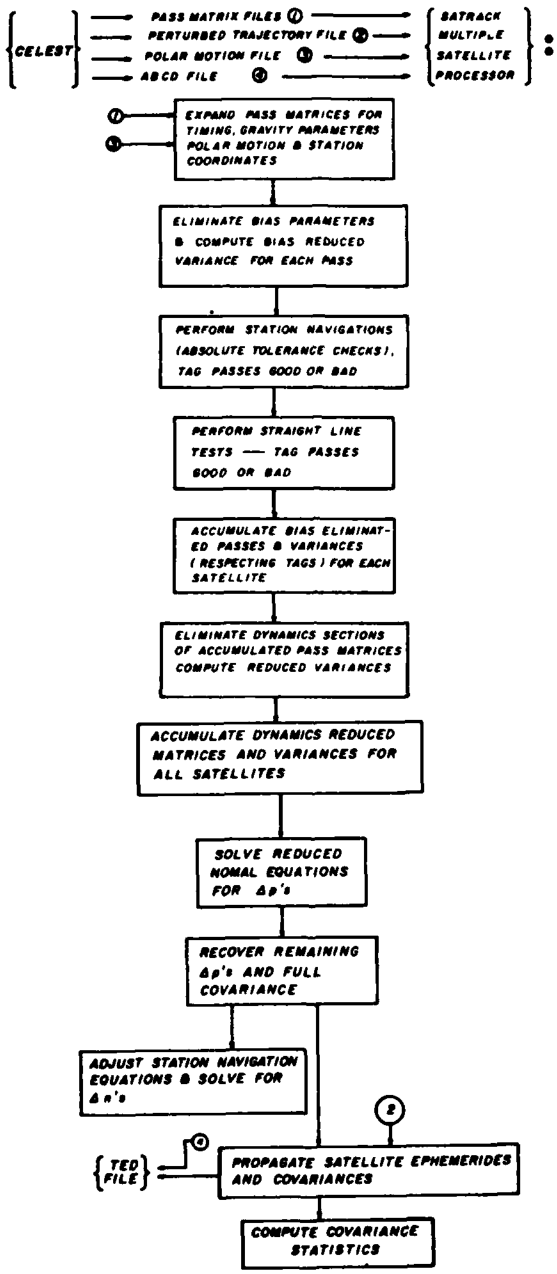


Figure 1. Method Flowchart

The program takes the normal equations as written on the pass matrix files and expands them to include station and satellite timing. If required, the pass matrices can be expanded to include up to 20 gravity parameters and four polar motion parameters. The bias section of the matrices are then eliminated.

Two different tests are performed to determine whether or not the matrices should be included in the solution. The first test rotates the bias section of the pass matrix to the radial, tangential, and out-of-plane directions to the satellite's path. The rotated equations are solved for the corrections to the stations' positions (Δn_1, Δn_2, and Δn_3). Each of these are compared to an input tolerance and the pass is rejected if any one of the tests fail. The second test consists of fitting, in a least squares sense, a straight line through the data points corresponding to Δn_i at TCA for each pass in each rotated direction. The standard deviation of the fit is computed, and any pass which lies outside of some specified multiple of this standard deviation in any of the directions tested is rejected.

All of the accepted passes are then summed for each satellite. The dynamic section of the accumulated normal equations for each satellite is eliminated and the resulting equations are summed.

At each matrix elimination, the reduced variance is computed. When the matrices are summed, the variances are also summed.

After all matrices have been accumulated, the resulting normal equations are solved for the parameter corrections (Δp's). The Δp's and covariance corresponding to the dynamics section of the normal equations are then recovered. These Δp's are used to adjust the right-hand side of the bias section of the rotated normal equations used in the station navigation section. The adjusted equations are solved for the correction to station position (Δn_i), and these are output for diagnostic purposes. Using the Δp's and the partials from the perturbed trajectory files, the satellites' positions are propagated over the fit span and output to the TED file as required. The covariance is also propagated over the fit span and written to the TED file when required. For each time to which the covariance is propagated, the satellite position section of the covariance is rotated to a reference frame which is radial, tangential, and out-of-plane to the satellites' trajectories at that time. The resulting sigmas in the rotated frame, as well as the sigmas for the clock terms of each satellite and station, are written on a ***Diagnostic Information File***.

Since the TED file format is discussed in several documents as well as this report, it will not be detailed here. The TED file written by this program must be reformatted by a second program into a form usable by JHU/APL. Appendix A contains a description of the final tape format.

SOLUTION

Appendix B contains a list of parameters which should be included as input. It also contains a list of the files which will be required by the program. Appendix C contains a description of the standard CELEST files that will be used by the SAMSAP program. The logic flowchart (Figure 2) has been numbered to correspond to the numbered steps (1 through 29) in this report.

On the pass matrix file, the parameters will be in the following order:

Position
Velocity
Thrust (if present)
Radiation Pressure (if present)
Station Position
Refraction
Bias
Drift
Aging

For the purpose of this report, position, velocity, thrust, radiation pressure, and satellite clock parameters (to be discussed later) will be referred to as orbit or dynamic parameters. Station position will be considered both a bias parameter and an arc parameter. Refraction will always be considered a bias parameter. Bias, drift, and aging (range data only) when multiplied by c, the speed of light, become the satellite clock parameters and when multiplied by minus c, become the station clock parameters. Satellite clock parameters will be considered dynamic parameters, and station clock parameters will be considered arc parameters. For range difference data, aging is not present; and bias and drift refer to frequency bias and frequency drift, respectively. Frequency bias and frequency drift are always considered bias parameters.

STEP (1)

Input values of times A6A, A6B, A5A, and A5B (defined in Appendix B) are packed as follows:

$$(\text{YEAR} - 1900) * 1000 + \text{DAY} + \text{SEC} * 10^{-5} \qquad (1)$$

Epoch of solution is A5A.

8

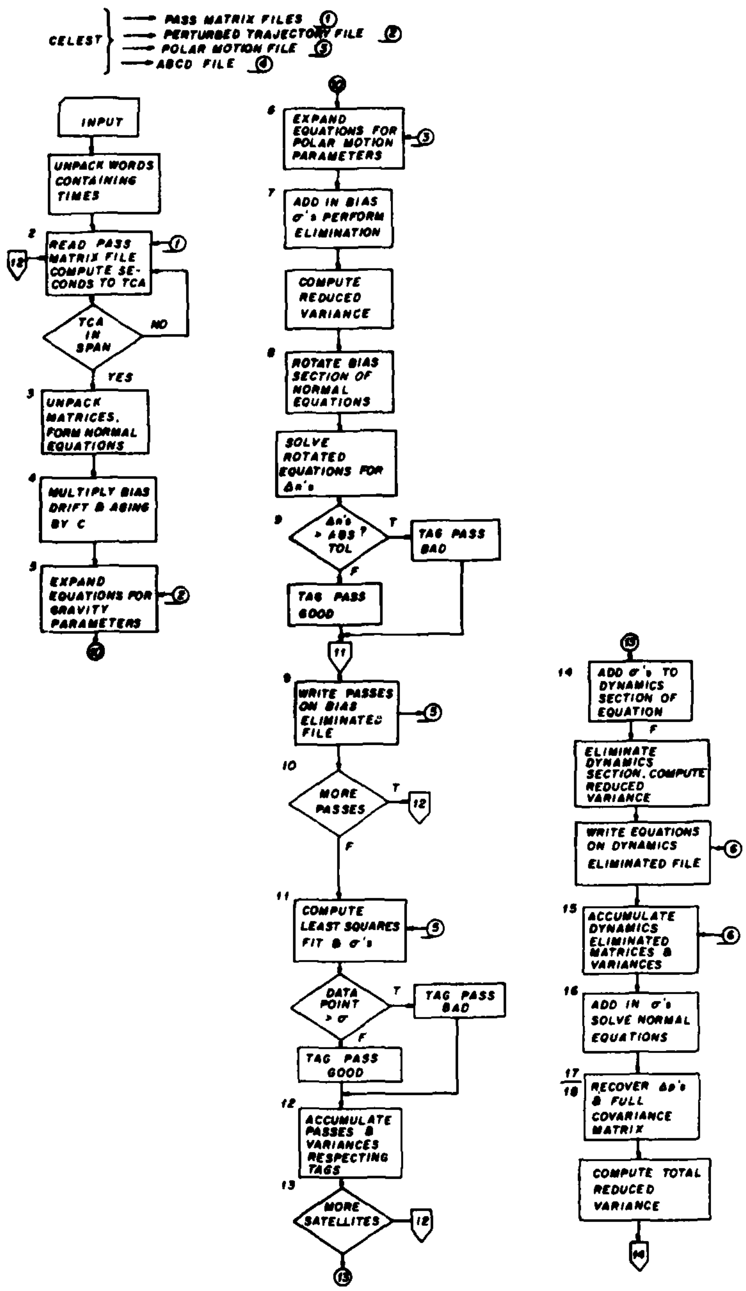


Figure 2. Detailed Logic Flowchart

9

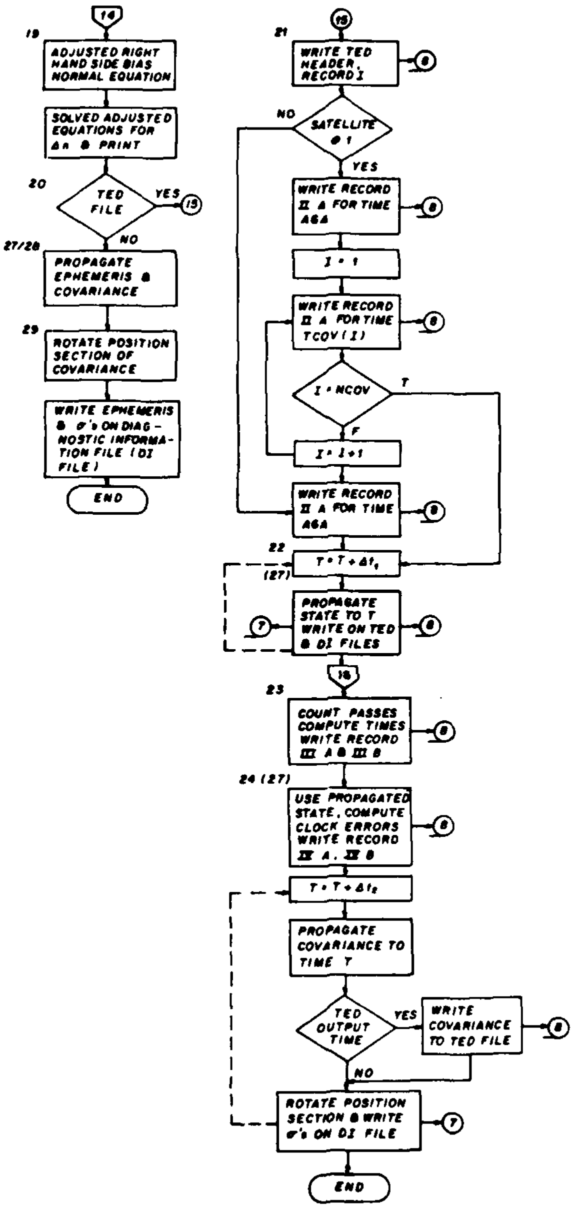


Figure 2. Detailed Logic Flowchart (Continued)

10

Unpack A5A, A6A, and A6B and compute seconds from A5A to A6A, A6A to A6B, and A5A to A6B.

Let

DAY5A = day number of time A5A
YR5A = year of A5A
SEC5A = seconds of time A5A

and so on to SEC6B.

A5A to A6A: If YR6A = YR5A,

$$\text{SEC5T6} = (\text{seconds from A5A to A6A}) = (\text{DAY 6A} - \text{DAY 5A}) * 86400 + (\text{SEC6A} - \text{SEC5A}) \quad (2)$$

If YR6A > YR5A, check for leap year [i.e., Mod (1900 + YR5A) with 4]; if it is 0, then YR5A is a leap year.

For leap years,

$$\text{SEC5T6} = (366 - \text{DAY5A} + \text{DAY6A}) * 86400 + (\text{SEC6A} - \text{SEC5A}) \quad (3)$$

For non-leap years,

$$\text{SEC5T6} = (365 - \text{DAY5A} + \text{DAY6A}) * 86400 + (\text{SEC6A} - \text{SEC5A}) \quad (4)$$

Similarly for A6A to A6B. A5A to A6B is then, of course, the sum of the two preceding calculations.

STEP (2)

This program must be set up to process range and/or range difference data. Although the order of processing is up to the programmer, it will be assumed in the following discussion that the order will be

11

Range data for first satellite
Range difference data for first satellite
Range data for second satellite and so on

Read in pass from i^{th} satellite from pass matrix file. Time-of-closest-approach (TCA) on the file is given in seconds from the beginning of the day in record type 2 of the file. Compute the seconds from A5A to TCA [same as Step (1)]. Check to see if this is within the time span during which the data are to be used. If not, skip to next pass.

STEP (3)

Unpack the pass matrix and form single satellite normal equations ($B\Delta p = E$).

