EARTH-BASED TRACKING OF A LUNAR BEACON

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EARTH-BASED TRACKING OF A LUNAR BEACON

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WDL Division
Palo Alto, California

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Prepared for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

FOREWORD

This report is written by Philco WDL in partial fulfillment of Contract NAS5-9939 for Goddard Space Flight Center.

The program decks for the program described by this report form another partial fulfillment of Contract NAS5-9939. They have been delivered previously.

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SUMMARY

A digital computer program for ascertaining the accuracy of lunar beacon location determination is described. The program simulates tracking of a beacon up to 12 Earth-based tracking stations at one time with capabilities for including the effects of a variety of random and bias errors in the determination. Errors are propagated according to the Schmidt-Kalman filter theory.

SECTION 1
INTRODUCTION

The use of beacons on the Moon's surface as aids in space navigation appears likely in the near future. This likelihood raises the question "How accurately could the location of a lunar beacon be determined by tracking the beacon from Earth-based stations?" A tool for answering this question has been developed--the EBTLB computer program.

The EBTLB (Earth-Based Tracking of a Lunar Beacon) program has been developed by Philco WDL for Goddard Space Flight Center under Contract NAS5-9939. It was originally planned that the capability of the EBTLB program would be included as an additional option of the Mark II Error Propagation Program (Reference 1) delivered to Goddard Space Flight Center by Philco WDL under Contract NAS5-9700. The options of that program were already so numerous and the size so large that it was decided to make EBTLB a separate program, since the nature of the problem was different anyway. The resulting special-purpose program runs rapidly and is small enough to require no linking (space-sharing) on the IBM 7094 computer. The rapid development of the EBTLB program was made possible by utilization of many subroutines and much logic of the Mark II and Patched Conic error propagation programs.

SECTION 2

THEORETICAL DESCRIPTION

The location of the beacon is described by the beacon's selenographic latitude, longitude, and altitude and the beacon's position vector relative to the lunar center is given by

$$R_{selenographic} = \left(radius_{Moon} + altitude\right) \begin{bmatrix} \cos(latitude)\cos(longitude) \\ \cos(latitude)\sin(longitude) \\ \sin(latitude) \end{bmatrix} \quad (1\text{-}1)$$

Unit vectors north(N), east(E), and down(D) at the beacon's location may be constructed as functions of the selenographic latitude and longitude. The uncertainty in the beacon's position is formulated as position deviations from $R_{selenographic}$ along N, E and D.

$$\Delta = \epsilon_n N + \epsilon_e E + \epsilon_d D \quad (1\text{-}2)$$

The state vector for this program is taken to be

$$X = \begin{bmatrix} \epsilon_n \\ \epsilon_e \\ \epsilon_d \end{bmatrix} \quad (1\text{-}3)$$

This state vector contrasts with the spacecraft position and velocity state vector of six components encountered in the Mark II Error Propagation Program (Reference 1) because a beacon is being observed rather than an orbiting spacecraft. The beacon's state vector consists of three elements which are constant in time so that the state transition matrix is an identity matrix and the state covariance matrix does not change between observations.

The state covariance matrix,

$$P = E(XX^T), \tag{1-4}$$

changes at each observation according to the equation

$$P_{after} = P_{before} - P_{before}H^T(H^T P_{before} H + Q)^{-1} HP_{before} \tag{1-5}$$

where H is the sensitivity of the measurements to state deviations and where Q is the covariance matrix of the random errors in the measurements. Reference 1, "User's Manual for the Mark II Error Propagation Program", contains a more completed description of the "filtering" process in its Section 2. The measurement partials, H, for the station measurements (EBTLB has all of the station measurement capability of the Mark II program) are found in Appendix A of Reference 1 with the provision that the spacecraft's position, R, and velocity, V, are replaced by the beacon's position and velocity relative to the center of the Earth.

$$R = R_{\text{Earth-to-Moon}} + T_{\text{selenographic-to-EEDate}} R_{\text{selenographic}} \tag{1-6}$$

$$V = V_{\text{Moon wrt Earth}} + T_{\text{selenographic-to-EEDate}} (\Omega_M \times R_{\text{selenographic}}) \tag{1-7}$$

In equations (1-6) and (1-7), $T_{\text{selenographic-to-EEDate}}$ is the transformation of coordinates from the selenographic system to the Earth's true equator and equinox of date coordinate system and Ω_M is the Moon's angular velocity vector. $R_{\text{Earth-to-Moon}}$ and $V_{\text{Moon wrt Earth}}$ are the Moon's position and velocity relative to the center of the Earth--obtained from the ephemeris tape and rotated into true equator and equinox of date coordinates. It was not known how to treat errors in the ephemeris of the Moon or in the transformations to equator and equinox of date, so these are assumed to be perfectly known in the EBTLB program.

SECTION 3

USE OF THE EBTLB PROGRAM

This section describes the means for running the EBTLB program. The specification of station measurement options is identical to that of the Mark II or Patched Conic error propagation programs and is described fully in Reference 1. Program decks have been delivered to Goddard Space Flight Center for those subroutines unique to the EBTLB program. The remaining required subroutines are to be found in the deck for the Patched Conic error propagation program, delivered earlier to Goddard Space Flight Center.

A. Input

Input to the EBTLB program is of four types: 1) the case header card, 2) floating point data for Common storage in the C array, 3) the control times card, and 4) processing options and changes. Input to EBTLB program is the same as input to the Patched Conic Error Propagation Program except for 2), floating point data for Common storage in the C array.

1. Case Header Card

The first card of each case is the case header card. This card reads in the ISW and BCD arrays according to format (6I1, 11A6).

The ISW Array

Only ISW(1) is used by the program, and for only one reason: ISW(1) is set 1 to stop the run. A one in column # 1 of this card should never appear on a case to be executed. This option is normally used on the last data card in the deck, following the last data card in the last case executed.

This card is printed out before the program stops, so it might be as follows

```
    ↙Col 1        ↙Col 7
1               NO MORE CASES
```

The BCD Array

Columns 7 through 72 are available for up to 11 words of alphanumeric data describing the case. This data is written out as the case header.

2. Floating Point Data Stored in the INPCOM Common C Array

All data of this type is read in according to format 4(I3,E12.8). That is, from one to four sets of an integer K and a number X to be stored as C(K) = X.

Each case requires data sufficient to define the starting epoch, the lunar beacon, and the initial 3x3 P covariance matrix.

The starting epoch is defined by

C(99) starting time from reference epoch, DH.MS
C(102) starting date YR,MONTH.DAY
C(103) starting time of day HR,MIN.SEC
C(101) maximum time interval of interest for this case, DH.MS.

Selenographic coordinates of the lunar beacon to be tracked are loaded into C(106-108)

C(106) latitude, degrees
C(107) longitude, degrees
C(108) altitude, meters

The program will stop if $80 < |C(107)| < 280$.

The initial 3x3 covariance matrix is defined by the PI array dimensioned 7 and loaded into C(112) through C(118). PI(1) has no significance, while PI(2-7) are eventually loaded into the P matrix as folows

PI(2)→P(1,1)
PI(3)→P(2,2)
PI(4)→P(3,3)
PI(5)→P(1,2) and P(2,1)
PI(6)→P(1,3) and P(3,1)
PI(7)→P(2,3) and P(3,2)

Thus PI(2-7) must define the initial covariance matrix of the error in the estimate of the beacon location (north-east-down) coordinates.

Note: Unlike the Patched Conic Program the prediction and guidance options have no significance in the EBTLB program.

All data read into the C array by the first case remains in core for subsequent cases, until new data is specified. Thus, if multiple cases are to be run on the same beacon, with the same covariance matrix, only a single blank card is required as input. A blank card signals the end of floating point data to be stored in the INPCOM Common array.

3. Control Times Card

See (Reference 1).

4. Processing Options and Changes

Method of inputting these two types of data is identical to the Mark II Error Propagation Program and is described in great detail in that program's User's Manual under "Specification of Error Source Input Data".

Note: This program requires only station data, since the equation of motion errors, vehicle onboard and multiple beacon measurement options have no application in the EBTLB Program.

B. Deck and Tape Setup

The running deck requires 9 binary decks unique to the EBTLB program, 3 decks which also are used by the PINT portion of the Mark II Program, and 21 additional routines in the form of binary decks or 21 IBLDR cards with appropriate IEDIT cards to read the Patched Conic Error Propagation Program's IEDIT tape. (Care should be taken for the sake of efficiency, that these IBLDR cards be arranged in order of subroutine appearance on the tape.) No origin cards are required since linkage is unnecessary. A planetary tape must be mounted on Logical Unit 8 and of course the Patched Conic IEDIT tape must be mounted if an IBLDR deck is used.

12 BINARY DECKS

MC13 Deck Name	Routine Name
BM	MAIN for EBTLB
IB	/INPCOM/BLOCK DATA for EBTLB
KB	BEAK
BB	BLDPB
HB	CHNGB
33	CONP33

EH	EHA*
EQ	EQTOR*
NM	NORMP
NP	NUTATE*
BO	OUTB
EB	SBEVB

21 $IBLDR CARDS

for required decks found on the Patched Conic IEDIT Tape

MF	ADOT/DOT/FNORM
AT	ARKTNS
9B	BIBCD
MC	CROSS
ER	ERROUT
MT	MTRN/VTRT
SN	SETN
TM	TIME(PACKAGE)
LA	LAYOVR
PI	PUTIN
RL	ROVLY
RY	ROYAL
FM	ANTR
SA	STAT
CR	CRITO
PB	PARAB
QC	QUARTC
SO	SORDR
EL	EVDEL
PG	PCHNG
CS	STATP

* Also included in Mark II: PINT

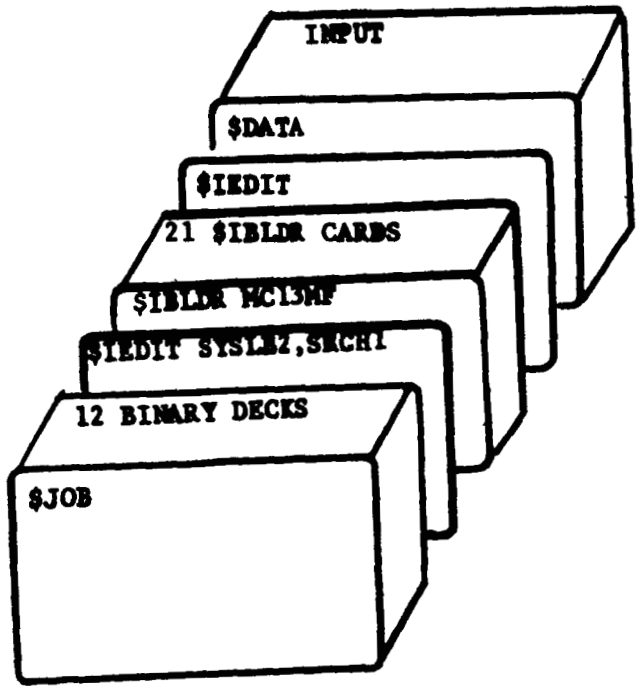


Figure 3-1 EBTLB PROGRAM DECK MAKEUP

SECTION 4

OUTPUT FROM THE EBTLB PROGRAM

This section exhibits print-out from a run made with the EBTLB program simulating the tracking of the Surveyor vehicle from three Earth-based stations, Goldstone, Johannesburg and Woomera.

Figure 4-1 shows the information which is printed at the beginning of each case. Much of this information is printed to provide case identification or to tell the user what he really told the program to do. Overlay input is seen first and consists of the information read into the C-array by input cards for this case. The case header is next seen in a single line of output. "Flight time, 300 days from the starting date, which is seen to be 11:17 pm on June 1, 1966. The beacon's selenographic latitude, longitude and altitude are seen next, followed by the beacon's Cartesian position (first three numbers), velocity (second three numbers) and acceleration relative to the Earth's center, expressed in km, km/sec and km/sec^2 respectively in the true equator and equinox of date coordinate system. The next six rows of numbers headed "BEAK check, etc." is debugging print-out and of little interest to the user. The "P MATRIX INPUT" printed out is the upper half of the (symmetric) state covariance matrix. It shows that the input variance of each component of beacon location error in the north, east, down system is 10 km^2 and that the initial errors are assumed uncorrelated. The control times and station measurements print-outs have been described fully in Reference 1 and will not, therefore, be described here. The normalized P matrix is printed out in coordinates of the beacon's local tangent plane system. "Normalized" means that the off-diagonal elements are correlation coefficients and the diagonal elements are standard deviations (square roots of the corresponding elements). The three columns of zeros following the normalized P-matrix are the initial correlations between the beacon's location errors and the station biases in effect for this case. Reference 1 describes the code for identifying these biases. The standard deviations of the biases considered form the last block of data in Figure 4-1.

Figure 4-2 shows the critical event schedule of station in-view and out-of-view times. Since the beacon is at selenographic longitude $-43^{\circ}.32$, it is never occulted from the Earth by the Moon.

Figure 4-3 shows a portion of the normal print-out seen during execution of the program followed by end conditions for the case. The blocks occur at regular output times (Event 1) critical times of in-view or out-of-view (Event 2) and at the end of the case(Event 7). The numbers labelled X, Y, and Z are the beacon's position components (km) and XD, YD, ZD are the beacon's velocity components (km/sec) relative to the Earth's center expressed in true equator and equinox of date coordinates. The current upper left 3x3 portion of the covariance matrix is printed out each time in north-east-down coordinates, showing the accuracy to which the beacon's location is known, statistically speaking. Finally, the normalized P-matrix and the correlation between beacon location and station biases is printed. Standard deviations of the station biases are seen to be unchanged for this case because these biases were considered but not solved for in this case.