1. Range data

$$B = \begin{bmatrix} \text{Station Position} \\ \text{Station Clock} \\ \text{Dynamic} \\ \text{*Bias} \end{bmatrix}$$

$$E = \begin{bmatrix} \text{Station Position} \\ \text{Station Clock} \\ \text{Dynamic} \\ \text{*Bias} \end{bmatrix}$$

*Bias section consists of refraction and station position.

2. Range difference data

$$B = \begin{bmatrix} \text{Station Position} \\ \text{Dynamic} \\ \text{*Bias} \end{bmatrix}$$

$$E = \begin{bmatrix} \text{Station Position} \\ \text{Dynamic} \\ \text{*Bias} \end{bmatrix}$$

*Bias section consists of station position, refraction, and frequency terms.

At this point, the values stored in the station clock positions should be the negative of the terms read in for bias, drift, and aging (range data). The values stored in the satellite clock positions should equal those values read in for bias, drift, and aging. The suggested order for arranging dynamic parameters is

Position
Velocity
Radiation Pressure
Thrust
Clock Bias
Clock Drift
Clock Aging

STEP (4)

Multiply all rows and columns of B and rows of E that contain clock parameters by c. (Note: Diagonal elements of B are thus multiplied by c^2.)

STEP (5)

Expand the normal equations for gravity parameters specified (from 0 to 20 parameters). Now consider the normal equations partitioned as

$$\begin{bmatrix} B_{aa} & B_{ad} & B_{ab} \\ B_{da} & B_{dd} & B_{db} \\ B_{ba} & B_{bd} & B_{bb} \end{bmatrix} \begin{bmatrix} \Delta p_a \\ \Delta p_d \\ \Delta p_b \end{bmatrix} = \begin{bmatrix} E_a \\ E_d \\ E_b \end{bmatrix} \tag{5}$$

where

sub a = arc parameters
sub d = dynamic parameters
sub b = bias parameters

Note that B is symmetric. Thus,

$$B_{ad} = B_{da}^T, \text{ etc.}$$

Now, letting sub g indicate gravity parameters and d indicate the first six dynamic parameters,

$$B_{gg} = \frac{\partial X_{TCA}}{\partial g}^{T} \frac{\partial X_{TCA}}{\partial X_0}^{-T} B_{dd} \frac{\partial X_{TCA}}{\partial X_0}^{-1} \frac{\partial X_{TCA}}{\partial g}$$

$$B_{gd} = B^{T}_{dg} = \frac{\partial X_{TCA}}{\partial g}^{T} \frac{\partial X_{TCA}}{\partial X_0}^{-T} B_{dd}$$

$$B_{ga} = B^{T}_{ag} = \frac{\partial X_{TCA}}{\partial g}^{T} \frac{\partial X_{TCA}}{\partial X_0}^{-T} B_{da} \tag{6}$$

$$B_{gb} = B^{T}_{bg} = \frac{\partial X_{TCA}}{\partial g}^{T} \frac{\partial X_{TCA}}{\partial X_0}^{-T} B_{db}$$

$$E_{g} = \frac{\partial X_{TCA}}{\partial g}^{T} \frac{\partial X_{TCA}}{\partial X_0}^{-T} E_{d}$$

where

X_0 = epoch elements
superscript T = transpose of matrix
superscript -T = transpose, inverse of matrix
$\frac{\partial X_{TCA}}{\partial g}$, $\frac{\partial X_{TCA}}{\partial X_0}$ = partials obtained from the perturbed trajectory file for the satellite;* and, X represents the state vector of the satellite

*An interpolation routine, NTRP8, must be used to obtain all values from the perturbed trajectory file (Appendix D).

14

Thus, the normal equations can now be written

$$\begin{bmatrix} B_{aa} & B_{ag} & B_{ad} & B_{ab} \\ B_{ga} & B_{gg} & B_{gd} & B_{gb} \\ B_{da} & B_{dg} & B_{dd} & B_{db} \\ B_{ba} & B_{bg} & B_{bd} & B_{bb} \end{bmatrix} \begin{bmatrix} \Delta p_g \\ \Delta p_a \\ \Delta p_d \\ \Delta p_b \end{bmatrix} = \begin{bmatrix} E_a \\ E_g \\ E_d \\ E_b \end{bmatrix} \quad (7)$$

STEP (6)

Expand normal equations for polar motion, if indicated.

Compute

$$A(TCA) = \begin{bmatrix} 1 & -\omega_3 & \omega_2 \\ \omega_3 & 1 & -\omega_1 \\ -\omega_2 & \omega_1 & 1 \end{bmatrix}$$

where

$$\begin{aligned} \omega_1 &= \Delta q = y \\ \omega_2 &= \Delta p = x \\ \omega_3 &= \tilde{\omega}(\Delta t + t\Delta\dot{t}) \\ \Delta t &= UT1 - UTC \\ t &= \text{time in seconds from beginning of year} \\ \tilde{\omega} &= \text{rotational rate of the earth} \end{aligned}$$

$\tilde{\omega}$ should be read from input. Δp, Δq, and Δt are available for the start of each day from the Polar Position File (Appendix E). A six-point Lagrangian interpolation should be used to obtain Δp, Δq, and Δt at TCA of the pass. Δt should currently be defaulted to zero; however, provisions should be made to read it from the Polar Position File and interpolate for $\Delta t(TCA)$ using the six-point Lagrangian interpolator.

Read station coordinates $\begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix}$ from pass matrix file and compute

$$Q = \begin{bmatrix} 0 & -s_3 & \tilde{\omega} s_2 & \tilde{\omega} t s_2 \\ s_3 & 0 & -\omega_1 s_1 & -\tilde{\omega} t s_1 \\ -s_2 & s_1 & 0 & 0 \end{bmatrix}$$

Then compute

$$B_{pp} = Q^T A^T B_{ss} A Q \tag{8}$$

where

B_{ss} = station-station section of B_{bb} (or B_{aa})

Also,

$$\begin{aligned} B_{bp} &= B_{pb}^T = B_{bs} AQ \\ B_{dp} &= B_{pd}^T = B_{ds} AQ \\ B_{ap} &= B_{pa}^T = B_{as} AQ \\ B_{gp} &= B_{pg}^T = B_{gs} AQ \\ E_p &= Q^T A^T E_s \end{aligned} \tag{9}$$

Thus, the normal equations can now be written as

$$\begin{bmatrix} B_{pp} & B_{pa} & B_{pg} & B_{pd} & B_{pb} \\ B_{ap} & B_{aa} & B_{ag} & B_{ad} & B_{ab} \\ B_{gp} & B_{ga} & B_{gg} & B_{gd} & B_{gb} \\ B_{dp} & B_{da} & B_{dg} & B_{dd} & B_{db} \\ B_{bp} & B_{ba} & B_{bg} & B_{bd} & B_{bb} \end{bmatrix} \begin{bmatrix} \Delta p_p \\ \Delta p_a \\ \Delta p_g \\ \Delta p_d \\ \Delta p_b \end{bmatrix} = \begin{bmatrix} E_p \\ E_a \\ E_g \\ E_d \\ E_b \end{bmatrix} \tag{10}$$

16

STEP (7)

Now consider the equations partitioned as

$$\begin{bmatrix} B_{nn} & B_{nb} \\ B_{bn} & B_{bb} \end{bmatrix} \begin{bmatrix} \Delta p_n \\ \Delta p_b \end{bmatrix} = \begin{bmatrix} E_n \\ E_b \end{bmatrix} \tag{11}$$

where B_{bb}, Δp_b, and E_b are defined as before and B_{nn} contains all nonbias terms.

Compute $1/\sigma^2$ for bias σ's and add to diagonal terms of B_{bb}. Compute the bias-eliminated normal equations and reduced variance:

$$B^{E1} = B_{nn} - B_{nb} B_{bb}^{-1} B_{bn} \tag{12}$$

$$E^{E1} = E_n - B_{nb} B_{bb}^{-1} E_b \tag{13}$$

$$V^{E1} = V - E_b^T B_{bb}^{-1} E_b \tag{14}$$

Write the reduced variance, bias-eliminated normal equations, and TCA of the pass on a ***bias eliminated*** file.

STEP (8)

Perform station navigations. Looking at the bias section of the normal equations

$$B_{bb} \Delta p_b = E_b$$

partition the matrices as

$$\begin{bmatrix} B_{ss} & B_{sc} \\ B_{os} & B_{oo} \end{bmatrix} \begin{bmatrix} \Delta p_s \\ \Delta p_o \end{bmatrix} = \begin{bmatrix} E_s \\ E_o \end{bmatrix}$$

17

where

s = station position parameters
o = all other parameters in the bias section

Rotate the equations to the radial, along track, and out-of-plane directions at TCA. The rotation matrices can be found on the pass matrix files. Let r be the 3 X 3 rotation matrix from the pass matrix files, then define

$$R = \begin{bmatrix} r & 0 \\ 0 & r \end{bmatrix} \tag{16}$$

The rotations are then

$$B_{bb}^{R} = R^{T} B_{bb} R \tag{17}$$

$$E_{b}^{R} = R^{T} E_{b}$$

Now compute

$$\Delta n = (B_{bb}^{R})^{-1} E_{b}^{R} \tag{18}$$

Output Δn, σ's from $(B_{bb}^{R})^{-1}$ (σ's = $\sqrt{\text{diag } (B_{bb}^{R})^{-1}}$).

Store $(B_{bb}^{R})^{-1}$, E_{b}^{R}, R, B_{sp}, and $B_{sd'}$ for future use.

B_{sp} = station position – polar motion submatrix
$B_{sd'}$ = station position – dynamic parameters submatrix without the station clock terms

STEP (9)

Perform the absolute tolerance test.

18

If

$$\Delta n_1 > (\text{absolute tolerance})_1$$

$$\Delta n_2 > (\text{absolute tolerance})_2 \tag{19}$$

or

$$\Delta n_3 > (\text{absolute tolerance})_3$$

tag the pass bad [(absolute tolerance)$_i$ should be read from input]. Write tag ($\Delta n_{1,2,3}$) on bias eliminated file.

STEP (10)

Return to Step (2) and process the next pass. When all passes from the i^{th} satellite of data class being processed have been completed, go to Step (11).

STEP (11)

Perform the straight line test. Read from the bias-eliminated file TCA, $\Delta n_{1,2,3}$ for each pass. Form the following matrices:

$$M = \begin{bmatrix} TCA)_{pass\ 1} & 1 \\ TCA)_{pass\ 2} & 1 \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ TCA)_{pass\ n} & 1 \end{bmatrix} \quad N_1 = \begin{bmatrix} \Delta n_1)_{pass\ 1} \\ \Delta n_1)_{pass\ 2} \\ \cdot \\ \cdot \\ \cdot \\ \Delta n_1)_{pass\ n} \end{bmatrix} \tag{20}$$

$$N_2 = \begin{bmatrix} \Delta n_2)_{pass\ 1} \\ \cdot \\ \cdot \\ \cdot \\ \Delta n_2)_{pass\ n} \end{bmatrix} \quad N_3 = \begin{bmatrix} \Delta n_3)_{pass\ 1} \\ \cdot \\ \cdot \\ \cdot \\ \Delta n_3)_{pass\ n} \end{bmatrix} \tag{21}$$

Now solve

$$\begin{bmatrix} m_1 \\ b_1 \end{bmatrix} = (M^T M)^{-1}(M^T N_1)$$

$$\begin{bmatrix} m_2 \\ b_2 \end{bmatrix} = (M^T M)^{-1}(M^T N_2) \tag{22}$$

$$\begin{bmatrix} m_3 \\ b_3 \end{bmatrix} = (M^T M)^{-1}(M^T N_3)$$

to form equations

$$\begin{aligned} y_1 &= m_1 t + b_1 \\ y_2 &= m_2 t + b_2 \\ y_3 &= m_3 t + b_3 \end{aligned} \tag{23}$$

Let

$$t = TCA)_{pass\ j} \quad j = 1, 2, \cdots, n$$

and compute y_1, y_2, and y_3 from Equation (23).

Test

$$|\Delta n_i - y_{i_{pass\ j}}| < \text{sig mult}_i * \sigma_i \Big]_{i=1,2,3} \quad j = 1, 2, \cdots, N \tag{24}$$

where sig mult_i is read from input

20

and

$$\sigma_i = \left[\sum_{j=1}^{N} \frac{\Delta n_i - y_i}{N}^{2} \right]^{1/2} \quad i = 1,2,3 \tag{25}$$

N = total number of passes
sig mult_i = input quantity

If for i = 1, 2, 3 the pass fails the test, tag it bad. The option should be available to test on i = 1, 2, ***or*** 3 or any combination thereof.

STEP (12)

Accumulate (paying attention to station and timing terms) pass matrices, respecting tags, for the satellite being processed. Sum elements of B^{E1}, E^{E1}, and V^{E1} as indicated for the satellite being processed:

$$\begin{aligned} B^S &= B^{E1})_{\text{pass } 1} + B^{E1})_{\text{pass } 2} + \cdots + B^{E1})_{\text{pass } N} \\ E^S &= E^{E1})_{\text{pass } 1} + \cdots + V^{E1})_{\text{pass } N} \\ V^S &= V^{E1})_{\text{pass } 1} + \cdots + V^{E1})_{\text{pass } N} \end{aligned} \tag{26}$$

STEP (13)

Return to Step (2) and begin processing next data class. When all data for a specific satellite has been processed, go to Step (14).

STEP (14)

Partition the summed normal equations (B^S, E^S) as

$$\begin{bmatrix} B_{mm} & B_{md} \\ B_{dm} & B_{dd} \end{bmatrix} \begin{bmatrix} \Delta p_m \\ \Delta P_d \end{bmatrix} = \begin{bmatrix} E_m \\ E_d \end{bmatrix} \tag{27}$$

21

where

d = dynamic parameters
m = all nondynamic parameters

Add $1/\sigma_i^2$ to the diagonals of the dynamic section of the matrix. Eliminate the dynamic section of the equations.

$$B^{E2} = B_{mm} - B_{md} B_{bb}^{-1} B_{dm}$$

$$E^{E2} = E_m - E_{md} B_{dd}^{-1} E_d$$

$$V^{E2} = V^S - E_d^T B_{dd}^{-1} E_d$$

Write the reduced normal equations and the variance on a ***dynamics eliminated file***. Save B_{dd}^{-1}, $B_{dd}^{-1} B_{dm}$, and $B_{dd}^{-1} E_d$ for future use.

Return to Step (2) and begin processing data for next satellite. When all satellites have been processed, go to Step (15).

STEP (15)

Accumulate matrices and variances as before; i.e.,

$$B^A = B^{E2})_{sat\ 1} + B^{E2})_{sat\ 2} + \cdots B^{E2})_{sat\ n}$$

$$E^A = E^{E2})_{sat\ 1} + \cdots + E^{E2})_{sat\ n} \qquad (29)$$

$$V^A = V^{E2})_{sat\ 1} + \cdots + V^{E2})_{sat\ n}$$

The equations are now

$$\begin{bmatrix} \text{Polar motion})_{\Delta q} & \\ \cdot & \\ \cdot & \text{(if present)} \\ \cdot & \\ \text{Polar motion})_{\Delta t} & \\ \text{Position})_{sta\ 1} & \\ \cdot & \\ \cdot & \\ \cdot & \\ \text{Position})_{sta\ m} & \\ \text{Clock})_{sta\ 1} & \\ \cdot & \\ \cdot & \\ \cdot & \\ \text{Clock})_{sta\ m} & \\ \text{Gravity})_{1} & \\ \cdot & \\ \cdot & \text{(if present)} \\ \cdot & \\ \text{Gravity})_{k} & \end{bmatrix} \begin{bmatrix} \Delta p_{\text{polar motion}} \\ \Delta p_{\text{station position}} \\ \Delta p_{\text{station clock}} \\ \Delta p_{\text{gravity}} \end{bmatrix} = \begin{bmatrix} E_{\text{polar motion}} \\ E_{\text{station position}} \\ E_{\text{station clock}} \\ E_{\text{gravity}} \end{bmatrix} \tag{30}$$

STEP (16)

Add in the appropriate σ's $(1/\sigma_i^2)$ to the diagonal terms and solve

$$\Delta p_m = (B^A)^{-1} E^A \tag{31}$$

Print Δp_m, $(B^A)^{-1}$.

STEP (17)

Recover the remainder of Δp's and the full covariance:

$$(\Delta p_d)_{sat\ i} = (B_{dd}^{-1} E_d)_{sat\ i} - (B_{dd}^{-1} B_{dm})_{sat\ i} \Delta p_m \quad \text{for satellite } i \tag{32}$$

23

STEP (18)

Represent the full covariance, B^{-1}, as

$$B^{-1} = \begin{bmatrix} K & M^T \\ M & N \end{bmatrix}$$

Then,

$$K = (B^A)^{-1} \tag{33}$$

$$M = \begin{bmatrix} -B_{dd}^{-1}B_{dm})_1 \\ -B_{dd}^{-1}B_{dm})_2 \\ \vdots \\ -B_{dd}^{-1}B_{dm})_n \end{bmatrix} K \qquad : n = \text{number of satellites} \tag{34}$$

$$N = \begin{bmatrix} B_{dd}^{-1})_1 & & 0 \\ & B_{dd}^{-1})_2 & \\ & & \ddots \\ 0 & & B_{dd}^{-1})_n \end{bmatrix} - \begin{bmatrix} B_{dd}^{-1}B_{dm})_1 \\ B_{dd}^{-1}B_{dm})_2 \\ \vdots \\ B_{dd}^{-1}B_{dm})_n \end{bmatrix} M^T \tag{35}$$

Output and save B^{-1}, and

$$\Delta p = \begin{bmatrix} \Delta p_m \\ \Delta p_d)_{sat\ 1} \\ \vdots \\ \Delta p_d)_{sat\ n} \end{bmatrix}$$

24

Compute and print total reduced variances for all satellites used in solution:

$$(V^{E\,2})^{Pred}_{sat\ i} = E^{E\,2}_{sat\ i} - E^{E\,2}_{sat\ i}\,\Delta p_m \tag{36A}$$

$$(V^{A})^{Pred} = V^{A} - E^{A}\,\Delta p_m \tag{36B}$$

where

Pred = predicted values

Let

$$\Delta p_n)_{sat\ i} = \begin{bmatrix} \Delta p_m \\ \Delta p_d)_{sat\ i} \\ \vdots \\ \Delta p_d)_{sat\ i} \end{bmatrix}$$

STEP (19)

Perform station navigations. Adjust the right-hand side of the rotated equations [Step (9)] for each phase of each satellite by

$$E_{b)adj} = E_b - B_{sp\,|\,d}\begin{bmatrix} \Delta p_b \\ \Delta p_{d'} \end{bmatrix}_{\substack{sat\ i \\ pass\ j}}$$

where

$B_{sp\,|\,d}$ = $[B_{sb} \quad B_{sd'}]$
Δp_p = corrections to the polar motion parameters
$\Delta p_{d'}$ = corrections to the dynamic parameters (without the clock terms

25

Solve for $\Delta n_i)_{adj}$:

$$\Delta n_i)_{adj} = \left[(B^R_{bb})^{-1} E^R_b)_{adj}\right]^{sat\ i}_{pass\ j} \tag{38}$$

Print $\Delta n_i)_{adj}$.

STEP (20))

There are two options to be considered at this point that depend on whether or not a TED file is to be written:

1. Propagating the satellites' ephemerides over a specified interval and writing the propagated ephemerides to a TED over a portion of this interval. Propagating the covariance matrix over another specified interval and writing the covariance to the TED file at specified times within the interval.

2. Propagating the ephemerides and covariance over the specified intervals and not writing a TED file.

In order to propagate the ephemerides and covariance, a start and stop time and step size should be input for each. In addition, a start and stop time and a step size should be input for the interval over which the propagated ephemerides are to be written to the TED file. It can be assumed that this interval will always be a subinterval of the time span over which the ephemerides are to be propagated. The step size can be assumed to be an integer multiple of the step size used in propagating the ephemerides. The times at which the covariance matrix is to be written to the TED file should be stored in an array (TCOV, Appendix B), and can be assumed to always be within the interval over which the covariance is being propagated. The times at which the covariance is to be written on the TED file will always be integer multiples of the step size, except for the first time the covariance is to be written. This time corresponds to missile launch time, and may not lie on an integer multiple of the step size. In this case, a separate propagation must be performed. At each time line of the covariance propagation, an option should be included to write a ***diagnostic reference file*** similar to Tape 73, Appendix C. The propagated ephemerides and the covariance matrices written to the TED file should also be printed.

TED FILE

STEP (21)

The first record written on the TED file consists of two words: (1) the number of satellites being processed, and (2) the number of time lines to be output in the ephemeris section. The number of time lines, NTL, is given by

$$NTL = IFIX[(A6B - A6A)/\text{output interval}] + 1 \tag{39}$$

and all quantities are in seconds.

All other records will be written as described in Appendix F. This part of the report will cover only the computations required to obtain the desired values.

I Header record – no computations required

IIA Ephemeris file header record – words 1 and 2 can be determined from input:

$$\begin{aligned} \text{Word } 1 &= IFIX(A6A) \\ \text{Word } 2 &= \text{decimal part of } A6A * 10^5 \end{aligned} \tag{40}$$

The program must write records IIA and B for the first satellite, then the second, and so on. The position and velocity of the satellite must be propagated to time A6A (see the PROPAGATION section). The right ascension of Greenwich and the transformation matrix at the start of each day can be obtained from the ABCD file (Appendix G). A six-point Lagrangian interpolation should be used to determine the values of the hour angle and transformation matrix at the time needed. Words 11 and 12 are simply read from input. For the first satellite, the header record is repeated for each time that the covariance matrix is to be output in part IV of the TED format [NCOV times, TCOV (I) contains the times]. The only words that must be changed when the record is repeated for satellite 1 are words 10 and 13 through 21. The words must be read in from the ABCD file for each time at which the records are to be written.

STEP (22)

Record IIB contains satellite position, velocity, and clock error for every time line between A6A and A6B. The step size to be used is an input value. Time is written on the file as elapsed time in seconds from A6A; however, all calculations must be done in seconds from epoch, A5A. The position and velocity must be propagated to the output time and the clock error is computed by

$$\Delta t = \Delta p_{clock\ bias} + \Delta p_{clock\ drift} \cdot t + 1/2 \cdot \Delta p_{clock\ aging} \cdot t^2 \Big|_{sat\ i} \qquad (41)$$

where

t = time in seconds from epoch

Record IIB is repeated for each time line until A6B is reached. Record IIA, and then IIB are written for the next satellite, and so on. If records IIA and B have been written for all satellites, an end-of-file is written.

STEP (23)

Record Type III: Station Files – One file must be written for each station, and the files should be ordered so that the stations occur in the same order as the station numbers are input (i.e., in the MSAT array).

All words contained in the header record are read from input except word 12 (the total number of passes), which must be computed.

To write the station files, all data from the pass matrix files must be sorted by station, accepted or rejected based on TCA of each pass, and counted. This, at the option of the programmer, may take place during the solution part of the program.

From the pass matrix files, which are satellite ordered, read (for each pass) year, day, station number, and number of points in the pass from record type 2; start (rise) and stop (set) time of passes from words five and six of record type 4; and TCA of the pass from record type 5. As in the solution portion of this program, the time in seconds from A5A to TCA of the pass should be compared to the time spans over which the data are to be processed. Those passes which lie outside the interval are to be discarded. For those passes which are accepted TCA, rise, and set times must be converted to seconds from A6A and the number of passes accepted for each station must be counted. When processing range ***or*** range difference data, all passes which lie in the acceptable time span are to be counted. When processing both range and range difference data, only range difference passes are to be tested and counted. Output would then be a header record followed by the appropriate number of data records for the first station (an end-of-file), and then the header record for the second station, and so on.

STEP (24)

Record Type IV: Solution Parameters and Multiple Satellite Covariance – These records are written for each time specified in input (TCOV array).

IV A Records – The time written in word one and stored in the TCOV array is with respect to time A6A. To propagate the state vector, it is necessary to reference this time to epoch. If a parameter does not appear in the satellites' state vector (i.e., radiation pressure and/or thrust), default values (9.9999E9) must be written for each absent parameter.

To compute the appropriate values for radiation pressure coefficients and thrust, the initial values of the parameters must be read from the perturbed trajectory file header record. To this value is added the computed correction (Δp) for the parameter; i.e.,

$$K1(I) = K1(I)_0 + \Delta p_{k1}(I)$$

$$K2(I) = K2(I)_0 + \Delta p_{k2}(I)$$

$$K3(I) = K3(I)_0 + \Delta p_{k3}(I)$$

$$T1(I) = T1(I)_0 + \Delta p_{t1}(I)$$

$$T2(I) = T2(I)_0 + \Delta p_{t2}(I)$$

$$T3(I) = T3(I)_0 + \Delta p_{t3}(I)$$

where

K1(I), K2(I), K3(I) = x, y, and z components of the radiation pressure coefficients, respectively, for the i^{th} satellite

T1(I), T2(I), T3(I) = x, y, and z components of thrust, respectively, for the i^{th} satellite

Subscript 0 = initial value, as read from the perturbed trajectory file of the satellite being processed

$\Delta p_j(I)$ = computed correction for the j^{th} component for the i^{th} satellite.

Δt for each satellite (station) is calculated by Equation (41), and $\dot{\Delta t}$, $\ddot{\Delta t}$ for each satellite (station) are computed from

$$\dot{\Delta t} = \Delta p_{clock\ drift} + \Delta p_{clock\ aging} \cdot t]_{sat\ i\ (sta\ i)} \qquad (42)$$

$$\Delta\ddot{t} = \Delta p_{clock\ aging}\Big]_{sat\ i\ (sta\ i)}$$

The a priori σ's to be written for the master station are the input σ's corresponding to the master station multiplied by 1000.