OVERLAY INPUT

102	0.66060099E 04	103	0.23170000E 04	-0	-0.	-0	-0.
106	-0.24899999E 01	107	-0.43319999E 02	108	0.	-0	-0.
113	0.09999999E 02	114	0.09999999E 02	115	0.09999999E 02	-0	-0.

STARTING CONDITIONS FOR CASE 1 ROOT,RA,DEC, FROM 3 STATIONS TRACK SURVEYOR NO RA-DEC BIAS

FLIGHT TIME 30000.00000H.MS
REF. TIME 0. DH.MS
DATE 6606.01 FDATE 2317.0000
BEACON COORDINATES
SELENOGRAPHIC LATITUDE= -2.490000 DEG. LONGITUDE= -43.320000 DEG ALTITUDE= 0. MET
CARTESIAN; EARTH CENTERED; TRUE EARTH EE DATE

-0.219759111E 06	-0.28132527E 06	-0.12125844E 06	0.81879999E 00	-0.54405137E 00	-0.34011580E-00
0.16150171E-05	0.20485006E-05	0.88226514E-06			

BEAK CHECK AP TRANSPOSE, APD TRANSPOSE

0.22277000E-01	-0.37891604E-00	0.92516284E 00
-0.11026112E-00	0.91881602E 00	0.37897156E-00
-0.99365288E 00	-0.11045185E-00	-0.21311243E-01
-0.47902949E-02	0.39917977E-01	0.16464426E-01
-0.99368248E 00	-0.93885542E-01	-0.61484833E-01
0.11015702E-00	-0.91794845E 00	-0.37861373E-00

P MATRIX INPUT

0.09999999E 02	0.	0.
	0.09999999E 02	0.
		0.09999999E 02

NEW CONTROL TIMES AT 0 DAY 0 HRS 0 MIN 0.000 SEC

START	0 DAY	0 HRS	0 MIN	0.000 SEC
STOP	7 DAY	0 HRS	0 MIN	0.000 SEC
DINTV	0 DAY	1 HRS	0 MIN	0.000 SEC

*** EARTH-BASED TRACKING IN EFFECT ***

NUMBER	NAME	LOCATION		OBSERVES
1	GOLDSN	LATITUDE = 35.38950 DEG		AT INTERVALS OF1800.00 SEC
		LONGITUDE = 243.15176 DEG		WHEN ELEVATION IS ABOVE 0. DEG
		ALTITUDE =1037.53996 MET		BUT LESS THAN 90.00 DEG
		MEASUREMENT ERROR SOURCES	RANDOM	BIAS
		RANGE RATE (MET/SEC)	0.00010	0.0183
		RIGHT ASCENSION (MR)	0.20000	0.
		DECLINATION (MR)	0.20000	0.
		STATION LATITUDE (MET-N)	0.	60.0000
		STATION LONG. (MET-EAST)	0.	60.0000
		STATION ALTITUDE (MET-D)	0.	60.0000
2	JOBURG	LATITUDE = -25.88735 DEG		AT INTERVALS OF1800.00 SEC
		LONGITUDE = 27.68478 DEG		WHEN ELEVATION IS ABOVE 0. DEG
		ALTITUDE =1381.91997 MET		BUT LESS THAN 90.00 DEG
		MEASUREMENT ERROR SOURCES	RANDOM	BIAS
		RANGE RATE (MET/SEC)	0.00010	0.0183
		RIGHT ASCENSION (MR)	0.20000	0.
		DECLINATION (MR)	0.20000	0.
		STATION LATITUDE (MET-N)	0.	60.0000
		STATION LONG. (MET-EAST)	0.	60.0000
		STATION ALTITUDE (MET-D)	0.	60.0000
3	WOMERA	LATITUDE = -31.38287 DEG		AT INTERVALS OF1800.00 SEC
		LONGITUDE = 136.88502 DEG		WHEN ELEVATION IS ABOVE 0. DEG
		ALTITUDE = 150.79000 MET		BUT LESS THAN 90.00 DEG
		MEASUREMENT ERROR SOURCES	RANDOM	BIAS
		RANGE RATE (MET/SEC)	0.00010	0.0183
		RIGHT ASCENSION (MR)	0.20000	0.
		DECLINATION (MR)	0.20000	0.
		STATION LATITUDE (MET-N)	0.	60.0000
		STATION LONG. (MET-EAST)	0.	60.0000
		STATION ALTITUDE (MET-D)	0.	60.0000

THE COVARIANCE MATRIX IS DIMENSIONED 3 X 15

NORMALIZED P MATRIX

	N	E	D
N	0.31622776E 01	0.	0.
E		0.31622776E 01	0.
D			0.31622776E 01
102	0.	0.	0.
107	0.	0.	0.
108	0.	0.	0.
109	0.	0.	0.
202	0.	0.	0.
207	0.	0.	0.
208	0.	0.	0.
209	0.	0.	0.
302	0.	0.	0.
307	0.	0.	0.
308	0.	0.	0.
309	0.	0.	0.

STD. DEV. OF UNSOLVED FOR PARAMETERS

102	0.1830000E-04	107	0.6000000E-01	108	0.6000000E-01
109	0.6000000E-01	202	0.1830000E-04	207	0.6000000E-01
208	0.6000000E-01	209	0.6000000E-01	302	0.1830000E-04
307	0.6000000E-01	308	0.6000000E-01	309	0.6000000E-01

Figure 4-1

STATION CRITICAL EVENT AND CONDITIONS

TIME FROM EPOCH	EVENT	RANGE	AZIMUTH	ELEVATION
0 DAY 0 HRS 0 MIN 0.000 SEC	GOLDSN OFF	0.37980630E 06	95.000	-27.312
0 DAY 0 HRS 0 MIN 0.000 SEC	JOBURG ON	0.37168333E 06	-84.771	56.495
0 DAY 0 HRS 0 MIN 0.000 SEC	WOMERA OFF	0.38017631E 06	-140.534	-30.009
0 DAY 2 HRS 26 MIN 1.000 SEC	GOLDSN ON	0.37720381E 06	114.647	-0.025
0 DAY 4 HRS 24 MIN 41.529 SEC	JOBURG OFF	0.37758163E 06	-111.360	0.018
0 DAY 7 HRS 53 MIN 16.059 SEC	WOMERA ON	0.37808345E 06	113.221	-0.005
0 DAY 12 HRS 36 MIN 35.277 SEC	GOLDSN OFF	0.37875891E 06	-116.854	0.016
0 DAY 15 HRS 34 MIN 4.280 SEC	JOBURG ON	0.37922321E 06	113.514	-0.011
0 DAY 22 HRS 4 MIN 7.137 SEC	WOMERA OFF	0.38022755E 06	-115.933	0.008
1 DAY 3 HRS 33 MIN 55.316 SEC	GOLDSN ON	0.38108796E 06	119.687	-0.023
1 DAY 5 HRS 27 MIN 30.953 SEC	JOBURG OFF	0.38140730E 06	-115.751	0.019
1 DAY 8 HRS 36 MIN 12.794 SEC	WOMERA ON	0.38192717E 06	117.634	-0.014
1 DAY 13 HRS 18 MIN 24.435 SEC	GOLDSN OFF	0.38268533E 06	-121.246	0.017
1 DAY 16 HRS 20 MIN 49.488 SEC	JOBURG ON	0.38321841E 06	117.186	-0.013
1 DAY 23 HRS 8 MIN 1.326 SEC	WOMERA OFF	0.38437510E 06	-119.428	0.013
2 DAY 4 HRS 38 MIN 56.414 SEC	GOLDSN ON	0.38531244E 06	123.023	-0.020
2 DAY 6 HRS 28 MIN 51.857 SEC	JOBURG OFF	0.38564616E 06	-118.522	0.020
2 DAY 9 HRS 24 MIN 32.593 SEC	WOMERA ON	0.38616320E 06	120.350	-0.016
2 DAY 14 HRS 6 MIN 29.035 SEC	GOLDSN OFF	0.38696335E 06	-123.780	0.009
2 DAY 17 HRS 12 MIN 2.287 SEC	JOBURG ON	0.38752836E 06	119.183	-0.010
3 DAY 0 HRS 8 MIN 2.189 SEC	WOMERA OFF	0.38874575E 06	-121.056	0.014
3 DAY 5 HRS 38 MIN 25.242 SEC	GOLDSN ON	0.38960195E 06	124.310	-0.020
3 DAY 7 HRS 26 MIN 41.433 SEC	JOBURG OFF	0.39002164E 06	-119.512	0.020
3 DAY 10 HRS 17 MIN 47.664 SEC	WOMERA ON	0.39052219E 06	121.187	-0.015
3 DAY 15 HRS 0 MIN 23.164 SEC	GOLDSN OFF	0.39131035E 06	-124.275	0.001
3 DAY 18 HRS 6 MIN 42.714 SEC	JOBURG ON	0.39186047E 06	119.408	-0.006
4 DAY 1 HRS 2 MIN 11.285 SEC	WOMERA OFF	0.39302294E 06	-120.787	0.004
4 DAY 6 HRS 30 MIN 28.027 SEC	GOLDSN ON	0.39390106E 06	123.555	-0.025
4 DAY 8 HRS 19 MIN 17.664 SEC	JOBURG OFF	0.39420740E 06	-118.756	0.020
4 DAY 11 HRS 14 MIN 27.335 SEC	WOMERA ON	0.39467677E 06	120.169	-0.013
4 DAY 15 HRS 58 MIN 24.949 SEC	GOLDSN OFF	0.39539056E 06	-122.798	0.002
4 DAY 19 HRS 3 MIN 7.894 SEC	JOBURG ON	0.39587702E 06	117.947	-0.003
5 DAY 1 HRS 49 MIN 24.789 SEC	WOMERA OFF	0.39686804E 06	-118.780	0.009
5 DAY 7 HRS 14 MIN 42.796 SEC	GOLDSN ON	0.39760591E 06	121.013	-0.023
5 DAY 9 HRS 5 MIN 58.390 SEC	JOBURG OFF	0.39786956E 06	-116.462	0.010
5 DAY 12 HRS 12 MIN 30.757 SEC	WOMERA ON	0.39828075E 06	117.508	-0.012
5 DAY 16 HRS 58 MIN 20.414 SEC	GOLDSN OFF	0.39885815E 06	-119.616	0.002
5 DAY 19 HRS 59 MIN 30.949 SEC	JOBURG ON	0.39923704E 06	115.036	-0.000
6 DAY 2 HRS 30 MIN 1.101 SEC	WOMERA OFF	0.39996639E 06	-115.348	0.020
6 DAY 7 HRS 52 MIN 2.648 SEC	GOLDSN ON	0.40050169E 06	117.056	-0.007
6 DAY 9 HRS 46 MIN 53.882 SEC	JOBURG OFF	0.40069976E 06	-112.908	0.008

Figure 4-2

```
   6 DAY 20 HRS 54 MIN 35.656 SEC                                          CASE  1  REC.  165  EVENT 2
EARTH  CENTERED, TRUE EEDATE
  X  0.31445778E 06    Y -0.21215461E 06    Z -0.13211924E 06  XD  0.61413720E 00  YD  0.69006101E 00  ZD  0.29130871E-00
                       CURRENT 3X3 P COVARIANCE MATRIX, N-E-D
                                 0.49757870E 01       0.29760300E-00      -0.44307110E-00
                                 0.29760300E-00       0.76687352E 01      -0.25015339E 01
                                -0.44307110E-00      -0.25015339E 01       0.71615643E 01


   6 DAY 21 HRS  0 MIN  0.000 SEC                                          CASE  1  REC.  166  EVENT 1
EARTH  CENTERED, TRUE EEDATE
  X  0.31465688E 06    Y -0.21193073E 06    Z -0.13202471E 06  XD  0.61350259E 00  YD  0.69048171E 00  ZD  0.29157175E-00
                       CURRENT 3X3 P COVARIANCE MATRIX, N-E-D
                                 0.49697568E 01       0.29508840E-00      -0.44848394E-00
                                 0.29508840E-00       0.76625963E 01      -0.25099698E 01
                                -0.44848394E-00      -0.25099698E 01       0.71490639E 01


   6 DAY 22 HRS  0 MIN  0.000 SEC                                          CASE  1  REC.  167  EVENT 1
EARTH  CENTERED, TRUE EEDATE
  X  0.31685277E 06    Y -0.20943662E 06    Z -0.13096981E 06  XD  0.60643441E 00  YD  0.69512009E 00  ZD  0.29447797E-00
                       CURRENT 3X3 P COVARIANCE MATRIX, N-E-D
                                 0.49549865E 01       0.29763664E-00      -0.44999919E-00
                                 0.29763664E-00       0.76538727E 01      -0.25174739E 01
                                -0.44999919E-00      -0.25174739E 01       0.71416384E 01


   6 DAY 23 HRS  0 MIN  0.000 SEC                                          CASE  1  REC.  168  EVENT 1
EARTH  CENTERED, TRUE EEDATE
  X  0.31902316E 06    Y -0.20692591E 06    Z -0.12990449E 06  XD  0.59832163E 00  YD  0.69970109E 00  ZD  0.29735939E-00
                       CURRENT 3X3 P COVARIANCE MATRIX, N-E-D
                                 0.49402457E 01       0.29995548E-00      -0.45170581E-00
                                 0.29995548E-00       0.76445770E 01      -0.25255504E 01
                                -0.45170581E-00      -0.25255504E 01       0.71336730E 01


   7 DAY  0 HRS  0 MIN  0.000 SEC                                          CASE  1  REC.  169  EVENT 1
EARTH  CENTERED, TRUE EEDATE
  X  0.32116786E 06    Y -0.20439883E 06    Z -0.12882884E 06  XD  0.59216477E 00  YD  0.70422450E 00  ZD  0.30021585E-00
                       CURRENT 3X3 P COVARIANCE MATRIX, N-E-D
                                 0.49255732E 01       0.30219045E-00      -0.45345569E-00
                                 0.30219045E-00       0.76350813E 01      -0.25337388E 01
                                -0.45345569E-00      -0.25337388E 01       0.71256810E 01

                                        END CONDITIONS


   7 DAY  0 HRS  0 MIN  0.000 SEC                                          CASE  1  REC.  169  EVENT 7
EARTH  CENTERED, TRUE EEDATE
  X  0.32116786E 06    Y -0.20439883E 06    Z -0.12882884E 06  XD  0.59216477E 00  YD  0.70422450E 00  ZD  0.30021585E-00
                       CURRENT 3X3 P COVARIANCE MATRIX, N-E-D
                                 0.49255732E 01       0.30219045E-00      -0.45345569E-00
                                 0.30219045E-00       0.76350813E 01      -0.25337388E 01
                                -0.45345569E-00      -0.25337388E 01       0.71256810E 01

                                        NORMALIZED P MATRIX
                                      N                    E                    D
                          N     0.22193632E 01       0.49277142E-01      -0.76540849E-01
                          E                          0.27631650E 01      -0.34351194E-00
                          D                                              0.26693971E 01
                        102    -0.16615553E-01      -0.34455940E-01      -0.40174420E-01
                        107     0.59081877E-01      -0.35695450E-01      -0.33131423E-01
                        108    -0.42399301E-01      -0.16717776E-01      -0.23735490E-01
                        109     0.77416641E-01      -0.49214893E-01      -0.46334092E-01
                        202     0.11452073E-02      -0.32941376E-01      -0.27469236E-01
                        207    -0.48062549E-01       0.51321223E-01       0.51824752E-01
                        208    -0.78866208E-01      -0.47843378E-01      -0.63546526E-01
                        209     0.10934691E-00      -0.10792591E-00      -0.10803898E-00
                        302    -0.13440865E-01      -0.58812350E-01      -0.62287388E-01
                        307    -0.58185097E-01       0.61559846E-01       0.63369073E-01
                        308    -0.85545794E-01      -0.51080373E-01      -0.67418019E-01
                        309     0.10446733E-00      -0.10259391E-00      -0.10470939E-00

                                  STD. DEV. OF UNSOLVED FOR PARAMETERS
                        102  0.1830000E-04 107  0.6000000E-01 108  0.6000000E-01
                        109  0.6000000E-01 202  0.1830000E-04 207  0.6000000E-01
                        208  0.6000000E-01 209  0.6000000E-01 302  0.1830000E-04
                        307  0.6000000E-01 308  0.6000000E-01 309  0.6000000E-01
```

Figure 4-3

APPENDIX A

BRIEF DESCRIPTIONS OF SUBROUTINES USED IN THE EBTLB PROGRAM

Subroutine Name	Description	Deck Name
ADOT	Computes the angle between two given vectors.	MF
ANTR	Interpolates ephemeris information from tape.	FM
ARKTNS	Computes the arc tangent and assigns quadrant.	AT
BEAK	Computes such time dependent data as inertial cartesian coordinates of a lunar beacon given epoch and selenographic coordinates of the beacon.	KB
BIBCD	Converts a binary integer to BCD.	9B
BLDPB	Builds the expanded 3x3 P covariance matrix for the EBTLB program and outputs the error sources included.	BB
BLOCK DATA	/INPCOM/ Loads data into INPCOM common block for use in the EBTLB program.	IB
CHNGB	Makes earth-based tracking station measurements of a lunar beacon and appropriately updates the expanded 3x3 P covariance matrix peculiar to the EBTLB program.	HB
CONP33	Converts a 6-vector to a symmetric 3x3 matrix and outputs the results as the initial P covariance matrix.	33
CRITO	Outputs station in-view, out-of-view critical events.	CR
CROSS	Computes the vector cross product.	MC
DOT	Computes the vector dot product, (ADOT*).	MF

* Refer to the bracketed subroutine for further description; e.g., DOT is described in the ADOT subroutine writeup.

EHA	Computes the Greenwich hour angle and the earth's angular velocity.	EH
EQTOR	Computes the transformation from mean equator and equinox of 1950.0 to mean equator and equinox of date.	EQ
ERROUT	Provides programmed response to anticipated errors.	ER
EVDEL	Orders the critical events chronologically and determines the advancing step size.	EL
FNORM	Computes the magnitude of a vector, (ADOT*).	MF
LAYOVR	Reads station data cards and converts to proper units.	LA
MAIN	Executive driver for the ELTLB program.	BM
MTRN	Multiplies one or more 3x3 matrices by a given 3x3 matrix.	MT
MTRT	Multiplies one or more 3x3 matrices by the transpose of a given 3x3 matrix, (MTRN*).	MT
NORMP	Normalizes and outputs the expanded 3x3 P covariance matrix, retaining the standard deviations on the diagonal.	NM
NUTATE	Computes the transformation from earth's mean equator, equinox to earth's true equator and/or moon's true equator, node.	NP
OUTB	Outputs time, state, and 3x3 covariance matrix of beacon location uncertainties, N-E-D.	BO
PARAB	Fits a parabola through three points.	PB
PCHNG	Updates the expanded covariance matrix at an observation.	PG

PUTIN	Reads in measurement error source keys.	PI
QUARTC	Finds the solutions to the quadratic equation.	QC
ROVLY	Reads program input into INPCOM common storage (C array).	RL
ROYAL	Outputs input random, bias, and timing errors associated with station error sources.	RY
SBEVB	Computes a chronologically ordered array of a lunar beacon in-view, out-of-view times for earth-based tracking stations.	EB
SETN	Sets read and write tape numbers.	SN
SORDR	Sorts an array X in ascending order while preserving the correspondence between array X and array NX.	SO
STAT	Computes cartesian coordinates of a point on the surface of a body and the orthogonal transformation relating cartesian to local tangent plane north-east-down.	SA
STATP	Calculates the partials of earth-based tracking station measurements with respect to the extended state vector.	CS
TFRAC	Updates time in whole and fractional days from epoch.	TM
TIMEC	Converts calendar date and time to whole and fractional days from January 1, 1950.	TM
TIMED	Converts time from (days, hours·minutes, seconds) to seconds.	TM
TIMES	Converts time from seconds to alphanumeric days, hours, minutes and seconds.	TM

VNORM	Normalizes a vector and also computes the magnitude, (ADOT*).	MF
VTRN	Multiplies one or more 3-vectors by a given 3x3 matrix, (MTRN*).	MT
VTRT	Multiplies one or more 3-vectors by the transpose of a given 3x3 matrix, (MTRN*).	MT

APPENDIX B

NEW SUBROUTINE WRITE-UPS

This appendix contains descriptions and listings of those subprograms which are unique to the EBTLB program. Descriptions of the remaining subroutines may be found in References 2 and 3.

Subroutine: MAIN(EBTLB)

Purpose: Executive Driver to direct the logic flow of EBTLB, earth based tracking of a lunar beacon.

Common storages used: INPCOM/C(700)/WCOM/IW(550),CW(1450)

Subroutines required: BEAK,BLDPB,CHNGB,CONP33,EVDEL,OUTB,NORMP,PUTIN, ROVLY,SBEVB,SORDR,TFRAC,TIMEC,TIMED,TIMES,/INPCOM/ BLOCK DATA(MC13IB)

EBTLB PROGRAM

Discussion

The EBTLB program tracks a given lunar beacon. The beacon is restricted in selenographic longitude to be between ± 80 degrees. This restriction avoids consideration of moon occultation due to lunar librations. (This libration can cause a variation of ± 7 degrees in the earth-moon vector).

The EBTLB program answers the question "How well can the location of a lunar beacon be determined from earth-based tracking, assuming the position of the moon relative to the earth and the required coordinate transformations are known ?"

The P covariance matrix is expanded from a 3x3 covariance matrix of the error in the estimate of the beacon's location on the moon (north - east - down).

The EBTLB program was created by making modifications to the Patched Conic Error Propagation program; consequently the basic logic flow is nearly identical. The latter program is described in some detail, see MAIN(P.C.), subroutine descriptions for the Mark II Error Propagation Program. Major differences between the two programs are:

1. The vehicle trajectory subroutine PCON was replaced by subroutine BEAK which computes cartesian coordinates of the lunar beacon.

2. The state vector XIN is cartesian coordinates of a lunar beacon earth true equator and equinox of date rather than of a vehicle, mean equator and equinox of 1950.0.

3. P is expanded from a 3 x 3 covariance matrix of the error in the estimate of the beacon's location on the moon (north-east - down), rather than from a 6 x 6 of the error in the estimate of the vehicle state, (EE50).

4. Propagation of the P matrix in time is not required, thus eliminating the need for subroutine PUPT and other related logic in the EBTLB Program.

5. Vehicle onboard and multiple beacon measurements as well as prediction and guidance options have no application in this program.