STEP (25)

Records IVB contain the station positions (x, y, and z) which can be read from the pass matrix files. The refraction correction assumed is always equal to zero. The a priori σ's in words 3M + 2 through 3M + 4 are the input σ's multiplied by 1000 which correspond to station positions x, y, and z, respectively, in the bias submatrix. Word 3M + 5 is the input σ for refraction.

STEP (26)

Records IVC contain the covariance matrix propagated to the output time. The matrix is written in rows for the upper diagonal half. Each write record contains the upper diagonal half of a row. The matrix is always written as a ***full*** matrix; i.e., it has locations for all parameters whether or not the parameters are present in the solution. If the parameters are not in the solution, default values are written in all rows and columns allocated to that parameter.

PROPAGATION

STEP (27)

State – The equation for propagating the state is

$$X_t = \tilde{X}_t + \sum_{i=1}^{n} \frac{\partial X_t}{\partial P_{i_{t_0}}} \Delta p_i \qquad (43)$$

where

X_t = corrected values at time t
$\tilde{X}_t$ = uncorrected values at time t, from perturbed trajectory file
n = total number of parameters

30

Δp_i is obtained from the solution vector of the satellite, Δp_{di} in Step (17), and $\partial X_t / \partial p_{i_{t_0}}$ are obtained from the perturbed trajectory file. If thrust is present in the solution, the partials of the orbit parameters with respect to the thrust parameters that are read from the perturbed trajectory files must be adjusted.

Let

$\psi_a(t)$ = partials of the six orbit parameters with respect to thrust, as read from the perturbed trajectory file for time t

$\psi(t)$ = partials of the six orbit parameters with respect to position and velocity from the perturbed trajectory file for time t

t_s = time at which thrusting starts, from perturbed trajectory file, for satellite i

t_e = time at which thrusting ends, from perturbed trajectory file, for satellite i

Then, the thrust partials required for propagation of the state, $\partial X_t / \partial T_{t_0}$, for time t are

$$\frac{\partial X_t}{\partial T_{t_0}} = 0 \quad \text{for} \quad t \leq t_s \tag{43A}$$

$$\frac{\partial X_t}{\partial T_{t_0}} = \psi_a(t) - \psi(t)\psi^{-1}(t_s)\psi_a(t_s) \quad \text{for} \quad t_s < t \leq t_e \tag{43B}$$

$$\frac{\partial X_t}{\partial T_{t_0}} = \psi(t)[\psi^{-1}(t_e)\psi_a(t_e) - \psi^{-1}(t_s)\psi_a(t_s)] \quad \text{for} \quad t > t_e \tag{43C}$$

It should be noted here that the order of the partial derivatives on the perturbed trajectory files does not correspond to the ordering suggested earlier in this report. The suggested ordering corresponds to the ordering required to write the TED files and was assumed throughout this report. However, the ordering used is up to the programmer. If the suggested ordering is used, care must be taken especially when propagating the state vector and the covariance matrix to insure that the correct partial derivatives are used. ***State*** in this case refers only to position and velocity.

STEP (28)

To propagate the covariance matrix, the complete state transition matrix, ψ, must be formed. ψ is constructed principally from the partials derivatives found on the perturbed trajectory file for each satellite. The equations for propagating the covariance is, in general,

$$P(t) = \psi(t)P(t_0)\psi^T(t) \tag{44}$$

where

$P(t_0)$ = covariance matrix to be propagated

In this instance, however, propagating the upper part of the covariance matrix containing polar motion and station position is not desired. Therefore, $P(t_0)$ will be defined as the lower square partition of B^{-1} when it is partitioned as

$$B^{-1} = \left[\begin{array}{cc|c} B^{-1}_{pp} & B^{-1}_{ps} & \\ B^{-1}_{sp} & B^{-1}_{ss} & \\ \hline & & P(t_0) \end{array}\right]$$

where

B^{-1}_{ss} = station position portion of B^{-1}_{aa}

The station clock portion of B_{aa} is contained in $P(t_0)$.

ψ will be a square matrix. It can be constructed as follows:

$$\Psi = \begin{bmatrix} \Psi_g & & & & & & & & & & 0 \\ & \Psi_{sta\ 1} & & & & & & & & & \\ & & \Psi_{sta\ 2} & & & & & & & & \\ & & & \cdot & & & & & & & \\ & & & & \cdot & & & & & & \\ & & & & & \cdot & & & & & \\ & & & & & & \Psi_{sta\ m} & & & & \\ & & & & & & & \Psi_{sat\ 1} & & & \\ & & & & & & & & \Psi_{sat\ 2} & & \\ & & & & & & & & & \cdot\ \cdot\ \cdot & \\ 0 & & & & & & & & & & \Psi_{sat\ n} \end{bmatrix} \tag{45}$$

32

$$\psi_g = I \tag{46A}$$

I is an n X n identity matrix where n is the number of gravity parameters present in the solution

$$\psi_{sta\ j} = \begin{bmatrix} 1 & t & 1/2\,t^2 \\ 0 & 1 & t \\ 0 & 0 & 1 \end{bmatrix} \tag{46B}$$

t = time from epoch to which covariance is being propagated

$\psi_{sta\ j}$ is the same for each station.

$$\psi_{sat\ i} = \begin{bmatrix} \psi_{i1} & & 0 \\ & \psi_{i2} & \\ 0 & & \psi_{i3} \end{bmatrix} \tag{47}$$

and

$$\psi_{i1} = \begin{bmatrix} \frac{\partial X_1}{\partial p_1} & \frac{\partial X_1}{\partial p_2} & \cdots & \frac{\partial X_1}{\partial p_L} \\ \frac{\partial X_2}{\partial p_1} & \frac{\partial X_2}{\partial p_2} & \cdots & \frac{\partial X_2}{\partial p_L} \\ \vdots & & & \vdots \\ \frac{\partial X_k}{\partial p_1} & & \cdots & \frac{\partial X_k}{\partial p_L} \end{bmatrix} \tag{48}$$

The partials in ψ_{i1} can be obtained from the perturbed trajectory file for satellite *i*; and ψ_{i1} may or may not be square, depending on L (the number of parameters in the solution). If thrust is a parameter, the partials with respect to thrust must be adjusted in the manner described in Step (27), Equations (43A), (43B), and (43C).

$$\psi_{i2} = I, \text{ the identity matrix} \tag{49}$$

The dimensions of ψ_{i2} are dependent on whether or not thrust and/or radiation pressure parameters are present in the solution. If thrust or radiation pressure alone is present, ψ_{i2} is a 3 X 3 matrix; if both are present, ψ_{i2} is a 6 X 6 matrix

$$\psi_{i3} = \psi_{sta\ j} \tag{50}$$

ψ_{i3}, like $\psi_{sta\ j}$, is the same for all satellites.

STEP (29)

Covariance Statistics – To compute the covariance statistics, the state of each satellite must be propagated to the time at which the statistics are to be computed [Step (27)].

The rotation matrices $H_i = (\hat{R}, \hat{\Gamma}, \hat{\Lambda})_i$ can be formed from the state vector

where

$$\bar{R}_i = \begin{bmatrix} R_{x_i} \\ R_{y_i} \\ R_{z_i} \end{bmatrix} \qquad \dot{\bar{R}}_i = \begin{bmatrix} \dot{R}_{x_i} \\ \dot{R}_{y_i} \\ \dot{R}_{z_i} \end{bmatrix}$$

$$\bar{\Gamma}_i = (\bar{R}_i \times \dot{\bar{R}}_i) \times \bar{R}_i$$

$$\bar{\Lambda}_i = \bar{R}_i \times \dot{\bar{R}}_i$$

$$R_{x_i} = x_{sat\ i} \qquad \dot{R}_{x_i} = \dot{x}_{sat\ i} \tag{51}$$

$$R_{y_i} = y_{sat\ i} \qquad \dot{R}_{y_i} = \dot{y}_{sat\ i}$$

$$R_{z_i} = z_{sat\ i} \qquad \dot{R}_{z_i} = \dot{z}_{sat\ i}$$

$$\hat{R}_i = \frac{\bar{R}_i}{|\bar{R}_i|} \qquad |\bar{R}_i| = (R_{x_i}^2 + R_{y_i}^2 + R_{z_i}^2)^{1/2}$$

$$\hat{\Gamma}_i = \frac{\bar{\Gamma}_i}{|\bar{\Gamma}_i|} \qquad |\bar{\Gamma}_i| = (\Gamma_{x_i}^2 + \Gamma_{y_i}^2 + \Gamma_{z_i}^2)^{1/2}$$

$$\hat{\Lambda}_i = \frac{\bar{\Lambda}_i}{|\bar{\Lambda}_i|} \qquad |\bar{\Lambda}_i| = (\Lambda_{x_i}^2 + \Lambda_{y_i}^2 + \Lambda_{z_i}^2)^{1/2}$$

$i = 1, 2, \cdots, n$
n = number of satellites

Using the rotation matrices, rotate the position-position part of the propagated covariance matrix for each satellite,

$$P^{R}_{P_i}(t) = H_i^T P_{P_i}(t) H_i$$

where

P_{P_i} = position-position part of P(t) for the i^{th} satellite

The rotated values should be printed. The square root of the diagonal terms of $P^{R}_{P_i}$ and the square roots of the diagonal terms corresponding to the clock bias, drift, and aging of the satellites and the stations should be written on the ***Diagnostic Information File*** (Appendix H).

35

APPENDIX A

SATRACK FINAL TAPE FORMAT

36

DK-10:JEJ:dw
13300
24 Jan 1977

MEMORANDUM

From: NSWC/DL (E. Johnson)
To: APL (R. J. McConahy)

Date: 25 January 1977

Subj: Comments on "SATRACK File Definition Sheet"

Ref: (a) "SATRACK File Definition Sheet," Version 1, dtd 11/18/76
(b) "SATRACK Ephemeris Data Tape Binary Format," 1/20/77 Revision

1. The "SATRACK File Definition Sheet" (Ref. (a)) as furnished to NSWC/DL by APL exhibits several shortcomings which quite probably result from incomplete knowledge of the logic in the TED tape generating programs at NSWC/DL. It was thus felt that it would be better to thoroughly document this logic for APL's use, rather than commenting on reference (a) line-by-line.

Those items in reference (a) which appear to be correct and should not be affected by any required changes in APL's program are:

(a) the listing of the possible file sequences, and

(b) the formats of those records which are of fixed length.

In the following discussion of the tape format, tape records will be referred to as denoted in reference (b). A diagram of the tape format has been included to further clarify the tape structure.

Packing words used in records I-IIIB are either 6's or 7's. The 6's are used only for header records, and the 7's are used for data records. In part IV the packing word takes the form 747X7YY7ZZZZ where X = 1, 2 or 3 indicating record IVA, IVB or IVC, respectively; YY = 01, 02..., NCOV indicates the number of times record type IV has been repeated; and ZZZZ = 0000 for parts IVA and IVB. In part IVC the covariance matrix is written row wise for the upper diagonal half, and ZZZZ indicates that the values that follow comprise that row of the upper diagonal half of the covariance matrix which contains ZZZZ number of elements. Since the covariance matrix is square, ZZZZ is also equal to the total number of rows in the covariance matrix +1 minus the row number being written, i.e., 15N+3M+1-i.

DK-10:JEJ:dw
13300
24 Jan 1977

To facilitate further discussion of the tape format, it is convenient to define a "packing record." A packing record consists of a packing word and nine data or padding words. If the data being printed does not completely fill the nine allocated words, the remaining words are filled with padding words (.9999100000000E+10). All data on the tape is contained in packing records. It should be noted that the nine data words are counted as per reference (b); thus, the fact that all alphanumeric words in reference (b) are two element arrays and appear on the TED tape as a single word must be accounted for.

The tape is written in blocks of 200 words. The blocks, however, cannot be interpreted strictly as logical records or as representing a particular portion of the TED tape. If the program writing the TED tape encounters an end-of-life (as specified in reference (b)) and the data being written has not filled a 200 word block, the remainder of the block is padded out.

The header record (Part I) of the TED tape is a variable length record depending only on the number of satellites. Packing records are written until all of the data in Part I is written. If the last data word in Part I does not correspond to the 10th word of a packing record, the packing record is padded out.

The next word written is the packing word for the 1st packing record of Part IIA. This is a constant length record of 21 words; thus, three packing records are written, the last of which is padded out. For satellite #1, Part IIA is repeated NCOV times. The packing record following the (NCOV+1) IIA record begins with a 7 and contains the eight data words of IIB and one padding word. These records are repeated for each time line in the ephemeris output span. Record IIA is then written (only once) for the 2nd satellite; records IIB are written for the 2nd satellite and so on to satellite N. If the last IIB packing record written for satellite N does not correspond to the end of a 200 word block, the remainder of the block is padded out.

Record IIIA starts at the beginning of the next 200 word block. It is a fixed length record of 12 words; therefore, it always appears in two packing records. The last six words of the second packing record are padded out.

The next packing record contains the 6 data words of record IIIB and 3 padding words. These records are repeated until all passes have been listed. If the last IIIB record written does not correspond to the end of a 200 word block, the block is padded out.

Records IIIA and IIIB as described above are then written for station #2 and so on to station M.