6. In any given case, changes in the treatment of error sources results in a reinitialization of the P matrix. Unlike the Patched Conic Program, the EBTLB is incapable of "Shuffling" the P matrix.

```
$IBFTC MC13BM  NOREF,M94,NODD,XR3
CMC13BM  MAIN PROGRAM FOR EARTH-BASED TRACKING OF LUNAR BEACONS          ETLB0010
C  SUBROUTINES REQUIRED BY MAIN                                         ETLB0020
CMC13KB    BEAK                                                        ETLB0030
CMC13BB    BLDPB                                                       ETLB0040
CMC13IB    INPCOM BLOCK DATA     MODIFIED                              ETLB0050
CMC13HB    CHNGB     MODIFIED CHNG                                     ETLB0060
CMC1333    CONP33                                                      ETLB0070
CMC13EL    EVDEL                                                       ETLB0080
CMC13BO    OUTB                                                        ETLB0090
CMC13NM    NORMP                                                       ETLB0100
CMC13PI    PUTIN                                                       ETLB0110
CMC13RL    ROVLY                                                       ETLB0120
CMC13EB    SBEVB                                                       ETLB0130
CMC13SO    SORDR                                                       ETLB0140
CMC13TM    TIME PACKAGE                                                ETLB0150
C  OTHER SUBROUTINES REQUIRED TO RUN  EBTLB                            ETLB0160
C  EBTLB = EARTH-BASED TRACKING OF A LUNAR BEACON                       ETLB0170
CMC13FM    ANTR1                                                       ETLB0180
CMC139B    BIBCD                                                       ETLB0190
CMC13CR    CRITO                                                       ETLB0200
CMC13MC    CROSS                                                       ETLB0210
CMC13MF    DOT                                                         ETLB0220
CMC13EH    EHA                                                         ETLB0230
CMC13EQ    EQTOR                                                       ETLB0240
CMC13ER    ERROUT                                                      ETLB0250
CMC13LA    LAYOVR                                                      ETLB0260
CMC13MT    MTRN,VTRN,MTRT,VTRT                                         ETLB0270
CMC13NP    NUTATE                                                      ETLB0280
CMC13PB    PARAB                                                       ETLB0290
CMC13PG    PCHNG                                                       ETLB0300
CMC13QC    QUARTC                                                      ETLB0310
CMC13RY    ROYAL                                                       ETLB0320
CMC13SN    SETN                                                        ETLB0330
CMC13SA    STAT                                                        ETLB0340
CMC13CS    STATP    TEMPORARY                                          ETLB0350
C  INPUT REQUIRED                                                      ETLB0360
C      CASE HEADER CARD  (ISW,BCD)                                     ETLB0370
C      ROVLY             C                                             ETLB0380
C           SECO         99       DH.MS     REFERENCE TIME FROM START EPOCH  ETLB0390
C           FLTM        101       DH.MS    (MAXIMUM RUN TIME)         ETLB0400
C           DATE        102       YEAR,MONTH.DAY                      ETLB0410
C           FDATE       103       HOUR,MINUTE.SECOND                  ETLB0420
C           BECDM(1)    106       BEACON SELENOGRAPHIC LATITUDE, DEG  ETLB0430
C           BECDM(2)    107       BEACON SELENOGRAPHIC LONGITUDE, DEG ETLB0440
C           BECDM(3)    108       BEACON SELENOGRAPHIC ALTITUDE  METERS  ETLB0450
C           PI(1)      112        P MATRIX 3X3   TYPE   (NO SIGNIFICANCE.)  ETLB0460
C           PI(2)      113        P(1,1)                              ETLB0470
C           PI(3)      114        P(2,2)                              ETLB0480
C           PI(4)      115        P(3,3)                              ETLB0490
C           PI(5)      116        P(1,2) = P(2,1)                     ETLB0500
C           PI(6)      117        P(1,3) =  P(3,1)                    ETLB0510
```

```
C          PI(7)     118        P(2,3) =  P(3,2)                                    ETLB0520
C      CONTROLS  TIMES CARD    NCH,TST(1,2,3)                                       ETLB0530
C      STATION CHANGE CARDS                                                         ETLB0540
C      STATION DATA   CARDS                                                         ETLB0550
       COMMON/INPCOM/C(700)/WCOM/IW(550),CW(1450)                                   ETLB0560
       DIMENSION      ICAS(3),  ISC(12),  ISEE(12), ISTIM(50),      ISW(6) ETLB0570
      1,              KEV(8)                                                       ETLB0580
      2,              AN(3,3),  BCD(11),  BECDM(3), BECRK(3)                       ETLB0590
      3,              EVNT(8),  ONAME(3)                                           ETLB0600
      4,             P(900),    PD(3,3),  PI(7)                                   ETLB0610
      5,              S(23,12), SECR(12), STIME(50)                                ETLB0620
      6,              TFORM(6), TIM(2),   TST(3),    TWT(3)                        ETLB0630
      7,             XIN(9),    AP(3,3),  APD(3,3)                                ETLB0640
       DIMENSION     TI(2)                                                        ETLB0650
       EQUIVALENCE    (C(5),DTR),    (C(7),RSPMSD),  (C(106),BECDM)                ETLB0660
      1,              (C(112),PI),   (C(200),S)                                   ETLB0670
       EQUIVALENCE    (CW(1),BECRK),(CW(26),PD),     (CW(162),P)                  ETLB0680
      1,             (CW(53),XIN),(CW(1140),TSEC)                                 ETLB0690
       EQUIVALENCE    (IW(8),ISC),    (IW(348),NIN), (IW(349),NOUT)               ETLB0700
      1,              (IW(350),NRP), (IW(351),NCP),(IW(355),ISEE)                 ETLB0710
      2,              (IW(377),ICAS)                                              ETLB0720
       EQUIVALENCE   (TI(1),TW),     (TI(2),TF)                                    ETLB0730
       DATA CMK/.001 /                                                            ETLB0740
       DATA (ONAME(J),J=1,3) /6H START, 6H  STOP, 6H OINTV/                       ETLB0750
700    FORMAT(6I1,11A6)                                                           ETLB0760
701    FORMAT(1H1,11X,28HSTARTING CONDITIONS FOR CASE,I3,1X,11A6)                 ETLB0770
702    FORMAT(1H0,13H FLIGHT TIME ,F12.4,5HDH.MS/ 10H REF. TIME,2X,F12.4,ETLB0780
      15HDH.MS/5H DATE,F8.2,2X,5HFDATE,F10.4/20H  BEACON COORDINATES /   ETLB0790
      226H SELENOGRAPHIC   LATITUDE=,F11.6,17H DEG.  LONGITUDE=,F12.6,15HETLB0800
      3 DEG  ALTITUDE=,F11.5, 4H MET/ 55H    CARTESIAN, EARTH CENTERED,  ETLB0810
      4TRUE EARTH EE DATE     /(6E20.8))                                         ETLB0820
706    FORMAT(I3,1E12.8,2(3X,1E12.8))                                             ETLB0830
707    FORMAT(21H0NEW CONTROL TIMES AT,6A6)                                       ETLB0840
708    FORMAT(1H ,1A6, 1X,6A6)                                                    ETLB0850
709    FORMAT(1H0,53X,14HEND CONDITIONS)                                          ETLB0860
       NIN=5                                                                      ETLB0870
       NOUT=6                                                                     ETLB0880
       ICAS = 0                                                                   ETLB0890
1      CONTINUE                                                                   ETLB0900
       READ(  5,700) ISW,BCD                                                      ETLB0910
       IF(ISW.EQ.1) GO TO 1001                                                    ETLB0920
       CALL ROVLY(C)                                                              ETLB0930
       ICAS=ICAS+1                                                                ETLB0940
       WRITE(   6,701)ICAS(1),BCD                                                 ETLB0950
       ICAS(2) =1                                                                 ETLB0960
       CALL TIMED (C(99),TSEC0)                                                   ETLB0970
       CALL TIMED(C(101),FLTIM)                                                   ETLB0980
       CALL TIMEC(C(102),C(103),TW0,TF0)                                          ETLB0990
       DO 2 I=1,2                                                                 ETLB1000
2      BECRK(I)=BECDM(I)*DTR                                                      ETLB1010
       BECRK(3)=BECDM(3)*CMK                                                      ETLB1020
       TW=TW0                                                                     ETLB1030
       TF=TF0                                                                     ETLB1040
```

```
C                                                                       ETLB1050
      CALL BEAK(TWO,TFO,BECRK,XIN,GHAR,OMGM,AP,APD)                     ETLB1060
C                                                                       ETLB1070
      WRITE(6,702) C(101),C(99),C(102),C(103),BECDM,XIN                 ETLB1080
      WRITE (6,800) AP,APD                                              ETLB1090
800   FORMAT(1H0,42H**BEAK CHECK AP TRANSPOSE, APD TRANSPOSE**/(3E20.8)) ETLB1100
      TEST=ABS(BECDM(2))                                                ETLB1110
      IF(TEST.GT.80..AND.TEST.LT.280.) GO TO 1002                       ETLB1120
      TSEC = TSECO                                                      ETLB1130
      INITS =-1                                                         ETLB1140
      CALL CONP33(PI,PD)                                                ETLB1150
      PTIME = FLTIM+9999.                                               ETLB1160
      GTIME = PTIME                                                     ETLB1170
      BTIME =PTIME                                                      ETLB1180
      OBTIME=PTIME                                                      ETLB1190
20    CONTINUE                                                          ETLB1200
      CALL TIMES(TSEC,D,TFORM)                                          ETLB1210
      READ(  5,706) NCH,TST                                             ETLB1220
      IF(NCH .EQ. 111) GO TO 250                                        ETLB1230
      WRITE (   6,707) TFORM                                            ETLB1240
      DO 21 I=1,3                                                       ETLB1250
      CALL TIMED(TST(I),TWT(I))                                         ETLB1260
      CALL TIMES(TWT(I),D,TFORM)                                        ETLB1270
21    WRITE(   6,708) ONAME(I),TFORM                                    ETLB1280
      IF(TWT(1) .LT. TSEC) TWT(1) = TSEC                                ETLB1290
      IF(TWT(1).GT.TWT(2).OR.TWT(3).EQ.0.) GO TO 1001                   ETLB1300
      IF(NCH .LE. 0) GO TO 22                                           ETLB1310
      CALL PUTIN(INITS)                                                 ETLB1320
      CALL BLDPB                                                        ETLB1330
      WRITE (   6,798) NRP,NCP                                          ETLB1340
798   FORMAT(1H0,36HTHE COVARIANCE MATRIX IS DIMENSIONED,I3,2H X,I3)    ETLB1350
      CALL NORMP(P,NRP,NCP,<PP)                                         ETLB1360
      MAX=NCP*NRP                                                       ETLB1370
      IF(MAX.GT.900.OR.NCP.GT.103) GO TO 1001                           ETLB1380
      INITS = 0                                                         ETLB1390
22    CONTINUE                                                          ETLB1400
      TSTART = TWT(1)                                                   ETLB1410
      IF(NCH.LT.0) TSTART=TWT(2)                                        ETLB1420
      KSTART = 1                                                        ETLB1430
      IF(TSTART .GT. TSEC) GO TO 40                                     ETLB1440
23    CONTINUE                                                          ETLB1450
      KSTART = 2                                                        ETLB1460
      TSTART = TWT(2)                                                   ETLB1470
      TIM(1) = TSEC                                                     ETLB1480
      TIM(2) = TWT(2)                                                   ETLB1490
      STIME = FLTIM + 9999.                                             ETLB1500
      IF(ISC .EQ. 0) GO TO 41                                           ETLB1510
      CALL SBEVB(TI,TIM,ISC,SECR,ISEE,ISTIM,STIME,MB)                   ETLB1520
      IK1=1                                                             ETLB1530
      KSMAX = MB                                                        ETLB1540
      GO TO 41                                                          ETLB1550
40    CONTINUE                                                          ETLB1560
      STIME=FLTIM + 9999.                                               ETLB1570
```

```
41    CONTINUE                                                          ETLB1580
      OTIME=TSEC + TWT(3)                                               ETLB1590
      EVNT(1)=OTIME                                                     ETLB1600
      EVNT(2)=STIME                                                     ETLB1610
      EVNT(3)=BTIME                                                     ETLB1620
      EVNT(4)=OBTIME                                                    ETLB1630
      EVNT(5)=GTIME                                                     ETLB1640
      EVNT(6)=PTIME                                                     ETLB1650
      EVNT(7)=TSTART                                                    ETLB1660
      EVNT(8)=FLTIM                                                     ETLB1670
      KCULT=-1                                                          ETLB1680
      DO 42 I=1,8                                                       ETLB1690
42    KEV(I)=I                                                          ETLB1700
      CALL SORDR(EVNT,KEV,8)                                            ETLB1710
      KINT=-1                                                           ETLB1720
      TSTP=TSEC                                                         ETLB1730
      DEL=864000.                                                       ETLB1740
      CALL OUTB(P,NRP,NCP)                                              ETLB1750
      IF(KSTART.EQ.1) GO TO 44                                          ETLB1760
43    CONTINUE                                                          ETLB1770
      CALL EVDEL(EVNT,KEV,DEL,KCULT)                                    ETLB1780
44    CONTINUE                                                          ETLB1790
      KSTOP=KEV(1)                                                      ETLB1800
      TSTOP=EVNT(1)                                                     ETLB1810
      KTM=1                                                             ETLB1820
45    IF(KINT.LT.0) GO TO 46                                            ETLB1830
      TDELT=(TSTP-TSEC)*RSPMSD                                          ETLB1840
      CALL TFRAC(TW,TF,TDELT)                                           ETLB1850
      CALL BEAK(TW,TF,BECRK,XIN,GHAR,OMGM,AP,APD)                       ETLB1860
      TSEC=TSTP                                                         ETLB1870
46    GO TO (60,47),KSTART                                              ETLB1880
47    CONTINUE                                                          ETLB1890
      IF(ISC.EQ.0) GO TO 60                                             ETLB1900
      CALL CHNGB(XIN,GHAR,NRP,NCP,P,SECR,OMGM,AP,APD)                   ETLB1910
60    KINT=0                                                            ETLB1920
      GO TO (61,65),KTM                                                 ETLB1930
61    TSTP=TSTP+DEL                                                     ETLB1940
      IF(TSTP-TSTOP) 45,62,62                                           ETLB1950
62    CONTINUE                                                          ETLB1960
      TSTP=TSTOP                                                        ETLB1970
      KTM=2                                                             ETLB1980
      GO TO 45                                                          ETLB1990
65    CONTINUE                                                          ETLB2000
      ICAS(3) = KSTOP                                                   ETLB2010
      GO TO (155,160,250,250,250,250,210,250),KSTOP                     ETLB2020
155   CONTINUE                                                          ETLB2030
C     OUTPUT SECTION                                                    ETLB2040
      OTIME = OTIME + TWT(3)                                            ETLB2050
      EVNT(1)=OTIME                                                     ETLB2060
      ICAS(2) = ICAS(2) +1                                              ETLB2070
156   CONTINUE                                                          ETLB2080
      CALL OUTB(P,NRP,NCP)                                              ETLB2090
      KINT = -1                                                         ETLB2100
```

```
      GO TO 43                                                                  ETLB2110
160   CONTINUE                                                                  ETLB2120
C     STATION CRITICAL EVENT SECTION                                            ETLB2130
      K = ISTIM(IK1)                                                            ETLB2140
      IF(K) 161,161,162                                                         ETLB2150
161   K=-K                                                                      ETLB2160
      ISEE(K) =-1                                                               ETLB2170
      GO TO 167                                                                 ETLB2180
162   ISEE(K) =0                                                                ETLB2190
      SECR(K)=TSEC                                                              ETLB2200
167   CONTINUE                                                                  ETLB2210
      IK1 = IK1+1                                                               ETLB2220
      IF (IK1-KSMAX)169,169,168                                                 ETLB2230
168   CONTINUE                                                                  ETLB2240
      TIM = TSEC                                                                ETLB2250
      TIM(2) = TWT(2)                                                           ETLB2260
      CALL SBEVB(TI,TIM,ISC,SECR,ISEE,ISTIM,STIME,MB)                           ETLB2270
      KSMAX = MB                                                                ETLB2280
      IK1 = 1                                                                   ETLB2290
169   CONTINUE                                                                  ETLB2300
      EVNT(1) = STIME(IK1)                                                      ETLB2310
      GO TO 156                                                                 ETLB2320
210   CONTINUE                                                                  ETLB2330
C     THIS SECTION FOR READING NEW CONTROL TIMES   KSTART = 1                   ETLB2340
C     FILLING UP STATION ARRAY  KSTART=2                                        ETLB2350
      IF(NCH.LT.0) GO TO 20                                                     ETLB2360
      GO TO (23,20) , KSTART                                                    ETLB2370
250   CONTINUE                                                                  ETLB2380
      WRITE(   6,709)                                                           ETLB2390
      CALL OUTB(P,NRP,NCP)                                                      ETLB2400
      CALL NORMP(P,NRP,NCP,KPP)                                                 ETLB2410
      GO TO 1                                                                   ETLB2420
1001  CONTINUE                                                                  ETLB2430
      WRITE (   6,701) ICAS(1),BCD                                              ETLB2440
      STOP                                                                      ETLB2450
1002  WRITE (6,799) BECDM(2)                                                    ETLB2460
799   FORMAT(1H0,24X,8H********/7X,32HBEACON SELENOGRAPHIC LONGITUDE =,          ETLB2470
     1F12.6,5H DEG./15X,35HBAD CHOICE DUE TO OCCULTING BY MOON/14X,26H          ETLB2480
     2**EXECUTION TERMINATED**)                                                 ETLB2490
      GO TO 1001                                                                ETLB2500
      END                                                                       ETLB2510
```

Subroutine: BEAK

Purpose: Given the epoch and selenographic coordinates of a lunar beacon, BEAK computes inertial cartesian coordinates of the beacon and other time dependent data required by the EBTLB* program.