Record IVA starts at the beginning of the next 200 word block, the first packing word being written as 747170170000. Since this is a variable size record of considerable length depending on the number of satellites and the number of stations, several packing records are required to completely write the record on the tape. The packing word in all of these packing records is 747170170000 indicating record IVA, 1st time. When the last packing record of IVA is written and padded out as required, the packing word is changed to 747270170000 indicating record IVB, 1st time. This is also a variable length record requiring a variable number of packing records; the last of which may be padded out.

After the last packing record for part IVB, the packing word is changed to 74737017XXXX, indicating part IVC, 1st time, and XXXX as in the preceding discussion of packing words. Row 1 of the covariance matrix is then written using the number of packing records required by the size of the matrix. The packing word is then changed to 74737017XXXY, where XXXY = XXXX -1, which indicates that the row of the upper diagonal half of the covariance matrix now being written contains 1 less element than the preceding row. The number of packing records used for each row can be computed from the value XXXX in the packing word for that row. The process is repeated until the packing word is 747370170001 indicating that the last row of the covariance matrix has been written. Part IVA is then written for the 2nd covariance output time, and the packing word for this cycle is 747170270000.

Parts IVB and IVC are then written, as described above, for the second covariance output time. This process is continued until the packing word becomes 74737XX70001, indicating the last row of the covariance has been written and XX = NCOV indicates that the covariance has been written for all the time lines requested. If the last packing record written does not correspond to the end of a 200 word block, the remainder of the block is padded out.

There are no locations on the tape in which default words (.9999900000000E10) are used exclusively. Default words fill spaces that are assigned to quantities that have not been used or solved for in the particular run, but may appear in other runs.

TED TAPE FILE DIAGRAM

(Based on Reference (b))

I.	Tape Header	I	Tape Header	
	Satellite 1	II	A A . . . A	NCOV + Times
			B B . . . B	One B for Each Time Line
	Satellite 2	II	A	
			B B . . . B	One B for Each Time Line
	. . .		. . .	
	Satellite N	II	A	
			B B . . . B	One B for Each Time Line
			E-O-F	
	Station 1	III	A	
			B B . . . B	One B for each Pass

TED TAPE FILE DIAGRAM (Continued)

(Based on Reference (b))

		E-O-F	
.		.	
.		.	
.		.	
Station M	III	A	
		B	One B for Each Pass
		B	
		.	
		.	
		.	
		B	
		E-O-F	
	IV	A	NCOV Times
		B	
		C	
	.		
	.		
	.		
	IV	A	
		B	
		C	
	.		
	.		
	.		
		E-O-F	
		E-O-F	

TRACKED EPHEMERIS DATA TAPE
BINARY FORMAT

Revised 1/19/77

I. **Tape Header (1 Per Tape)**

Word Number	Format	Definition
1,2	A	APL – Tape User
3,4	A	NSWC/Dahlgren – Tape Generator
5,6	A	MODX – OD/CT Version X
7	I	(Yr - 1900) * 1000 + Day Number Run Specified (A1 – RSF)
8	I	N – Number Satellites
8 + 1	I	N1 – Satellite Number
8 + 2	I	N2 – Satellite Number
	.	
	.	
	.	
8 + N	I	NN – Satellite Number
8 + N + 1	I	M – Number Stations
8 + N + 2, 8 + N + 3	A	RW or FW – Real or Fitted Trajectories
8 + N + 4	I	NCOV – Number of Covariance Matrices Written Out
8 + N + 5	E	(Yr - 1900) * 1000 + Day Number + Sec/10^5 (A5a-RSF)
8 + N + 6	E	(Yr - 1900) * 1000 + Day Number + Sec/10^5 (A5b-RSF)
8 + N + 7	E	(Yr - 1900) * 1000 + Day Number + Sec/10^5 (A6a-RSF)
8 + N + 8	E	(Yr - 1900) * 1000 + Day Number + Sec/10^5 (A6b-RSF)

42

II. Ephemeris Files (1 Per Satellite)

A. Header Record[1]

Word Number	Format	Definition	
1	I	(Yr - 1900) * 1000 + Day of Ephemeris Record	
2	E	t - Seconds UTC After Midnite (A6a-RSF)	
3	I	Satellite Number	
4	E	X Satellite Number (A6a-RSF)	
5	E	Y Satellite Number	
6	E	Z Satellite Number	
7	E	$\dot{X}$ Satellite Number	
8	E	$\dot{Y}$ Satellite Number	
9	E	$\dot{Z}$ Satellite Number	
10	E	True Right Ascension of Greenwich at Epoch A6A-PSF (Radians)	
11	E	X – Complete Polar Motion at Epoch	
12	E	Y – Complete Polar Motion at Epoch	
13	E	(1, 1)	Elements of Transformation Matrix From Mean 1950.0 Inertial to Earth-Fixed Geocentric Equatorial at Solution Epoch (A6a-RSF)
14	E	(1, 2)	
15	E	(1, 3)	
16	E	(2, 1)	
17	E	(2, 2)	
18	E	(2, 3)	
19	E	(3, 1)	
20	E	(3, 2)	
21	E	(3, 3)	

(1)Note: Header record written for time A6a for all satellites; for satellite number 1, it is repeated NCOV times with the right ascension of Greenwich and the transformation matrix updated to correspond to the times that the covariance matrix will be output in part IV.

B. **Ephemeris Data Records (1 Per Time Line)**

Word Number	Format	Definition
1	E	Time (sec) Relative to Epoch (A6A)
2	E	X – Coordinate (km) in Mean 1950.0
3	E	Y – Coordinate (km) in Mean 1950.0
4	E	Z – Coordinate (km) in Mean 1950.0
5	E	$\dot{X}$ – Coordinate (km) in Mean 1950.0
6	E	$\dot{Y}$ – Coordinate (km) in Mean 1950.0
7	E	$\dot{Z}$ – Coordinate (km) in Mean 1950.0
8	E	Δt – Satellite Clock Error

The last epheremis file terminates with E.O.F.

III. Station Files (1 Per Station)

A. **Header Record**

Word Number	Format	Definition
1	I	Station Number
2	E	ϕ – Latitude (deg) in WGS-72 System
3	E	λ – Longitude (deg) in WGS-72 System
4	E	h – Height (m) in WGS-72 System
5	I	Data Class 1 = Range 2 = Range Difference 3 = Both
6	E	Mean on Range Data (= 0.0)
7	E	Sigma of Noise on Range Data in Data Generation R
8	E	Range Data Rate – Data Generation Run (sec)

III. Station Files (1 Per Station) (Continued)

Word Number	Format	Definition
9	E	Mean on Range Difference Data (= 0.0)
10	E	Sigma of Noise on Range Difference Data in Data Generation R
11	E	Range Difference Data Rate – Data Generation Run
12	I	K – Total Passes From Station

B. Data Records (1 Per Pass)

Word Number	Format	Definition
1	I	Pass Number
2	E	Start Time (sec from A6a)
3	E	End Time (sec from A6a)
4	I	Tracked Satellite's Number
5	E	TCA (sec from A6A)
6	I	L = Number Data Points

Each station file is terminated with E.O.F.

IV. Solution Parameters and Multisatellite Covariance (NCOV Per Tape)

A. Solution Parameters

Word Number	Format	Value[2]
1	E	Time (A8-RSF) in sec (Relative to A6a)
2	E	X for Satellite 1
3	E	Y for Satellite 1
4	E	Z for Satellite 1
5	E	$\dot{X}$ for Satellite 1
6	E	$\dot{Y}$ for Satellite 1
7	E	$\dot{Z}$ for Satellite 1
8	E	K_1 – Solar Radiation Parameter Satellite 1
9	E	K_2 – Solar Radiation Parameter Satellite 1

[2]Note: Default Value is 9.9999E + 9

45

IV. Solution Parameters and Multisatellite Covariance (NCOV Per Tape) (Continued)

Word Number	Format	Value
10	E	K_3 – Solar Radiation Parameter Satellite 1
11	E	T_1 – Thrust Parameter Satellite 1
12	E	T_2 – Thrust Parameter Satellite 1
13	E	T_3 – Thrust Parameter Satellite 1

Words 2-13 are repeated for all other satellites.

Word Number	Format	Value
12N + 2	E	Δt – Time Bias for Satellite N_1
12N + 3	E	$\dot{\Delta t}$ – Time Drift for Satellite N_1
12N + 4	E	$\ddot{\Delta t}$ – Aging Rate for Satellite N_1
12N + 5	E	Δt – Time Bias for Satellite N_2
12N + 6	E	$\dot{\Delta t}$ – Time Drift for Satellite N_2
12N + 7	E	$\ddot{\Delta t}$ – Aging Rate for Satellite N_2
.	.	.
.	.	.
.	.	.
15N - 1	E	Δt – Time Bias for Satellite N_N
15N	E	$\dot{\Delta t}$ – Time Drift for Satellite N_N
15N + 1	E	$\ddot{\Delta t}$ – Aging Rate for Satellite N_N
15N + 2	E	Δt – Time Bias for Station 1
15N + 3	E	$\dot{\Delta t}$ – Time Drift for Station 1
15N + 4	E	$\ddot{\Delta t}$ – Aging Rate for Station 1
.	.	.
.	.	.
.	.	.
15N + 3M - 1	E	Δt Time Bias for Station M
15N + 3M	E	$\dot{\Delta t}$ Time Drift for Station M
15N + 3M + 1	E	$\ddot{\Delta t}$ Aging Rate for Station M
15N + 3M + 2	E	a priori Sigma on Δt (Master Station m)
15N + 3M + 3	E	a priori Sigma on $\dot{\Delta t}$ (Master Station m)
15N + 3M + 4	E	a priori Sigma on $\ddot{\Delta t}$ (Master Station m)

B. Considered Parameters

1	E	X – Station 1 (assumed)
2	E	Y – Station 1 (assumed)
3	E	Z – Station 1 (assumed)
4	E	X – Station 2 (assumed)
5	E	Y – Station 2 (assumed)
6	E	Z – Station 2 (assumed)
.	.	. . . .
.	.	. . . .
.	.	. . . .
3M - 2	E	X – Station M (assumed)
3M - 1	E	Y – Station M (assumed)
3M	E	Z – Station M (assumed)
3M + 1	E	C_R – Refraction Connection Assumed (= 0.0)
3M + 2	E	a priori Sigma (m) on 1, 4, 7, etc.
3M + 3	E	a priori sigma (m) on 2, 5, 8, etc.
3M + 4	E	a priori Sigma (m) on 3, 6, 9, etc.
3M + 5	E	a priori sigma (%) on 3M + 1

C. Multisatellite Covariance Upper Triangular Halt

1 Row Per Record   Total 12N + 3(N + M)Records

Word Number	Format	Definition	
1	E	Cov X1, X1 (1, 1) Element	Dynamical Parameters Satellite 1
2	E	Cov X1, Y1 (1, 2) Element	
3	E	Cov X1, Z1 (1, 3) Element	
4	E	Cov X1, $\dot{X}1$ (1, 4) Element	
5	E	Cov X1, $\dot{Y}1$ (1, 5) Element	
6	E	Cov X1, $\dot{Z}1$ (1, 6) Element	
7	E	Cov X1, K1 (1, 7) Element	
8	E	Cov X1, K2 (1, 8) Element	
9	E	Cov X1, K3 (1, 9) Element	
10	E	Cov X1, T1 (1, 10) Element	
11	E	Cov X1, T2 (1, 11) Element	
12	E	Cov X1, T3 (1, 12) Element	
13	E	Cov X1, X2 (etc.) Element	

C. Multisatellite Covariance Upper Triangular Halt (Continued)

Word Number	Format	Definition	
.	.	.	Dynamical Parameters Satellite 2
.	.	.	
.	.	.	
24	E	Cov X1, T3	
(N - 1)12 + 1	E	Cov X1, Xn	Dynamical Parameters Satellite N
(N - 1)12 + 2	E	Cov X1, Yn	
.	.	.	
.	.	.	
.	.	.	
(N) 12	E	Cov X1, T3	
	E	Cov X1, TB_1	Time Satellite
	E	Cov X1, $\dot{TB}_1$	
	E	Cov X1, $\ddot{TB}_1$	
	.	Cov X1, TB_2	Time Satellite 2
	.	Cov X1, $\dot{TB}_2$	
	E	Cov X1, $\ddot{TB}_2$	
	.	Cov X1, TB_N	Time Satellite N
	.	.	
	E	Cov X1, $\ddot{TB}_N$	
	E	Cov X1, TB_1	Time Station 1
	E	Cov X1, $\dot{TB}_1$	
	.	Cov X1, $\ddot{TB}_1$	
	.	Cov X1, TB_M	Time Station M (Master Station)
	.	.	
	.	.	
	E	Cov X1, $\ddot{TB}_M$	

Row 2

1	E	Cov Y1 Y1
2	E	Cov Y1 Z1
3	E	Cov Y1 $\dot{X}1$
etc.		etc.

Row 3

1	E	Cov Z1 Z1
2	E	Cov Z1 $\dot{X}1$
3	E	Cov Z1 $\dot{Y}1$
etc.		etc.

APPENDIX B

PARAMETERS AND FILES FOR SATRACK

REQUIRED INPUTS AND SUGGESTED DATA CARDS

Data Quantities

*User (1) = 3HAPL
*User (2) = 10H
*Version (2) = 10H
*Creator (1) = 10 HNSWC/DAHLG
*Creater (2) = 10HREN
*Version (2) = 10H

Inputs (Not intended to be a complete or limiting list)

IDATE – (Yr – 1900) * 1000 + Day Number
*Version (1) – alphanumeric variable for output on TED File
*NSAT – number of satellites to be processed (maximum = 10)
*NSTAT – number of stations for which data are present (maximum number = 7)
*NCOV – number of times covariance matrix is to be output on TED (maximum number = 10)
*MSAT(I) – satellite number for each satellite being processed
*MSTAT(I) – station number for each station (Note: The last station in the array is always considered the master station)
*TCOV(I) – array containing times to which covariance matrix is to be propagated and output on TED file (I = 1, 10; program should be written so maximum value of I can be changed without causing problems)
*NDYNP – number of dynamic parameters in solution; to be used for computing array sizes and location of variables in pass matrices
*POLARX, POLARY – x, y components of polar motion at epoch
*A5A, A5B, A6A, A6B – (Yr - 1900) * 1000 + Day + SEC * 10^{-5} times from Run Specification Form (RSF) parts A5A, A5B, A6A, and A6B
RSTART, RSTOP – begin and end times for range data used in solution
RDSTART, RDSTOP – begin and end times for range difference used in solution
KEY – flag to indicate whether range, range difference, or both types of data are to be processed
SIGR, SIGRD – sigmas used on noise for range and range difference data, respectively, in data generation runs
RATR, RATRD – data rate for range and range difference data used in data generation runs
*SIGMA(I) – I = 1, 27; Sigma values for use in solution. Suggested array ordering:

SIGM(1) – sigma for 1^{st} element of satellite state vector (x)
SIGM(2) – sigma for 2^{nd} element of satellite state vector (y)
SIGM(3) – sigma for 3^{rd} element of satellite state vector (z)
SIGM(4) – sigma for 4^{th} element of satellite state vector ($\dot{x}$)
SIGM(5) – sigma for 5^{th} element of satellite state vector ($\dot{y}$)
SIGM(6) – sigma for 6^{th} element of satellite state vector ($\dot{z}$)
SIGM(7) – sigma for x component of radiation pressure
SIGM(8) – sigma for y component of radiation pressure
SIGM(9) – sigma for z component of radiation pressure
SIGM(10) – sigma for x component of thrust
SIGM(11) – sigma for y xomponent of thrust
SIGM(12) – sigma for z component of thrust
SIGM(13) – sigma for satellite clock bias
SIGM(14) – sigma for satellite clock drift
SIGM(15) – sigma for satellite clock aging
SIGM(16) – sigma for station clock bias
SIGM(17) – sigma for station clock drift
SIGM(18) – sigma for station clock aging
SIGM(19) – sigma for master station bias
SIGM(20) – sigma for master station drift
SIGM(21) – sigma for master station aging
SIGM(22) – sigma for x component of station position (bias parameter)
SIGM(23) – sigma for y component
SIGM(24) – sigma for z component
SIGM(25) – sigma for x component of station position (dynamic parameters)
SIGM(26) – sigma for y component
SIGM(27) – sigma for z component
SIGM(28) – sigma for refraction
SIGM(29) – sigma for frequency bias
SIGM(30) – sigma for frequency drift

Most variable names used above are not intended to restrict the programmer in his own selection; however, it would be convenient if those variable names marked with * were retained as they frequently occur in conversation at NSWC and in communication between NSWC and JHU/APL.

Input Files

1. Perturbed Trajectory Files (1 for each satellite)

2. Pass Matrix Files (1 for each data class of each satellite)

3. Polar Motion File (see Appendix F for format)

4. ABCD File (see Appendix G for format)

APPENDIX C

DESCRIPTION OF CELEST FILES

PROPAGATED TRAJECTORY FILE (EARTH-FIXED OR INERTIAL) (TAPE51)

THE PASS MATRIX FILE CONTAINS THE B-MATRIX FOR EACH PASS OF DATA INCLUDED IN THE SPAN OF THE TRAJECTORY USED FOR FILTERING THE DATA. ONLY THE ACCEPTED PASSES ARE WRITTEN ON THE PASS MATRIX FILE. RECORD TYPE 1 IS A HEADER RECORD FOR THE FILE AND APPEARS ONLY AS THE FIRST RECORD OF EACH FILE. INFORMATION IN THIS RECORD IS COMPARED WITH THE SAME TYPE INFORMATION FROM THE TRAJECTORY IN THE BSOLVR SECTION OF CELEST. IF THERE IS A DIFFERENCE IN INFORMATION, AN ERROR STOP OCCURS. RECORD TYPES 2 THRU 5 ARE REPEATED FOR EACH DATA PASS.

FORMAT OF PASS MATRIX FILE

RECORD TYPE 1

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
1	F	TRAT(1)	YEAR OF EPOCH OF TRAJECTORY
2	F	TRAT(2)	DAY " " " "
3	A	ITIME	TIME CLOCK VALUE WHEN TRAJECTORY WAS MADE
4	I	ID(1)	SATELLITE NUMBER
5	A	SAT(1)	SATELLITE NAME
6	A	SAT(2)	SATELLITE NAME (CONT)
7	I	ID(2)	SATELLITE NUMBER OF 2ND SATELLITE
8	A	SAT2(1)	SATELLITE NAME OF 2ND SATELLITE
9	A	SAT2(2)	SATELLITE NAME (CONT)

RECORD TYPE 2

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
1	I	IPASS	PASS NO. - EACH DATA PASS READ FROM THE OBS FILE IS COUNTED. IF PASSES ARE REJECTED THE PASS NOS. WILL NOT BE CONSECUTIVE.
2	F	YEAR	YEAR OF OBSERVATION PASS
3	F	DAY	DAY OF OBSERVATION PASS
4	A	ISTA	STATION NO. OF OBSERVING STATION
5	I	NO	DATA CLASS
6	I	ITYPE	DATA TYPE
7	I	NO	NUMBER OF OBSERVATIONS IN PASS
8	I	ITOLP	TOTAL NUMBER OF PARAMETERS IN B-MATRIX, INCLUDING BIASES
9	I	NOF	NO. OF ACCEPTED POINTS IN PASS
10	I	IPS	PASS STATUS =0,GOOD,NOT =0,BAD(ALWAYS 0,NOW)
11	O	PL	PARAMETER LABEL. THIS WORD INDICATES WHICH PARAMETERS MAKE UP THE MATRIX. A BINARY BIT IS ALLOWED FOR EACH PARAMETER LEFT ADJUSTED IN THE FOLLOWING ORDER. X, Y, Z, XDOT, YDOT, ZDOT, OR (A, ES, EC, I, AMO, OMEGA), CD, FX, FY,FZ,KR,XS,YS,ZS,REF,F,FDOT
12	F	V	VARIENCE

RECORD TYPE 2 (CONT.)

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
13	F	ELEV	ELEVATION AT TCA OF PASS (DEG)
14	F	PHIO	STATION LONGITUDE (DEG)
15	F	FNS	FILTERED NOISE
16	F	FSS	SATELLITE FREQUENCY
17	F	XO	EARTH-FIXED X COMPONENT OF STATION POSITION
18	F	YO	EARTH-FIXED Y COMPONENT OF STATION POSITION
19	F	ZO	EARTH-FIXED Z COMPONENT OF STATION POSITION

RECORD TYPE 3

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
1	F	BMAT	LOWER TRIANGULAR PART OF B-MATRIX FOR PASS
2	F	.	
.	.	.	
.	.	.	
*N	F	.	
N+1	F	EVEC(1)	E-VECTOR FOR PASS
N+2	F	.	
.	.	.	
.	.	.	
.	.	.	
** M	F	EVEC (ITOLP)	

WHERE N =(ITOLP(ITOLP+1))/2

**WHERE M = N+ITOLP

RECORD TYPE 4

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
1	I	NOBIAS	NO. OF BIASES
2	I	IHRMIN	RISE TIME OF PASS (PACKED AS HR AND MIN)
3	I	IDUR	DURATION OF PASS (MIN)
4	I	IAC	AUTOCORRELATION
5	I	IVERS	INDICATES FROM WHICH CELEST VERSION FILE MADE
6	F	TRISE	RISE TIME OF PASS (SEC. FROM MIDNIGHT)
7	F	TSET	SET TIME OF PASS (SEC. FROM MIDNIGHT)

RECORD TYPE 5

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
1	F	TCA	TIME OF CLOSEST APPROACH OF PASS(SEC. FROM MIDNIGHT)
2	F	RMAT(1,1)	ROTATION MATRIX TO ROTATE FROM INERTIAL
3	F	RMAT(1,2)	TO EARTH-FIXED AT TCA.
.	.	.	
.	.	.	
.	.	.	
10	F	RMAT(3,3)	

RECORD TYPES 2 THRU 5 ARE REPEATED FOR EACH DATA PASS

INERTIAL PERTURBED TRAJECTORY FILE (TAPE9)

THE INERTIAL PERTURBED TRAJECTORY FILE CONSISTS OF TWO RECORD TYPES - RECORD TYPE 1 BEING A HEADER RECORD APPEARING ONLY ONCE, AND RECORD TYPE 2 WHICH CONTAINS THE POSITION OF THE SATELLITE AND PARTIALS OF POSITION WITH RESPECT TO EACH PARAMETER. ONLY THE CANONICAL PARTIALS WRT DRAG AND THRUST APPEAR ON THE TRAJ. THE PARAMETER ORDER IS AS FOLLOWS. THE SIX ORBIT PARAMETES ARE FIRST, EITHER COORDINATES OR ELEMENTS, FOLLOWED BY DRAG, THREE THRUST, AND RADIATION PRESSURE. DRAG, THRUST, AND RADIATION ARE OPTIONAL. A SYMBOLIC LIST AND ORDER OF PARAMETERS IS AS FOLLOWS. X, Y, Z, XDOT, YDOT, ZDOT, OR (A, ES, EC, I, AMO, OMEGA), CD, FX, FY, FZ, KR RECORD TYPE 2 IS REPEATED FOR EACH TIME LINE OF THE TRAJECTORY.

FORMAT OF INERTIAL PERTURBED TRAJECTORY FILE

RECORD TYPE 1

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
1	I	NB	RECORD NO. = 1
2	F	TRAT(1)	YEAR OF EPOCH OF TRAJECTORY
3	F	TRAT(2)	DAY " " " "
4	F	TRAT(3)	SEC " " " "
5	F	TRAT(4)	TVE-TO, TIME OF VERNAL EQUINOX MINUS EPOCH OF THE TRAJECTORY
6	F	TRAT(5)	INTERVAL AT WHICH TRAJ IS WRITTEN (SEC)
7	F	TRAT(6)	LAST TIME ON TRAJECTORY(SEC FROM EPOCH)
8	F	TRAT(7)	INTEGRATION INTERVAL USED WHEN CREATING THE TRAJECTORY (SEC)
9	I	IFLOW	KIND OF TRAJECTORY = 6,7,4,OR 5.
10	I	ID(1)	SATELLITE NUMBER
11	I	KCG(10)	INDICATES IF TRAJECTORY WAS MADE USING EPOCH OF DATE=1, OR EPOCH OF 1950= 0
12	I	ID(3)	IMPROVEMENT CYCLE NUMBER
13	A	IDATE	TIME CLOCK VALUE WHEN TRAJECTORY WAS MADE
14	I	NPAR	NUMBER OF PARAMETERS

60

RECORD NO. 1 (CONT.)