Calling Sequence: CALL BEAK(TW,TF,B,XB,GHAR,ØMGM,AP,APD)

Input and Output

I/Ø	Symbolic Name or Location	Program Dimensions	Math Symbol	Data Dimensions or Units	Definition
I	TW			Days	Date, whole days from 1950.0.
I	TF			Days	Date and time, fractional days from 1950.0.
I	B	3		Radians Radians Km	Selenographic coordinates of lunar beacon B(1) = latitude B(2) = longitude B(3) = altitude
Ø	XB	9		Km Km/Sec Km/Sec^2	Earth centered cartesian coordinates of B, true earth equator-equinox of date TW, TF. X $\dot{X}$ $\ddot{X}$
Ø	GHAR			Radians	Greenwich hour angle at TW, TF epoch. (Right ascension of the greenwich meridian measured from true equinox of epoch).
Ø	ØMGM	ω'		Rad/Sec	Moon's rotation rate.
Ø	AP	3,3		Kms	These matrices are required by subroutine CHNGB to compute the measurement partials for the EBTLB* program.
Ø	APD	3,3		Kms	

Common Storages required: /INPCØM/C(700)

Subroutines required: ANTR,CRØSS,DØT,EHA,EQTØR,MTRN,NUTATE,STAT

* EBTLB: Earth-based tracking of a lunar beacon.

PROGRAM NAME	DIMENSION	DESCRIPTION
A	3,3	Transformation matrix, mean EE50 (earth equator, equinox of 1950.0) to mean EEdate.
AN	3,3	Transformation matrix, mean EE50 to true EEdate = (TN) (A).
AP	3,3	Matrix required for computation of measurement partials. = (TRF) (BS).
APD	3,3	Matrix required for computation of measurement partials = (TRF(I,3)) X(AP).
BRAD	2	(1) equatorial radius of moon. (2) polar radius of moon.
BS	3,3	Orthogonal transformation relating cartesian quantities $\vec{DUM}$ to moon beacon's local tangent plane quantities North, East, and Down. $= \begin{bmatrix} N_1 & E_1 & D_1 \\ N_2 & E_2 & D_2 \\ N_3 & E_3 & D_3 \end{bmatrix}$
D	3,3	Matrix transformation, moon true equator node to selenographic $= \begin{bmatrix} \cos RA & \sin RA & 0 \\ -\sin RA & \cos RA & 0 \\ 0 & 0 & 1. \end{bmatrix}$

DTM	3,3	Matrix transformation, mean EEdate to selenographic. = (D) (TM).
DUM	9	Cartesian selenographic coordinates of beacon. DUM(1-3) = R DUM(4-6) = $\dot{R}$ = $\emptyset$MG X R DUM(7-9) = $\ddot{R}$ = $\emptyset$MG X $\dot{R}$
$\emptyset$MG	3	Moon rotation vector, (0, 0, $\emptyset$MGM).
RA		Argument of moon's prime meridian, measured in moon equator from ascending node of moon equator on ecliptic, (radians).
RB	9	Moon centered coordinates of beacon, true EEdate = (TRF) (DUM) $= (TRF)\begin{pmatrix} R_1 & \dot{R}_1 & \ddot{R}_1 \\ R_2 & \dot{R}_2 & \ddot{R}_2 \\ R_3 & \dot{R}_3 & \ddot{R}_3 \end{pmatrix}$
RM	9	Earth centered coordinates of moon, EE50. RM(7-9) = VDUM.
TIME		Days from 1950.0 = TW + TF.
TM	3,3	Transformation matrix, mean EEdate to true moon equator , node.
TN	3,3	Transformation matrix, mean EEdate to true EEdate.

TRF	3,3	Transformation matrix, selenographic to true EEdate = (TN) $(DTM)^T$.
VDUM	3	Equivalent to RM(7-9), mean EE50 $= -\mu_E \frac{\vec{R}_M}{\lvert R_M \rvert^3} - \mu_s \left(\frac{\vec{R}_{sM}}{\lvert R_{sM} \rvert^3} + \frac{\vec{R}_{sE}}{\lvert R_{sE} \rvert^3} \right)$ where R_M = position of Moon wrt Earth R_{sE} = position of Earth wrt Sun R_{sM} = position of Moon wrt Sun
XB	9	Position, velocity, and acceleration coordinates of beacon with respect to earth, true EEdate = (AN) (RM) + RB

```
$IBFTC MC13KB  NOREF,M94,NODD,XR3
CMC13KB  SUBROUTINE BEAK COMPUTES COORDINATES OF MOON BEACON                BEAK0010
      SUBROUTINE BEAK(TW,TF,B,XB,GHAR,OMGM,AP,APD)                          BEAK0020
C  SUBROUTINES REQUIRED                                                     BEAK0030
C     ANTR1                                                                BEAK0040
C     CROSS                                                                BEAK0050
C     EHA                                                                  BEAK0060
C     EQTOR                                                                BEAK0070
C     MTRN,VTRT                                                            BEAK0080
C     NUTATE                                                               BEAK0090
C     STAT                                                                 BEAK0100
C  INPUT                                                                   BEAK0110
C     TW       WHOLE DAYS FROM 1950.0                                      BEAK0120
C     TF       FRACTIONAL DAYS FROM 1950.0                                 BEAK0130
C     B        BEACON SELENOGRAPHIC LATITUDE,LONGITUDE,ALTITUDE,(RAD,KM)   BEAK0140
C  OUTPUT                                                                  BEAK0150
C     XB       EARTH-CENTERED CARTESIAN INERTIAL COORD. OF BEACON,         BEAK0160
C                 TRUE EEDATE  (XB(7)=VDOT)                                BEAK0170
C     GHAR     GREENWICH HOUR ANGLE AT TW+TF                               BEAK0180
C     OMGM     ROTATION RATE OF MOON                                       BEAK0190
C     AP        =TRF*(N,E,D)       USED FOR PARTIALS IN CHNGB             BEAK0200
C     APD       =TRF*(WX)(N,E,D)   USED FOR PARTIALS IN CHNGB             BEAK0210
C  MATRIX TRANSFORMATIONS,(EARTH EQUATOR EQUINOX = EE, DATE = TW,TF)       BEAK0220
C     AN       TRANSF.  MEAN EE 1950.0 TO TRUE EE DATE                     BEAK0230
C     A        MEAN EE 1950.0 TO MEAN EE DATE                              BEAK0240
C     D        MOON TRUE EQUATOR, NODE TO SELENOGRAPHIC                    BEAK0250
C     TM       MEAN EE DATE TO TRUE MOON EQUATOR,NODE                      BEAK0260
C     TN       MEAN EE DATE TO TRUE EE DATE                                BEAK0270
C     TRF      SELENOGRAPHIC TO TRUE EEDATE  = TN*TM TRANSPOSE*D TRANSPOS  BEAK0280
C                                                                          BEAK0290
C  VECTORS                                                                 BEAK0300
C     BS(1,I) UNIT NORTH                                                   BEAK0310
C     BS(2,I) UNIT EAST                                                    BEAK0320
C     BS(3,I) UNIT DOWN                                                    BEAK0330
C     RM       EARTH CENTERED COORDINATES OF MOON   EE50                   BEAK0340
C     RB       MOON  CENTERED COORDINATES OF BEACON  EEDATE                BEAK0350
C  DEFINITIONS OF OTHER VARIABLES                                          BEAK0360
C     RA       ARGUMENT OF MOON PRIME MERIDIAN MEASURED IN MOON EQUATOR    BEAK0370
C                FROM ASCENDION NODE OF MOON EQUATOR ON ECLIPTIC           BEAK0380
C     OMGE     ROTATION RATE OF EARTH                                      BEAK0390
      COMMON/INPCOM/C(700)                                                 BEAK0400
      DIMENSION    A(3,3),   AN(3,3),  B(3),     BODC(10,8)              BEAK0410
     1,            BRAD(2),  BS(3,3),  D(3,3),   OMG(3),   PO(21)        BEAK0420
     2,            SC(5),    TM(3,3),  DTM(3,3),   TRF(3,3)              BEAK0430
     3,            DUM(9),   RB(9),   RM(9),   XB(9),   U(3)             BEAK0440
     4,            TN(3,3),   VE(21),   AP(3,3),   APD(3,3)              BEAK0450
     5,            VDUM(3)                                               BEAK0460
      EQUIVALENCE   (C(11),BODC),   (C(21),U),   (RM(7),VDUM)            BEAK0470
      DATA OMG,D/ 11*0.,1./                                              BEAK0480
      BRAD(1)=BODC(2,3)                                                  BEAK0490
      BRAD(2)=BODC(2,4)                                                  BEAK0500
      TIME = TW+TF                                                       BEAK0510
      CALL EQTOR(TIME,A,OBL)
```

```
      CALL NUTATE(3,TW,TF,TN,TM,RA,OMGM)                                BEAK0520
      CALL MTRN(TN,A,AN)                                                BEAK0530
      CALL EHA(TW,TF,TN(2,1),GHAR,OMGE)                                 BEAK0540
      D(1,1)=COS(RA)                                                    BEAK0550
      D(2,2)=D(1,1)                                                     BEAK0560
      D(1,2)=SIN(RA)                                                    BEAK0570
      D(2,1)=-D(1,2)                                                    BEAK0580
      CALL MTRN(D,TM,DTM)                                               BEAK0590
      DO 1 I=1,3                                                        BEAK0600
      DO 1 J=1,3                                                        BEAK0610
      TRF(I,J)=0.                                                       BEAK0620
      DO 1 K=1,3                                                        BEAK0630
1     TRF(I,J)=TRF(I,J)+TN(I,K)*DTM(J,K)                                BEAK0640
      CALL STAT(B,0.,BS,DUM,SC,BRAD)                                    BEAK0650
      CALL MTRN(TRF,BS,AP)                                              BEAK0660
      DO 3 I=1,3                                                        BEAK0670
3     CALL CROSS(TRF(1,3),AP(1,I),APD(1,I))                             BEAK0680
      OMG(3)=OMGM                                                       BEAK0690
      CALL CROSS(OMG,DUM,DUM(4))                                        BEAK0700
      CALL CROSS(OMG,DUM(4),DUM(7))                                     BEAK0710
      CALL MTRN(TRF,DUM,RB)                                             BEAK0720
      CALL ANTR1(TW,TF,0,PO,1,VE,BRAD(1))                               BEAK0730
      DO 10 J=1,3                                                       BEAK0740
      KK=3+J                                                            BEAK0750
      RM(J)=PO(KK)                                                      BEAK0760
10    RM(KK)=VE(KK)                                                     BEAK0770
      R3=DOT(RM,RM)                                                     BEAK0780
      R3=-U(1)/(R3*SQRT(R3))                                            BEAK0790
      DO 11 I=1,3                                                       BEAK0800
      VDUM(I)=R3*RM(I)                                                  BEAK0810
11    DUM(I)=-PO(I+6)                                                   BEAK0820
      KEY=1                                                             BEAK0830
12    R3=DOT(DUM,DUM)                                                   BEAK0840
      R3=-U(3)/(R3*SQRT(R3))                                            BEAK0850
      DO 13 I=1,3                                                       BEAK0860
13    VDUM(I)=VDUM(I)+R3*DUM(I)                                         BEAK0870
      GO TO (14,16),KEY                                                 BEAK0880
14    DO 15 I=1,3                                                       BEAK0890
15    DUM(I)=RM(I)+DUM(I)                                               BEAK0900
      KEY=2                                                             BEAK0910
      GO TO 12                                                          BEAK0920
16    CONTINUE                                                          BEAK0930
      CALL MTRN(AN,RM,XB)                                               BEAK0940
      DO 20 I=1,9                                                       BEAK0950
20    XB(I)=XB(I)+RB(I)                                                 BEAK0960
      RETURN                                                            BEAK0970
      END                                                               BEAK0980
```

Subroutine: BLOCK DATA/INPCOM/

Purpose: To supply data to the program concerned with earth-based tracking of a lunar beacon, EBTLB. This Block Data routine is similar to that for the Patched Conic Program; Table 1 describes the pertinent exceptions.

Common storages used: /INPCOM/C(700)

Subroutines required: None

TABLE 1

LOCATION	NAME	COMPILED VALUE	DEFINITION
10	CON(10)	3600.	Step size for subroutine SBEVB, seconds.
106-108	BECDM		Selenographic location of the lunar beacon
106	BECDM(1)	45.	Latitude, degrees
107	(2)	-30.	Longitude, degrees
108	(3)	100.	Altitude, meters.
112	PI		Data required to define initial 3x3 P covariance matrix, local beacon N-E-D coordinates.
112	PI(2)	100.	P(1,1)
114	PI(3)	100.	P(2,2)
115	PI(4)	100.	P(3,3)
116	PI(5)	0.	P(1,2) = P(2,1)
117	PI(6)	0.	P(1,3) = P(3,1)
118	PI(7)	0.	P(2,3) = P(3,2).

```
$IBFTC MC13IB  NOREF,M94,NODD,XR3
CMC13IB  INPCOM  BLOCK DATA FOR EBTLB                                          LBBD0010
      BLOCK DATA                                                               LBBD0020
      COMMON/INPCOM/C(700)                                                     LBBD0030
      DIMENSION   BODC(10,8),       CON(10),      BECDM(3),    PI(22)        LBBD0040
      EQUIVALENCE (C(11),BODC),       (C(99),SECO),      (C(100),TARG)       LBBD0050
     1,           (C(1),CON),        (C(102),DATE),     (C(103),FDATE)      LBBD0060
     2,           (C(101),FLTM),     (C(104),BCEN),     (C(105),TYPEX)      LBBD0070
     3,           (C(106),BECDM),    (C(112),PI)                            LBBD0080
C                 C(1)= PI/2    C(2)= PI      C(3)= 2*PI                     LBBD0090
      DATA(CON(I),I=1,10)/1.57079633,3.14159265,6.2831853                    LBBD0100
C     C(4)= RTD   C(5)= DTR    C(6)= SPMSD   C(7)= RSPMSD  C(8)= KM/AU        LBBD0110
     1,57.2957796,.0174532926,8640.,1.1574074E-5,.149599E9                   LBBD0120
C     C(9)= SPD OF LIGHT    C(10)=  SBEVB TIME STEP CONSTANT IN SECONDS      LBBD0130
     2,299774., 3600. /                                                       LBBD0140
C     NAMES OF BODIES                                                        LBBD0150
      DATA (BODC(I,1),I=1,10)/5HEARTH,4HMOON,3HSUN,5HVENUS,4HMARS,           LBBD0160
     16HSATURN,6HJUPITR,6HBODY 8,6HBODY 9,6HBOD 10/                          LBBD0170
C     GRAVITY CONSTANTS                                                      LBBD0180
      DATA(BODC(I,2),I=1,7)/398603.2,4900.7568,.1327154E12,324769.5,         LBBD0190
     142977.8,3.791870E7,1.2671066E6/                                        LBBD0200
C     SEMI-MAJOR AXIS                                                        LBBD0210
      DATA(BODC(I,3),I=1,7)/6378.165,1738.,695500.,6200.,3400.,60400.        LBBD0220
     1,71350./                                                               LBBD0230
C     SEMI-MINOR AXIS                                                        LBBD0240
      DATA(BODC(I,4),I=1,7)/6356.5838,1738.,695500.,6200.,3400.,54050.       LBBD0250
     1,66600./                                                               LBBD0260
C     SPHERE OF INFLUENCE (KM)                                               LBBD0270
      DATA (BODC(I,5),I=1,7)/925000.,66000.,1.E10,616000.,565000.            LBBD0280
     1,.546E8,.48E8/                                                         LBBD0290
C     ROTATION RATES (RAD/SEC)                                               LBBD0300
      DATA (BODC(I,7),I=1,7)/.72921*52E-4,  .266169952E-5,  0.0              LBBD0310
     1, 0.0  ,.70682177E-4  ,.170553547E-3  ,.177491110E-3/                  LBBD0320
C     MAX STEP SIZE  (SEC)                                                   LBBD0330
      DATA (BODC(I,6),I=1,7)/43200.      ,21600.    ,864000.   ,43200.      LBBD0340
     1,43200.   ,86400.    ,172800./                                         LBBD0350
C     INTERPOLATION INTERVALS                                                LBBD0360
      DATA (BODC(I,8),I=1,7)/7*40./                                          LBBD0370
      DATA SECO,TARG,FLTM,DATE,FDATE,BCEN,TYPEX/                             LBBD0380
     1    .0 ,5.0 ,30000. ,7502.16 ,201.25146 ,1.0 ,0.0/                     LBBD0390
      DATA (BECDM(I),I=1,3)/                                                 LBBD0400
     1 45., -30., 100./                                                      LBBD0410
      DATA(PI(I),I=1,22)/0.,100.,100.,100.,18*0./                            LBBD0420
      DATA (C(I),I=167,700)/534*0./                                          LBBD0430
       END                                                                   LBBD0440
```

EBTLB/INPCOM/-3

Subroutine: BLDPB

Purpose: To build the P covariance matrix for the EBTLB* program from the input 3 x 3 and other error sources, to compute and store logic necessary to updating this matrix outside BLDPB, and to write out the error sources included.

BLDPB is an extraction of subroutine BLDP. The EBTLB program has no need for onboard measurements or extensive multi-beacon logic, thus BLDPB excludes it also. Also, BLDPB always initializes the extended covariance matrix; it does not contain BLDP's ability to shuffle consideration of error sources.

Calling Sequence: CALL BLDPB

Common storages used: INPCOM/C(700)/WCOM/IW(550),GW(1450)

Subroutines required: ROYAL

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* EBTLB: Earth-based tracking of a lunar beacon.

```
$IBFTC MC13BB  NOREF,M94,NODD,XR3                                                BDBB0010
CMC13BB   BLDPB    LOAD AND OUTPUT ELEMENTS OF BEACON 3X3 EXTENDED               BDBB0020
      SUBROUTINE BLDPB                                                           BDBB0030
      COMMON/INPCOM/C(700)/WCOM/Iw(550),Cw(1450)                                 BDBB0040
      DIMENSION    ISC(12),   IS(11,12),     MCOL(5),      S(23,12)            BDBB0050
     1,            PD(3,3)                                                      BDBB0060
     2,            IEMP(24),  IND(4),        PUV(100)                          BDBB0070
     3,                       MPO(100),      P(900),       EMP(24)             BDBB0080
     4,            VAR(100),  NIND(4),       MP(100)                           BDBB0090
     5,                       BODC(10,8)                                        BDBB0100
      DIMENSION    EQNA(3,24)                                                   BDBB0110
      EQUIVALENCE  (C(4),RTD),     (C(7),RSPMSD),     (C(11),BODC)              BDBB0120
     1,            (C(200),S),     (C(476),B),        (C(567),UB)               BDBB0130
     2,            (C(585),EMP)                                                 BDBB0140
      EQUIVALENCE  (Iw(8),ISC),    (Iw(20),IBC),      (Iw(30),IEMP)             BDBB0150
     1,                                               (Iw(76),MPO)              BDBB0160
     2,            (IW(176),IND),  (Iw(180),IS)                                 BDBB0170
     3,            (Iw(348),NIN),  (Iw(349),NOUT),    (Iw(350),MCOL)            BDBB0180
     4,            (MCOL(1),NRP),  (MCOL(2),NCP)                                BDBB0190
      EQUIVALENCE  (Cw(26),PD),    (Cw(62),PUV),      (Cw(162),P)               BDBB0200
      DATA RTS/.20626481E6/                                                      BDBB0210
      DATA (EQNA(1,J),J=1,12)/                                                   BDBB0220
     118HASTRO UNIT KM/AU  ,                                                     BDBB0230
     218HEARTH M FRAC/SUN  ,                                                     BDBB0240
     318HMOON  M FRAC/SUN  ,                                                     BDBB0250
     418HVENUS M FRAC/SUN  ,                                                     BDBB0260
     518HMARS  M FRAC/SUN  ,                                                     BDBB0270
     618HJUPTR M FRAC/SUN  ,                                                     BDBB0280
     718HSATRN M FRAC/SUN  ,                                                     BDBB0290
     818HMRCRY M FRAC/SUN  ,                                                     BDBB0300
     918H2ND ZONAL HARM    ,                                                     BDBB0310
     118H3RD ZONAL HARM    ,                                                     BDBB0320
     218H4TH ZONAL HARM    ,                                                     BDBB0330
     318H5TH ZONAL HARM    /                                                     BDBB0340
      DATA(EQNA(1,J),J=13,24)/                                                   BDBB0350
     418H1ST LONG HARM RAD ,                                                     BDBB0360
     518H2ND LONG HARM RAD ,                                                     BDBB0370
     618H3RD LONG HARM RAD ,                                                     BDBB0380
     718H4TH LONG HARM RAD ,                                                     BDBB0390
     818H1ST LUNAR KM**2   ,                                                     BDBB0400
     918H2ND LUNAR KM**2   ,                                                     BDBB0410
     118H3RD LUNAR KM**2   ,                                                     BDBB0420
     218H1ST DRAG   1/(KM) ,                                                     BDBB0430
     318H2ND DRAG   1/(KM) ,                                                     BDBB0440
     418HSOLAR RAD K**3/S*S,                                                     BDBB0450
     518HVENT. THR. KM/SEC ,                                                     BDBB0460
     618HSPEED LGT ERROR   /                                                     BDBB0470
      DO 10 I=1,4                                                                BDBB0480
   10 NIND(I)=0                                                                  BDBB0490
      NPRNT=1                                                                    BDBB0500
      NTIME=1                                                                    BDBB0510
      N=0
```

```
      DO 16 I=1,24                                                          BDBB0520
      IF(IEMP(I))17,16,16                                                   BDBB0530
   17 N=N+1                                                                 BDBB0540
C     HERE WE ARE IF THE ITH EQ OF MO PARAM IS TO BE SOLVED FOR             BDBB0550
      MP(N)=I                                                               BDBB0560
      VAR(N)=EMP(I)                                                         BDBB0570
      IEMP(I)=-N-3                                                          BDBB0580
   16 CONTINUE                                                              BDBB0590
      NIND(1)=N                                                             BDBB0600
      NN=N                                                                  BDBB0610
      IF(ISC) 30,30,20                                                      BDBB0620
   20 CONTINUE                                                              BDBB0630
      GO TO (201,202),NPRNT                                                 BDBB0640
  201 WRITE(NOUT,101)                                                       BDBB0650
  101 FORMAT(1H0,41X,38H*** EARTH-BASED TRACKING IN EFFECT ***/7H NUMBER    BDBB0660
     1,6X,4HNAME,22X,8HLOCATION,42X,8HOBSERVES)                             BDBB0670
  202 DO 28 I=1,12                                                          BDBB0680
      ISTAT=ISC(I)                                                          BDBB0690
      IF(ISTAT)30,30,21                                                     BDBB0700
   21 CONTINUE                                                              BDBB0710
      GO TO (211,212),NPRNT                                                 BDBB0720
  211 SLAT=S(3,ISTAT)*RTD                                                   BDBB0730
      SLON=S(4,ISTAT)*RTD                                                   BDBB0740
      AH=S(6,ISTAT)*RTD                                                     BDBB0750
      SALT=S(5,ISTAT)*1000.                                                 BDBB0760
      EM=S(7,ISTAT)*RTD                                                     BDBB0770
      WRITE(NOUT,102) ISTAT,S(1,ISTAT),SLAT,S(2,ISTAT),SLON,AH,SALT,EM      BDBB0780
  102 FORMAT(1H0,2X,I2,8X,A6,12X,11HLATITUDE  =,F10.5,4H DEG,20X,15HAT IBDBB0790
     1NTERVALS OF,F9.2,4H SEC/31X,11HLONGITUDE =,F10.5,4H DEG,20X,23HwHEBDBB0800
     2N ELEVATION IS ABOVE,F7.2,4H DEG/31X,11HALTITUDE  =,F10.5,4H MET,2BDBB0810
     3 X,13HBUT LESS THAN,F7.2,4H DEG)                                      BDBB0820
      WRITE(NOUT,103)                                                       BDBB0830
  103 FORMAT(1H0,28X,25HMEASUREMENT ERROR SOURCES,11X,6HRANDOM,9X,4HBIASBDBB0840
     1)                                                                     BDBB0850
  212 DO 27 J=2,11                                                          BDBB0860
      GO TO (22,24),NTIME                                                   BDBB0870
   22 IF(IS(J,ISTAT).EQ.0) GO TO 27                                         BDBB0880
      CALL ROYAL(1,IS(1,ISTAT),J,S(1,ISTAT),NOUT)                           BDBB0890
      IF(IS(J,ISTAT).GT.0) GO TO 27                                         BDBB0900
   23 NN=NN+1                                                               BDBB0910
      IS(J,ISTAT)=-NN-3                                                     BDBB0920
      GO TO 26                                                              BDBB0930
   24 IF(IS(J,ISTAT).LE.0.OR.IS(J,ISTAT).EQ.2) GO TO 27                     BDBB0940
      NN=NN+1                                                               BDBB0950
      IS(J,ISTAT)= NN+3                                                     BDBB0960
   26 MP(NN)=100*ISTAT+J-1                                                  BDBB0970
      JK=J+12                                                               BDBB0980
      VAR(NN)=S(JK,ISTAT)                                                   BDBB0990
   27 CONTINUE                                                              BDBB1000
   28 CONTINUE                                                              BDBB1010
   30 CONTINUE                                                              BDBB1020
      IBC=0                                                                 BDBB1030
      I=2*NTIME                                                             BDBB1040
```

```
      NIND(I)=NN-N                                                      BDBB1050
      N=NN                                                              BDBB1060
      GO TO (50,60),NTIME                                               BDBB1070
50    DO 59 I=1,24                                                      BDBB1080
      IF(IEMP(I))59,59,51                                               BDBB1090
   51 NN=NN+1                                                           BDBB1100
      MP(NN)=I                                                          BDBB1110
      VAR(NN)=EMP(I)                                                    BDBB1120
      IEMP(I)=NN+3                                                      BDBB1130
   59 CONTINUE                                                          BDBB1140
      NIND(3)=NN-N                                                      BDBB1150
      N=NN                                                              BDBB1160
      NTIME=2                                                           BDBB1170
      NPRNT=2                                                           BDBB1180
      GO TO 20                                                          BDBB1190
   60 CONTINUE                                                          BDBB1200
      NK=NIND(1)                                                        BDBB1210
      NKL=NK+NIND(2)                                                    BDBB1220
      NKLM=NKL+NIND(3)                                                  BDBB1230
      NKLMN=NKLM+NIND(4)                                                BDBB1240
      NRP=3+NKL                                                         BDBB1250
      NCP=3+NKLMN                                                       BDBB1260
      MCOL(3)=3+NK                                                      BDBB1270
      MCOL(4)=NRP+1                                                     BDBB1280
      MCOL(5)=3+NKLM                                                    BDBB1290
      IF(IEMP(24)) 55,57,56                                             BDBB1300
55    MCOL(3)=MCOL(3)-1                                                 BDBB1310
      GO TO 57                                                          BDBB1320
56    MCOL(5)=MCOL(5)-1                                                 BDBB1330
57    CONTINUE                                                          BDBB1340
      DO 501 I=1,900                                                    BDBB1350
501   P(I)=0.                                                           BDBB1360
      K=0                                                               BDBB1370
      DO 503 I=1,3                                                      BDBB1380
      DO 502 J=1,3                                                      BDBB1390
      K=K+1                                                             BDBB1400
502   P(K)=PD(J,I)                                                      BDBB1410
      K=I*NRP                                                           BDBB1420
503   CONTINUE                                                          BDBB1430
      IF(NKL.EQ.0) GO TO 505                                            BDBB1440
      K=NRP*3+3                                                         BDBB1450
      DO 504 I=1,NKL                                                    BDBB1460
      K=K+1                                                             BDBB1470
      P(K)=VAR(I)                                                       BDBB1480
504   K=K+NRP                                                           BDBB1490
505   CONTINUE                                                          BDBB1500
      IF(NRP.EQ.NCP) GO TO 507                                          BDBB1510
      K=NIND(3)+NIND(4)                                                 BDBB1520
      DO 506 I=1,K                                                      BDBB1530
      KK=NKL+I                                                          BDBB1540
506   PUV(I)=VAR(KK)                                                    BDBB1550
507   CONTINUE                                                          BDBB1560
      DO 508 I=1,100                                                    BDBB1570
```

```
508   MPO(I)=MP(I)                                                          BDBB1580
      DO 509 I=1,4                                                          BDBB1590
509   IND(I)=NIND(I)                                                        BDBB1600
      K=0                                                                   BDBB1610
      DO 590 I=1,24                                                         BDBB1620
      IF(IEMP(I)) 585,590,585                                               BDBB1630
585   IF(K.GT.0) GO TO 586                                                  BDBB1640
      K=1                                                                   BDBB1650
      WRITE (NOUT,111)                                                      BDBB1660
586   WRITE (NOUT,112) (EQNA(J,I),J=1,3),EMP(I)                             BDBB1670
590   CONTINUE                                                              BDBB1680
111   FORMAT(1H0,42X,35H***OTHER DET. UNKNOWNS IN EFFECT***)                BDBB1690
112   FORMAT(1H ,3A6,2X,E15.8)                                              BDBB1700
      RETURN                                                                BDBB1710
      END                                                                   BDBB1720
```