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
15	O	LABELP	PARAMETER LABEL WORD. THIS WORD INDICATES WHICH PARAMETERS WERE USED WHEN THE FILE WAS MADE. A BINARY BIT IS ALLOWED FOR EACH PARAMETER INDICATED ABOVE, LEFT ADJUSTED. FOR EXAMPLE, X OR A IS INDICATED IN THE LEFT MOST BIT OF THE WORD, Y OR ES IS IN THE NEXT, ETC. IF THE BIT IS ON (=1), THEN THE PARAMETER WAS USED. IF THE BIT IS OFF (=0), THE PARAMETER WAS NOT USED.
16	I	NDPA	NO. OF DRAGS USED WHEN MAKING TRAJECTORY
17	I	NTPA	NO. OF THRUST USED WHEN MAKING THE TRAJ
18	F	DTIM(1)	END TIME OF 1ST DRAG SEGMENT (SEC FROM EPOCH)
19	F	DTIM(2)	" " " 2ND " " " " "
.	F	.	" " " " " " " "
.	F	.	" " " " " " " "
.	F	.	" " " " " " " "
* N	F	DTIMS(NDPA)	END TIME OF LAST DRAG SEGMENT

* WHERE N=NDPA+17 OR N=18, IF NDPA=0

6d

RECORD NO. 1 (CONT.)

```
WORD       SYMBOLIC
 NO. TYPE  NAME         DESCRIPTION
 --- ----  ----         -----------

 N+1   F   TTIMS(1,1) START TIME OF 1ST THRUST SEGMENT
 N+2   F   TTIMS(2,1) END    "    "   "    "       "
  .    F      .
  .    F      .
  .    F      .
  .    F      .
**M-1  F   TTIMS(1,L) START TIME OF LAST THRUST SEGMENT
  M    F   TTIMS(2,L) END    "    "   "    "       "
 M+1   F   OI(1)      X   )
 M+2   F   OI(2)      Y   )- INERTIAL COMPONENTS OF SATELLITE
 M+3   F   OI(3)      Z   )     POSITION AT EPOCH (KM)
 M+4   F   OI(4)      XDOT  )
 M+5   F   OI(5)      YDOT  )- INERTIAL COMPONENTS OF SATELITE
 M+6   F   OI(6)      ZDOT  )     VELOCITY AT EPOCH (KM/SEC)
 M+7   F    OI(7)     CD1 - COEFFICIENT OF DRAG FOR 1ST DRAG SEG
 M+8   F    OI(8)     CD2 -      .         .    .   .  2ND  .   .
 M+9   F    OI(9)     CD3 -      .         .    .   .  3RD  .   .
 M+10  F    OI(10)    CD4        .         .    .   .  4TH  .   .
 M+11  F    OI(11)    CD5        .         .    .   .  5TH  .   .
 M+12  F    OI(12)    CD6        .         .    .   .  6TH  .   .
```


62

M+13	F	OI(13)	CD7	.	.	.	.	7TH	.	.
M+14	F	OI(14)	CD8	.	.	.	.	8TH	.	.
M+15	F	OI(15)	CD9	.	.	.	.	9TH	.	.
M+16	F	OI(16)	CD10	.	.	.	.	10TH	.	.
M+17	F	OI(17)	CD11	.	.	.	.	11TH	.	.
M+18	F	OI(18)	CD12	.	.	.	.	12TH	.	.
M+19	F	OI(19)	CD13	.	.	.	.	13TH	.	.
M+20	F	OI(20)	CD14	.	.	.	.	14TH	.	.
M+21	F	OI(21)	CD15	.	.	.	.	15TH	.	.
M+22	F	OI(22)	CD16	.	.	.	.	16TH	.	.
M+23	F	OI(23)	CD17	.	.	.	.	17TH	.	.
M+24	F	OI(24)	CD18	.	.	.	.	18TH	.	.
M+25	F	OI(25)	CD19	.	.	.	.	19TH	.	.
M+26	F	OI(26)	CD20	.	.	.	.	20TH	.	.

** WHERE M= N+2*(NTPA) OR M=N+2, IF NTPA=0

RECORD NO. 1 (CONT.)

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
M+27	F	OI(27)	AX1)
M+28	F	OI(28)	AY1)-COMPONENTS OF 1ST THRUST(KM/SEC**2)
M+29	F	OI(29)	AZ1)
M+30	F	OI(30)	AX2)
M+31	F	OI(31)	AY2)-COMPONENTS OF 2ND THRUST(KM/SEC**2)
M+32	F	OI(32)	AZ2)
M+33	F	OI(33)	AX3)
M+34	F	OI(34)	AY3)-COMPONENTS OF 3RD THRUST(KM/SEC**2)
M+35	F	OI(35)	AZ3)
M+36	F	OI(36)	AX4)
M+37	F	OI(37)	AY4)-COMPONENTS OF 4TH THRUST(KM/SEC**2)
M+38	F	OI(38)	AZ4)
M+39	F	OI(39)	KR - RADIATION PRESSURE COEFFICIENT
M+40	F	OI(40)	KR2-2ND RADIATION PRESSURE COEFFICIENT
M+41	F	OI(41)	KR3-3RD RADIATION PRESSURE COEFFICIENT
		NGPA	NO. OF GRAVITY PARAMETERS
		IDGD	GRAVITY ID ARRAY (32)
		DLPGP(I),	I=1,NGPA DELTA P GRAVITY
		NRPA	NO OF RADIATION PARAMETERS BEING IMPROVED

RECORD TYPE 2

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION								
1	I	NB	CONSECUTIVE RECORD NO.=2,3,4...N								
2	F	TI	TI-TO (SECONDS FROM EPOCH)								
3	F	TRA(2)	X)								
4	F	TRA(3)	Y !- INERTIAL COMPONENTS OF SATELLITE								
5	F	TRA(4)	Z) POSITION AT TIME (TI) (KM)								
6	F	TRA(5)	PARTIAL	X	AT	(TI)	WRT	PARAMETER	(1)	AT	(TO)
7	F	TRA(6)	.	Y	.	.	.	.	(1)	.	.
8	F	TRA(7)	.	Z	.	.	.	.	(1)	.	.
9	F	TRA(8)	.	X	.	.	.	.	(2)	.	.
10	F	TRA(9)	.	Y	.	.	.	.	(2)	.	.
11	F	TRA(10)	.	Z	.	.	.	.	(2)	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
N-2	F	TRA(M-2)	.	X	.	.	.	.	NPAR	.	.
N-1	F	TRA(M-1)	.	Y	.	.	.	.	NPAR	.	.
N	F	TRA(M)	.	Z	.	.	.	.	NPAR	.	.

WHERE NPAR = NO. OF PARAMETERS

= 6 ORBIT +MINO(1,NDPA)+3*MINO(1,NTPA)+MINO(1,NRPA)

NDPA=NO. OF DRAG SEGMENTS

NTPA=NO. OF THRUST SEGMENTS

NRPA=NO. OF RADIATION PRESSURE PARAMETERS (0 OR 1)

N= 5+3*NPAR

M= 4+3*NPAR

DIAGNOSTIC INFORMATION FILE (TAPE16)

THE DIAGNOSTIC INFORMATION FILE IS CREATED BY THE COVAR SECTION OF CELEST TO BE USED BY THE GRAPHICS OR POST ANALYSIS SECTION FOR CELEST. IT CONTAINS STATISTICAL DATA WHICH IS USED AS A MEASURE OF HOW GOOD THE FIT OVER A PARTICULAR SPAN IS. IT CONSISTS OF FOUR RECORD TYPES. RECORD TYPES 1,2, AND 4 APPEAR ONLY ONCE FOR A REV, BUT ARE REPEATED IF MORE THAN ONE REV IS PROCESSED. RECORD TYPE 3 IS REPEATED FOR EACH OUTPUT DELTA T DURING THE SPAN OF THE REV.

FORMAT OF DIAGNOSTIC INFORMATION FILE

RECORD TYPE 1

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
1	F	TO(1)	YEAR OF EPOCH OF REV
2	F	TO(2)	DAY . . . .
3	F	TO(3)	SEC. . . . .
4	I	ID(1)	SATELLITE NUMBER
5	I	CS	SCALE FACTOR FOR COVARIANCE
6	I	NREV	REV NUMBER OF SATELLITE
7	F	TRAT(1)	YEAR OF EPOCH OF FERT TRAJ (LONG ARC)
8	F	TRAT(2)	DAY . . . .
9	F	TRAT(3)	SEC. . . . .
10	F	TDLT	OUTPUT DELTA T FOR EARTH-FIXED VALUES
11	I	MT	MULTIPLE OF TDLT TO OUTPUT INERTIAL VALUES

RECORD TYPE 2

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
1	F	TLT	LAST TIME FOR WHICH RECORD TYPE 3 IS WRITTEN (SEC. FROM REV EPOCH)

RECORD TYPE 3

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
1	F	TIM	TIME IN SEC. FROM REV EPOCH
2	F	ƏR(1,1))	CONFIDENCE IN THE TRAJECTORY IN THE
3	F	ƏR(2,2) !-	RADIAL, TANGENTIAL, AND OUT OF PLANE (RXV)
4	F	ƏR(3,3))	DIRECTION AT TIME (TIM)

RECORD TYPE 3 IS REPEATED FOR EACH OUTPUT TIME IN REV SPAN.

THE LAST TYPE 3 RECORD CONTAINS FOUR WORDS OF ZERO VALUE.

RECORD TYPE 4

WORD NO.	TYPE	SYMBOLIC NAME	DESCRIPTION
1	F	SIG2R	AVERAGE SIGMA RADIAL FOR ENTIRE REV
2	F	SIG2V	AVERAGE SIGMA TANGENTIAL FOR ENTIRE REV
3	F	S2RXV	AVERAGE SIGMA (RXV) FOR ENTIRE REV

APPENDIX D

SUBROUTINE NTRP8

SUBROUTINE NTRP8

Common/NTRP/IPRNT, ITRAJ, IR, PCTIO, ITRA1, ITRA2, TRA(8,133), TRAI(267) TRAT(7), CTIO

TRAT(1) = year of Epoch TRAT(2) = day of Epoch TRAT(3) = seconds of Epoch TRAT(4) = $t_{ve} - t_0$ (GHA) TRAT(5) = Δt_w	from header record of trajectory file

IPRNT – output file, so error messages can be written

ITRAJ – intput trajectory (perturbed trajectory) file

TRA – array containing records 2-9 of trajectory file; these must be read in before 1st call to NTRP8

TRAI – array containing the interpolated values

TRAI(1) – x	TRAI(7) – $\ddot{x}$	TRAI(10 + K) TRAI(11 + K) TRAI(12 + K)	ψ_x	K = 0; NPAR-1
TRAI(2) – y	TRAI(8) – $\ddot{y}$			
TRAI(3) – z	TRAI(9) – $\ddot{z}$			
TRAI(4) – $\dot{x}$		TRAI(13 + K) TRAI(14 + K) TRAI(15 + K)	$\psi_{\dot{x}}$	
TRAI(5) – $\dot{y}$				
TRAI(6) – $\dot{z}$				

NPAR – number of parameters (from header record)

CTIO – time in seconds for which to interpolate (from A5A)

PCTIO – previous time for which interpolation was done; initialize to -9999. in calling program

ITRA1 – number of words in last record read from trajectory file (NPAR * 3 + 4)

ITRA2 – block number of last record read from trajectory file

IER – error return from NTRP8
- = 0 interpolation was done
- = 1 time to interpolated occurred too early to interpolate (before fourth time on trajectory)

= 2 time to interpolate occurred too late to interpolate (not enough data on trajectory)

IR – indicates what to interpolate for

= 1, interpolate for r, $\dot{r}$
= 2, interpolate for r, $\dot{r}$, $\ddot{r}$
= 3, interpolate for ψ_x
= 4, interpolate for ψ_x, $\psi_{\dot{x}}$

NOTE:

1. *Subroutine must be called twice* (IR = 1 and IR = 4) when position, velocity, and partials are required.

2. Subroutine must be reinitialized for each satellite (trajectory files must, of course, be rewound before reading header and 1st records prior to calling NTRP8).

3. The order of the partials in the TRAI array for ψ_x or $\psi_{\dot{x}}$ is

   partials with respect to position
   partials with respect to velocity
   partials with respect to drag (not used by the SATRACK program)
   partials with respect to three components of thrust (if present in the solution)
   partials with respect to three components of radiation pressure (if present in the *solution)*
   partials with respect to gravity parameters (if present in the solution)

APPENDIX E

POLAR POSITION FILE

71

POLAR POSITION FILE

REF: "Polar Position File System," R. G. Barker, January 1975

There are nine records, also referred to as subfiles, indexed by integer labels:

1. IPMS – preliminary pole position
2. IPMS – final pole position
3. BIH – preliminary pole position
4. BIH – final pole position
5. BIH UT1-UTC
6. USNO UT1-UTC
7. Bi-daily solutions from the CELEST program
8. Predicted pole position
9. Predicted UT1-UTC

Data in each subfile are in order by day of the year. Space is reserved for each day, whether or not data are available for that day. The first word is always year number. Only one additional word per day is needed in each of the subfiles for UT1-UTC (numbers 5, 6, and 9). Two words are needed in each of the other subfiles for the x and y coordinates of polar position. Moreover, two words are allocated for the standard deviation of these coordinates in subfiles 4 and 7. The later subfile, namely the Bi-daily solutions, also provides for a word of alphanumeric characters identifying the satellite or source of data. It differs from the other subfiles in another way: three complete sets of data may be stored each day, corresponding to different satellites. Thus, 18 words are set aside for every day in the subfile. The following figure indicates the various subfile structures. All numerical data are in floating point format.