Subroutine: CHNGB

Purpose: To make station observations of a lunar beacon and appropriately update the P covariance matrix. CHNGB is subroutine CHNG modified to compute partials of measurements with respect to beacon location errors (rather than vehicle state) for the EBTLB* program.

Calling Sequence: CALL CHNGB(X,GHA,NRW1,NCOL,P,SECR,OMGM,AP,APD)

Input and Output

I/Ø	Symbolic Name or Location	Program Dimensions	Math Symbol	Data Dimensions or Units	Definition
I	X	9	XB	Km ; Sec	Position, velocity, acceleration of beacon with respect to Earth, true EEdate.
I	GHA			Radians	Greenwich hour angle.
I	NRW1				Number of rows of P.
I	NCOL				Number of columns of P.
I/Ø	P	NRW1,NCOL			P covariance matrix.
I/Ø	SECR	12		Seconds	Array of next time to make an observation for each station. If an observation is made in CHNGB at SECR(II), SECR(II) is set to the next time to observe from station ISC(II).
I	OMGM		$\lvert\omega\rvert$		Rotation rate of the moon.
I	AP	3,3	$\frac{\partial S}{\partial \Delta_B}$		Partial of range vector with respect to beacon location errors N,E,D.
I	APD	3,3	$\frac{1}{\lvert\omega\rvert}\ \frac{\partial \dot{S}}{\partial \Delta_B}$		$\frac{1}{\lvert\omega\rvert}$. partial of range rate vector with respect to beacon location error N,E,D.

Common storages used: /INPCOM/C(700)/WCOM/IW(550),CW(1450)

Subroutines required: STATP,VTRT,PCHNG

*EBTLB: Earth-based tracking of a lunar beacon.

Discussion:

Given X(1-6), coordinates of the lunar beacon with respect to the Earth, True EEdate, and X(7-9) or VDOT, subroutine STATP computes H measurement partials as required. These partials are in the form required by the EBTLB program with two exceptions: STATP computes $H(1\text{-}3) = \frac{\partial M}{\partial x}$, and for rate measurements

$H(1\text{-}3) = \frac{\partial \dot{M}}{\partial x}$ and $H(4\text{-}7) = \frac{\partial \dot{M}}{\partial \dot{x}}$. CHNGB utilizes these H partials to to compute those required by EBTLB, $HH(1\text{-}3) = \frac{\partial M}{\partial \Delta_B}$ or $\frac{\partial \dot{M}}{\partial \Delta_B}$.

Derivation of HH(1-3)

Let M represent the measurement,

Δ_B represent the beacon location errors, n, e, d,

S represent the range vector

$= X_m - RT + (TRF)\ (RB)$

$\dot{S}$ represent the range rate vector.

$= \dot{X}_m - \Omega \times RT + (TRF)\ (\omega \times RB)$

where RT is inertial position of tracking station, true EEdate.

X_m are earth-centered moon coordinates, true EEdate

Ω earth rotation vector $(0, 0, |\Omega|)$

ω, moon rotation vector $(0, 0, |\omega|)$

RB, selenographic coordinates of lunar beacon

TRF, transformation matrix, selenographic to true EEdate.

$HH(1\text{-}3) = \frac{\partial M}{\partial \Delta_B}$ or $\frac{\partial \dot{M}}{\partial \Delta_B}$ is the measurement partial required by subroutine PCHNG to update the expanded 3x3 P covariance matrix for the EBTLB program.

$$\frac{\partial M}{\partial \Delta_B} = \frac{\partial M}{\partial S} \cdot \frac{\partial S}{\partial \Delta_B}$$

$$\frac{\partial \dot{M}}{\partial \Delta_B} = \frac{\partial \dot{M}}{\partial S} \frac{\partial S}{\partial \Delta_B} + \frac{\partial \dot{M}}{\partial \dot{S}} \frac{\partial \dot{S}}{\partial \Delta_B}$$

STATP provides $H(1\text{-}3) = \frac{\partial M}{\partial X} = \frac{\partial M}{\partial S}$

or, in the case of rate measurements

$$H(1\text{-}3) = \frac{\partial \dot{M}}{\partial X} = \frac{\partial M}{\partial S}$$

$$H(4\text{-}6) = \frac{\partial \dot{M}}{\partial \dot{X}} = \frac{\partial \dot{M}}{\partial X}$$

Subroutine BEAK provides the CHNGB call list with AP and APD

$$AP = \frac{\partial S}{\partial \Delta_B} = TRF \cdot (N,E,D)$$

$$|\omega| (APD) = \frac{\partial \dot{S}}{\partial \Delta_B} = TRF(\omega x)\ (N,E,D)$$

$$= (TRF\omega) X (TRF \cdot (N,E,D))$$

But $\omega = (0,\ 0\ |\omega|)$,

so $(TRF\omega) = |\omega|$ (column 3 of TRF).

thus, $\frac{\partial \dot{S}}{\partial \Delta_B} = |\omega| \left(TRF(I,3)\right) AP = |\omega| (APD)$

Consequently $\frac{\partial M}{\partial \Delta_B} = (AP)^T (H)$

and $\frac{\partial \dot{M}}{\partial \Delta_B} = (AP)^T (H_{1\text{-}3}) + |\omega| (APD)^T (H_{4\text{-}6})$

```
$IBFTC MC13HB  NOREF,M94,NODD,XR3
CMC13HB  CHNGB  CALLS STATP AND COMPUTES MEAS PART WRT BEACON LOCA 3X3  CHGB0010
      SUBROUTINE CHNGB(X,GHA,NRW1,NCOL,P,SECR,OMGM,AP,APD)              CHGB0020
C    X IS POS, VEL, ACC, OF BEACON WRT CENTER OF EARTH TRUE EE DATE     CHGB0030
C     GHA IS THE GHA AT TIME OF X                                       CHGB0040
C     SUBROUTINES REQUIRED ARE                                          CHGB0050
C         VTRN, VTRT  (MC13MT)                                          CHGB0060
C         STATP    STAT,DOT,CROSS                                       CHGB0070
C         PCHNG                                                         CHGB0080
C                                                                       CHGB0090
      COMMON/INPCOM/C(700)/WCOM/IW(550),CW(1450)                        CHGB0100
      DIMENSION   ISC(12),      ISEE(12),      IS(11,12),        S(23,12)CHGB0110
     1,             LL(2),                   BODC(10,8),     P(NRW1,NCOL)CHGB0120
     2,          MTYPE(5),                       H(12),          HH(9) CHGB0130
     3,            NCG(6),          G(6),       SECR(12),         NCH(9) CHGB0140
     4,           BRAD(3)                                              CHGB0150
     5,            X(9),   AP(3,3),    APD(3,3),    W(100)            CHGB0160
      EQUIVALENCE  (MEAS,MTYPE),  (MTYPE(5),ISAN),    (LL(1),KJ)       CHGB0170
     1,            (LL(2),JJ),    (C(11),BODC)                        CHGB0180
     2,                           (C(200),S)                          CHGB0190
     3,            (IW(8),ISC),   (IW(53),ISL),       (IW(180),IS)    CHGB0200
     4,            (IW(355),ISEE),(CW(62),W),         (CW(1140),TIM)  CHGB0210
C                                                                       CHGB0220
      BRAD(1)=BODC(1,3)                                                 CHGB0230
      BRAD(2)=BODC(1,4)                                                 CHGB0240
      BRAD(3)=BODC(1,7)                                                 CHGB0250
      DO 1000 I=1,3                                                     CHGB0260
1000  NCH(I)=I                                                          CHGB0270
      MTYPE(4)=-1                                                       CHGB0280
      IF(ISL.NE.0) MTYPE(4)=0                                           CHGB0290
      NTBIAS=1                                                          CHGB0300
      II=1                                                              CHGB0310
1     CONTINUE                                                          CHGB0320
      IF(ISC(II)) 100,100,3                                             CHGB0330
3     IF(ISEE(II))21,4,4                                                CHGB0340
4     IF(SECR(II).GT.TIM) GO TO 21                                      CHGB0350
      NST=ISC(II)                                                       CHGB0360
      SECR(II)=SECR(II)+S(2,NST)                                        CHGB0370
      MTYPE(3)=-1                                                       CHGB0380
      MTYPE(2)=-1                                                       CHGB0390
      DO 7 I=8,10                                                       CHGB0400
7     IF(IS(I,NST).NE.0) MTYPE(2)=0                                     CHGB0410
      IF(IS(11,NST).NE.0) MTYPE(3)=0                                    CHGB0420
      ISAN=IS(1,NST)                                                    CHGB0430
      NN=7                                                              CHGB0440
      IF(ISAN.EQ.0) NN=3                                                CHGB0450
      IK=0                                                              CHGB0460
      DO 20 J=2,NN                                                      CHGB0470
      M=IS(J,NST)                                                       CHGB0480
      IF(M.EQ.0) GO TO 20                                               CHGB0490
      MEAS=J-1                                                          CHGB0500
      MM=MEAS                                                           CHGB0510
      Q=S(MEAS+7,NST)                                                   CHGB0520
```

```
9       CALL STATP(S(3,NST),X     ,GHA,H,IK,MTYPE,BRAD,X(7),Q)                  CHGB0530
        KJ=3                                                                    CHGB0540
        CALL VTRT(AP,H,HH)                                                      CHGB0550
        GO TO (12,11,12,12,11,11),MM                                            CHGB0560
11      DO 10 I=1,3                                                             CHGB0570
10      HH(I)=HH(I)+OMGM*DOT(H(4),APD(1,I))                                     CHGB0580
12      JJ=0                                                                    CHGB0590
        IF(M-2) 13,15,14                                                        CHGB0600
13      CONTINUE                                                                CHGB0610
        KJ=KJ+1                                                                 CHGB0620
        HH(KJ)=1.                                                               CHGB0630
        NCH(KJ)=-M                                                              CHGB0640
        GO TO 15                                                                CHGB0650
14      JJ=JJ+1                                                                 CHGB0660
        G(JJ)=1.                                                                CHGB0670
        NCG(JJ)=M                                                               CHGB0680
15      CONTINUE                                                                CHGB0690
        KK=8                                                                    CHGB0700
        IF(MTYPE(2).LT.0) KK=11                                                 CHGB0710
        DO 18 I=KK,12                                                           CHGB0720
        IF(I.EQ.12) GO TO 158                                                   CHGB0730
        M=IS(I,NST)                                                             CHGB0740
        GO TO 159                                                               CHGB0750
158     M=ISL                                                                   CHGB0760
        IF(MM.NE.1) GO TO 18                                                    CHGB0770
159     IF(M) 16,18,17                                                          CHGB0780
16      CONTINUE                                                                CHGB0790
        KJ=KJ+1                                                                 CHGB0800
        NCH(KJ)=-M                                                              CHGB0810
        HH(KJ)=H(I)                                                             CHGB0820
        GO TO 18                                                                CHGB0830
17      JJ=JJ+1                                                                 CHGB0840
        NCG(JJ)=M                                                               CHGB0850
        G(JJ)=H(I)                                                              CHGB0860
18      CONTINUE                                                                CHGB0870
        CALL PCHNG(P,NRW1,NCOL,LL,W,G,NCG,HH,NCH,Q)                             CHGB0880
20      CONTINUE                                                                CHGB0890
21      CONTINUE                                                                CHGB0900
        II=II+1                                                                 CHGB0910
        IF(II.LE.12) GO TO 1                                                    CHGB0920
100     RETURN                                                                  CHGB0930
        END                                                                     CHGB0940
```

Subroutine: CONP33

Purpose: To convert a 6-vector to a symmetric 3 x 3 and output the result so as to describe the initial P covariance matrix.