Subfiles

5, 6, 9	year	UT1-UTC				
1, 2, 3, 8	year	x	y			
4	year	x	y	σ_x	σ_y	
7	year	x	y	σ_x	σ_y	satellite

APPENDIX F

TRACKED EPHEMERIS DATA TAPE BINARY FORMAT

TRACKED EPHEMERIS DATA TAPE
BINARY FORMAT

Revised 1/19/77

I. Tape Header (1 Per Tape)

Word Number	Format	Definition
1,2	A	APL – Tape User
3,4	A	NSWC/Dahlgren – Tape Generator
5,6	A	MODX – OD/CT Version X
7	I	(Yr - 1900) * 1000 + Day Number Run Specified (A1 – RSF)
8	I	N – Number Satellites
8 + 1	I	N1 – Satellite Number
8 + 2	I	N2 – Satellite Number
	.	
	.	
	.	
8 + N	I	NN – Satellite Number
8 + N + 1	I	M – Number Stations
8 + N + 2, 8 + N + 3	A	RW or FW – Real or Fitted Trajectories
8 + N + 4	I	NCOV – Number of Covariance Matrices Written Out
8 + N + 5	E	(Yr - 1900) * 1000 + Day Number + Sec/10^5 (A5a-RSF)
8 + N + 6	E	(Yr - 1900) * 1000 + Day Number + Sec/10^5 (A5b-RSF)
8 + N + 7	E	(Yr - 1900) * 1000 + Day Number + Sec/10^5 (A6a-RSF)
8 + N + 8	E	(Yr - 1900) * 1000 + Day Number + Sec/10^5 (A6b-RSF)

II. Ephemeris Files (1 Per Satellite)

A. Header Record[1]

Word Number	Format	Definition
1	I	(Yr - 1900) * 1000 + Day of Ephemeris Record
2	E	t - Seconds UTC After Midnite (A6a-RSF)
3	I	Satellite Number
4	E	X Satellite Number (A6a-RSF)
5	E	Y Satellite Number
6	E	Z Satellite Number
7	E	$\dot{X}$ Satellite Number
8	E	$\dot{Y}$ Satellite Number
9	E	$\dot{Z}$ Satellite Number
10	E	True Right Ascension of Greenwich at Epoch A6A-PSF (Radians)
11	E	X – Complete Polar Motion at Epoch
12	E	Y – Complete Polar Motion at Epoch
13	E	(1, 1) Elements of Transformation Matrix From Mean 1950.0 Inertial to Earth-Fixed Geocentric Equatorial at Solution Epoch (A6a-RSF)
14	E	(1, 2)
15	E	(1, 3)
16	E	(2, 1)
17	E	(2, 2)
18	E	(2, 3)
19	E	(3, 1)
20	E	(3, 2)
21	E	(3, 3)

[1]Note: Header record written for time A6a for all satellites; for satellite number 1, it is repeated NCOV times with the right ascension of Greenwich and the transformation matrix updated to correspond to the times that the covariance matrix will be output in part IV.

B. Ephemeris Data Records (1 Per Time Line)

Word Number	Format	Definition
1	E	Time (sec) Relative to Epoch (A6A)
2	E	X – Coordinate (km) in Mean 1950.0
3	E	Y – Coordinate (km) in Mean 1950.0
4	E	Z – Coordinate (km) in Mean 1950.0
5	E	$\dot{X}$ – Coordinate (km) in Mean 1950.0
6	E	$\dot{Y}$ – Coordinate (km) in Mean 1950.0
7	E	$\dot{Z}$ – Coordinate (km) in Mean 1950.0
8	E	Δt – Satellite Clock Error

The last epheremis file terminates with E.O.F.

III. Station Files (1 Per Station)

A. Header Record

Word Number	Format	Definition
1	I	Station Number
2	E	ϕ – Latitude (deg) in WGS-72 System
3	E	λ – Longitude (deg) in WGS-72 System
4	E	h – Height (m) in WGS-72 System
5	I	Data Class 1 = Range 2 = Range Difference 3 = Both
6	E	Mean on Range Data (= 0.0)
7	E	Sigma of Noise on Range Data in Data Generation R
8	E	Range Data Rate – Data Generation Run (sec)

76

III. **Station Files (1 Per Station) (Continued)**

Word Number	Format	Definition
9	E	Mean on Range Difference Data (= 0.0)
10	E	Sigma of Noise on Range Difference Data in Data Generation R
11	E	Range Difference Data Rate – Data Generation Run
12	I	K – Total Passes From Station

B. **Data Records (1 Per Pass)**

1	I	Pass Number
2	E	Start Time (sec from A6a)
3	E	End Time (sec from A6a)
4	I	Tracked Satellite's Number
5	E	TCA (sec from A6A)
6	I	L = Number Data Points

Each station file is terminated with E.O.F.

IV. **Solution Parameters and Multisatellite Covariance (NCOV Per Tape)**

A. **Solution Parameters**

Word Number	Format	Value(2)
1	E	Time (A8-RSF) in sec (Relative to A6a)
2	E	X for Satellite 1
3	E	Y for Satellite 1
4	E	Z for Satellite 1
5	E	$\dot{X}$ for Satellite 1
6	E	$\dot{Y}$ for Satellite 1
7	E	$\dot{Z}$ for Satellite 1
8	E	K_1 – Solar Radiation Parameter Satellite 1
9	E	K_2 – Solar Radiation Parameter Satellite 1

(2)Note: Default Value is 9.9999E + 9

IV. **Solution Parameters and Multisatellite Covariance (NCOV Per Tape) (Continued)**

Word Number	Format	Value
10	E	K_3 – Solar Radiation Parameter Satellite 1
11	E	T_1 – Thrust Parameter Satellite 1
12	E	T_2 – Thrust Parameter Satellite 1
13	E	T_3 – Thrust Parameter Satellite 1

Words 2-13 are repeated for all other satellites.

Word Number	Format	Value
12N + 2	E	Δt – Time Bias for Satellite N_1
12N + 3	E	$\dot{\Delta t}$ – Time Drift for Satellite N_1
12N + 4	E	$\ddot{\Delta t}$ – Aging Rate for Satellite N_1
12N + 5	E	Δt – Time Bias for Satellite N_2
12N + 6	E	$\dot{\Delta t}$ – Time Drift for Satellite N_2
12N + 7	E	$\ddot{\Delta t}$ – Aging Rate for Satellite N_2
.	.	.
.	.	.
.	.	.
15N - 1	E	Δt – Time Bias for Satellite N_N
15N	E	$\dot{\Delta t}$ – Time Drift for Satellite N_N
15N + 1	E	$\ddot{\Delta t}$ – Aging Rate for Satellite N_N
15N + 2	E	Δt – Time Bias for Station 1
15N + 3	E	$\dot{\Delta t}$ – Time Drift for Station 1
15N + 4	E	$\ddot{\Delta t}$ – Aging Rate for Station 1
.	.	.
.	.	.
.	.	.
15N + 3M - 1	E	Δt Time Bias for Station M
15N + 3M	E	$\dot{\Delta t}$ Time Drift for Station M
15N + 3M + 1	E	$\ddot{\Delta t}$ Aging Rate for Station M
15N + 3M + 2	E	a priori Sigma on Δt (Master Station m)
15N + 3M + 3	E	a priori Sigma on $\dot{\Delta t}$ (Master Station m)
15N + 3M + 4	E	a priori Sigma on $\ddot{\Delta t}$ (Master Station m)

B. Considered Parameters

1	E	X – Station 1 (assumed)
2	E	Y – Station 1 (assumed)
3	E	Z – Station 1 (assumed)
4	E	X – Station 2 (assumed)
5	E	Y – Station 2 (assumed)
6	E	Z – Station 2 (assumed)
.	.	. . . .
.	.	. . . .
.	.	. . . .
3M - 2	E	X – Station M (assumed)
3M - 1	E	Y – Station M (assumed)
3M	E	Z – Station M (assumed)
3M + 1	E	C_R – Refraction Connection Assumed (= 0.0)
3M + 2	E	a priori Sigma (m) on 1, 4, 7, etc.
3M + 3	E	a priori sigma (m) on 2, 5, 8, etc.
3M + 4	E	a priori Sigma (m) on 3, 6, 9, etc.
3M + 5	E	a priori sigma (%) on 3M + 1

C. Multisatellite Covariance Upper Triangular Halt

1 Row Per Record **Total 12N + 3(N + M)Records**

Word Number	Format	Definition	
1	E	Cov X1, X1 (1, 1) Element	Dynamical Parameters Satellite 1
2	E	Cov X1, Y1 (1, 2) Element	
3	E	Cov X1, Z1 (1, 3) Element	
4	E	Cov X1, $\dot{X}1$ (1, 4) Element	
5	E	Cov X1, $\dot{Y}1$ (1, 5) Element	
6	E	Cov X1, $\dot{Z}1$ (1, 6) Element	
7	E	Cov X1, K1 (1, 7) Element	
8	E	Cov X1, K2 (1, 8) Element	
9	E	Cov X1, K3 (1, 9) Element	
10	E	Cov X1, T1 (1, 10) Element	
11	E	Cov X1, T2 (1, 11) Element	
12	E	Cov X1, T3 (1, 12) Element	
13	E	Cov X1, X2 (etc.) Element	

C. Multisatellite Covariance Upper Triangular Halt (Continued)

Word Number	Format	Definition	
•	•	•	Dynamical
•	•	•	Parameters
•	•	•	Satellite 2
24	E	Cov X1, T3	
(N − 1)12 + 1	E	Cov X1, Xn	Dynamical
(N − 1)12 + 2	E	Cov X1, Yn	Parameters
•	•	•	Satellite N
•	•	•	
•	•	•	
(N)12	E	Cov X1, T3	
	E	Cov X1, TB_1	Time Satelliet 1
	E	Cov X1, $\dot{TB}_1$	
	E	Cov X1, $\ddot{TB}_1$	
	•	Cov X1, TB_2	
	•	Cov X1, $\dot{TB}_2$	Time Satellite 2
	E	Cov X1, $\ddot{TB}_2$	
	•	Cov X1, $\dot{TB}_N$	
	•	•	Time Satellite N
	E	Cov X1, $\ddot{TB}_N$	
	E	Cov X1, TB_1	
	E	Cov X1, $\dot{TB}_1$	Time Station 1
	•	Cov X1, $\ddot{TB}_1$	
	•	Cov X1, TB_M	
	•	•	Time Station M
	•	•	(Master Station)
	E	Cov X1, $\ddot{TB}_M$	

Row 2

1	E	Cov Y1 Y1
2	E	Cov Y1 Z1
3	E	Cov Y1 $\dot{X}1$
etc.		etc.

Row 3

1	E	Cov Z1 Z1
2	E	Cov Z1 $\dot{X}1$
3	E	Cov Z1 $\dot{Y}1$
etc.		etc.

APPENDIX G

ABCD FILE

ABCD FILE

This file contains the ABCD rotation matrix from CELEST and the Greenwich Hour Angles (arguments of the B matrix). The first record is a header and the remaining records correspond to each time line in the integration.

RECORD TYPE 1

Word Number	Type	Description
1	I	Block Number (= 1)
2	F	Epoch
3	F	Step Size
4	I	KGC(3) Not Used by SAMSAP Program
5	I	
6	I	

RECORD TYPE 2

Word Number	Type	Description
1	I	Block Number (= 2, 3, 4 ···)
2	F	Time in Seconds from Epoch
3-11	F	ABCD Transformation Matrix (Column Wise 3 X 3)
12	Double Precision	Greenwich Hour Angle

APPENDIX H

DIAGNOSTIC INFORMATION FILE

83

DIAGNOSTIC INFORMATION FILE

The format of this file is similar to that of the Diagnostic Information File (Tape 73) of CELEST (Appendix C). It has, however, been expanded to handle the multiple satellite case and the clock parameters required by the SATRACK program. A header record containing the number of satellites and stations has been added. Record types 2, 3, 4, and 5 appear for each satellite separated by an end-of-file. Record type 4 appears for each output time for each satellite.

RECORD TYPE 1

Word Number	Type	Description
1	I	Number of Satellites (N)
2	I	Number of Stations (M)

RECORD TYPE 2

Word Number	Type	Description
1	F	Year of Epoch
2	F	Day of Epoch
3	F	Seconds of Epoch
4	I	Satellite Number
5	I	Scale Factor (= 1)
6	I	Rev Number (= 1)
7	F	Year of Epoch
8	F	Day of Epoch
9	F	Seconds of Epoch
10	F	Output Delta T (step size)
11	I	Dummy (= 1)

RECORD TYPE 3

Word Number	Type	Description
1	F	Last Time for Which Record Type 3 is Written (stop time for outputting covariance matrices)

RECORD TYPE 4

Word Number	Type	Description
1	F	Time in Seconds From Epoch
2	F	Sigma Radial Component Satellite 1
3	F	Sigma Tangential Component Satellite 1
4	F	Sigma Out-of-Plane Component Satellite 1
5	F	Sigma Clock Bias Satellite 1
6	F	Sigma Clock Drift Satellite 1
7	F	Sigma Clock Aging Satellite 1
8	F	Sigma Clock Bias Station 1
9	F	Sigma Clock Drift Station 1
10	F	Sigma Clock Aging Station 1
J •		
J •		
J •		
3(M - 1) + 7 + 1	F	Sigma Clock Bias Station M
3(M - 1) + 7 + 2	F	Sigma Clock Drift Station M
3(M - 1) + 7 + 3	F	Sigma Clock Aging Station M

Record Type 4 is output for each time in covariance propagation span. The last Record Type 4 (for each satellite) is zero filled.

RECORD TYPE 5

Word Number	Type	Description
1	F	Not Used – Should Contain
2	F	
3	F	Dummy Values

An end-of-file is written after Record Type 5. Record Types 2, 3, 4, and 5 are then repeated for the next satellite. A double end-of-file is written after Record Type 5 for the last satellite.

85