Calling Sequence:

CALL CONP33 (PI, PD)

Input and Output

I/Ø	Symbolic Name or Location	Program Dimensions	Math Symbol	Data Dimensions or Units	Definition
I	PI	7			Input 6-vector PI(2) - PI(7) PI(1) is ignored.
Ø	PD	3,3			Output 3x3 matrix such that PD(1,1) = PI(2) PD(2,2) = PI(3) PD(3,3) = PI(4) PD(1,2) = PD(2,1) = PI(5) PD(1,3) = PD(3,1) = PI(6) PD(2,3) = PD(3,2) = PI(7)

Common storages used: None

Subroutines required: None

```
$IBFTC MC1333  NOREF,M94,NODD,XR3
CMC1333  CONP33  LOADS PI(2 TO 7) INTO APPROP PD(3,3)                    CP330010
      SUBROUTINE CONP33(PI,PD)                                           CP330020
      DIMENSION PI(7),  PD(3,3)                                          CP330030
      DO 1 I=1,3                                                         CP330040
1     PD(I,I)=PI(I+1)                                                    CP330050
      K=4                                                                CP330060
      DO 2 I=1,2                                                         CP330070
      KK=I+1                                                             CP330080
      DO 2 J=KK,3                                                        CP330090
      K=K+1                                                              CP330100
      PD(I,J)=PI(K)                                                      CP330110
2     PD(J,I)=PI(K)                                                      CP330120
      WRITE (6,100) ((PD(I,J),J=I,3),I=1,3)                              CP330130
100   FORMAT(1H0,50X,15H P MATRIX INPUT/30X,3E20.8/50X,2E20.8/70X,E20.8)CP330140
      RETURN                                                             CP330150
       END                                                               CP330160
```

Subroutine: NORMP

Purpose: To output the normalized P covariance matrix. NORMP is similar to LOUT with two exceptions: 1. the basic P matrix is a 3 by 3 rather than a 6 by 6, as required by the EBTLB* program, and 2. the diagonal terms contain the standard deviations rather than 1.0. .

Calling Sequence: CALL NORMP(P, NR, NC, KPP)

Input and Output

I/Ø	Symbolic Name or Location	Program Dimensions	Math Symbol	Data Dimensions or Units	Definition
I	P	NR, NC			Covariance matrix.
I	NR				Number of rows of P.
I	NC				Number of columns of P.
Ø	KPP				KPP = -1, normal KPP = 1, negative element on diagonal of P matrix. KPP = 2 , off diagonal of normalized P greater than 1.

Common storages used: /WCOM/IW(550),CW(1450)

Subroutines required: None

*EBTLB stands for Earth-based tracking of a lunar beacon.

```
$IBFTC MC13NM  NOREF,M94,NODD,XR3                                              NRMP0010
CMC13NM  NORMP  OUTPUTS NORMALIZED EXTENDED P MATRIX                          NRMP0011
      SUBROUTINE NORMP(P,NR,NC,KPP)                                            NRMP0012
      COMMON/INPCOM/C(700)/WCOM/IW(550),CW(1450)                               NRMP0013
      DIMENSION   P(NR,NC),   PUV(100),   MPO(100),   D(103)                   NRMP0014
     1,            B(3),     PD(3,3),     BN(3)                               NRMP0015
      EQUIVALENCE   (IW(76),MPO),   (CW(26),PD),  (CW( 62),PUV)                NRMP0016
      DATA (BN(I),I=1,3)/2H N,2H E,2H D/                                       NRMP0017
      KPP = -1                                                                 NRMP0018
      WRITE (   6,701) BN                                                      NRMP0019
701   FORMAT(1H0,49X,20H NORMALIZED P MATRIX/1H ,39X,A2,2(17X,A2))             NRMP0020
      DO 2 I=1,3                                                               NRMP0021
      IF(P(I,I).LT.0.) KPP=1                                                   NRMP0022
      D(I)=SQRT(P(I,I))                                                        NRMP0023
2     PD(I,I) = D(I)                                                           NRMP0024
      DO 3 I=2,3                                                               NRMP0025
      K=I-1                                                                    NRMP0026
      DO 3 J=I,3                                                               NRMP0027
      PD(K,J)=P(K,J)/(D(K)*D(J))                                               NRMP0028
3     IF (ABS(PD(K,J)).GT.1.) KPP=2                                            NRMP0029
      WRITE (   6,702) (BN(I),(PD(I,J),J=I,3),I=1,3)                           NRMP0030
702   FORMAT(1H ,27X,A2,3E19.8/1H ,27X,A2,19X,2E19.8/1H ,27X,A2,38X,E19.       NRMP0031
     18)                                                                       NRMP0032
      IF(NR.EQ.3) GO TO 5                                                      NRMP0033
      DO 4 I=4,NR                                                              NRMP0034
      IF(P(I,I).LT.0.)KPP =1                                                   NRMP0035
4     D(I) = SQRT(P(I,I))                                                      NRMP0036
5     CONTINUE                                                                 NRMP0037
      IF(NR.EQ.NC) GO TO 7                                                     NRMP0038
      KK = NR+1                                                                NRMP0039
      DO 6 I=KK,NC                                                             NRMP0040
      JJ = I-NR                                                                NRMP0041
6     D(I) = SQRT(PUV(JJ))                                                     NRMP0042
7     CONTINUE                                                                 NRMP0043
      IF(NC.EQ.3) GO TO 20                                                     NRMP0044
      DO 9 I=4,NC                                                              NRMP0045
      KQ=I-3                                                                   NRMP0046
      DO 8 J=1,3                                                               NRMP0047
      B(J)=P(J,I)/(D(J)*D(I))                                                  NRMP0048
      IF(ABS(B(J)).GT.1.)  KPP=2                                               NRMP0049
8     CONTINUE                                                                 NRMP0050
      WRITE (   6,703) MPO(KQ),B                                               NRMP0051
703   FORMAT(1H ,25X,I4,3E19.8)                                                NRMP0052
9     CONTINUE                                                                 NRMP0053
      K=3                                                                      NRMP0054
10    IF(NR.LE.K) GO TO 20                                                     NRMP0055
      KK=NR-K                                                                  NRMP0056
      JJ=3                                                                     NRMP0057
      IF(KK.LT.3) JJ=KK                                                        NRMP0058
      DO 12 I=1,JJ                                                             NRMP0059
      L=K+I                                                                    NRMP0060
      DO 11 J=1,I
```

```
      M=K+J                                                              NRMP0061
      PD(I,J)=P(L,M)/(D(L)*D(M))                                         NRMP0062
      IF(ABS(PD(I,J)).GT.1.000001) KPP=2                                 NRMP0063
11    CONTINUE                                                           NRMP0064
      PD(I,I)=D(L)                                                       NRMP0065
12    CONTINUE                                                           NRMP0066
      KK=L-JJ+1                                                          NRMP0067
      KKJ=KK-3                                                           NRMP0068
      LLJ=L-3                                                            NRMP0069
      WRITE(   6,704) (MPO(I),I=KKJ,LLJ)                                 NRMP0070
704   FORMAT(1H0,49X,20HDETERMINISTIC ERRORS/1H ,36X,I4,2(15X,I4))       NRMP0071
      KK=KK-1                                                            NRMP0072
      DO 15 I=1,JJ                                                       NRMP0073
      KJ=KK+I                                                            NRMP0074
      KKJ=KJ-3                                                           NRMP0075
15    WRITE (   6,703) MPO(KKJ),(PD(I,J),J=1,I)                          NRMP0076
      IF(NC.EQ.KJ) GO TO 20                                              NRMP0077
      KJ=KJ+1                                                            NRMP0078
      DO 17 I=KJ,NC                                                      NRMP0079
      KQ=I-3                                                             NRMP0080
      DO 16 J=1,JJ                                                       NRMP0081
      L=KK+J                                                             NRMP0082
      B(J)=P(L,I)/(D(L)*D(I))                                            NRMP0083
      IF(ABS(B(J)).GT.1.) KPP=2                                          NRMP0084
16    CONTINUE                                                           NRMP0085
      WRITE (   6,703) MPO(KQ),(B(J),J=1,JJ)                             NRMP0086
17    CONTINUE                                                           NRMP0087
      K=K+JJ                                                             NRMP0088
      GO TO 10                                                           NRMP0089
20    CONTINUE                                                           NRMP0090
      IF(NR.EQ.NC) GO TO 22                                              NRMP0091
      L=NR-2                                                             NRMP0092
      M=NC-3                                                             NRMP0093
      I=0                                                                NRMP0094
      DO 21 J=L,M                                                        NRMP0095
      I=I+1                                                              NRMP0096
21    D(J)=SQRT(PUV(I))                                                  NRMP0097
      WRITE (   6,705)                                                   NRMP0098
705   FORMAT(1H0,45X,36HSTD. DEV. OF UNSOLVED FOR PARAMETERS)            NRMP0099
      WRITE(   6,706) (MPO(I),D(I),I=L,M)                                NRMP0100
706   FORMAT(I30,E15.7,I4,E15.7,I4,E15.7)                                NRMP0101
22    IF(KPP.LT.0) GO TO 31                                              NRMP0102
      WRITE (   6,707) KPP                                               NRMP0103
707   FORMAT(21H0EXECUTION TERMINATED/1H ,I1,1X,27H TYPE PROBLEM WITH P  NRMP0104
     1MATRIX)                                                            NRMP0105
31    CONTINUE                                                           NRMP0106
      RETURN                                                             NRMP0107
      END                                                                NRMP0108
```

```
$IBFTC MC13BO  NOREF,M94,NODD,XR3
CMC13BO  OUTB  OUTPUT ROUTINE FOR EARTH-BASED TRACK OF LUNAR BEACONS     OUTB0010
      SUBROUTINE OUTB(P,NR ,NC )                                        OUTB0020
      COMMON/INPCOM/C(700)/WCOM/Iw(550),Cw(1450)                        OUTB0030
      DIMENSION  P(NR,NC),    A(6),      ICAS(3),  BODC(10,6),     B(6) OUTB0040
     1,          XIN(6),      ARMS(26), MPO(100)                       OUTB0050
      EQUIVALENCE  (C(11),BODC)                                         OUTB0060
      EQUIVALENCE  (Iw(76),MPO),        (Iw(377),ICAS)                  OUTB0070
     1,            (Cw(53),XIN),(Cw(1140),TSEC)                       OUTB0080
      DATA (B(I),I=1,6)/2H X,2H Y,2H Z,2HXD,2HYD,2HZD/                  OUTB0090
700   FORMAT(//1H0,6A6,55X,4HCASE,I3,2X,4HREC.,I5,2X,5HEVENT,I2)        OUTB0100
701   FORMAT(1H ,A6,24H CENTERED, TRUE EEDATE  )                        OUTB0110
702   FORMAT(6(2X,A2,1X,E15.8))                                         OUTB0120
703   FORMAT(1H ,37X,18HCURRENT RMS VALUES)                             OUTB0130
704   FORMAT(1H ,26X,38HCURRENT 3X3 P COVARIANCE MATRIX, N-E-D/(32X,3E20OUTB0140
     1.8))                                                              OUTB0150
705   FORMAT(6(1X,I4,1H=,E14.7))                                        OUTB0160
      CALL TIMES(TSEC,D,A)                                              OUTB0170
      WRITE (6   ,700) A,ICAS                                           OUTB0180
      WRITE(6,701) BODC(1,1)                                            OUTB0190
      WRITE (6   ,702) (B(I),XIN(I),I=1,6)                              OUTB0200
      WRITE (6,704)  ((P(I,J),J=1,3),I=1,3)                             OUTB0210
      K=NR-3                                                            OUTB0220
      IF(K.EQ.0) GO TO 3                                                OUTB0230
      WRITE (6   ,703)                                                  OUTB0240
      DO 2 I=4,NR                                                       OUTB0250
      N=I-3                                                             OUTB0260
2     ARMS(N)=SQRT(P(I,I))                                              OUTB0270
      WRITE (6   ,705)           (MPO(I),ARMS(I),I=1,K)                 OUTB0280
3     CONTINUE                                                          OUTB0290
      RETURN                                                            OUTB0300
       END                                                              OUTB0310
```

Subroutine: OUTB

Purpose: To write the output required during execution of the EBTLB program. Output includes earth centered cartesian coordinates of the Lunar beacon, true equator-equinox of date, the 3 x 3 P covariance matrix of beacon location uncertainties N-E-D, and the square roots of the diagonal elements of solved for parameters. This output is at regular output points and other critical event times.

Calling Sequence: CALL OUTB(P,NR,NC)

Input and Output

I/Ø	Symbolic Name or Location	Program Dimensions	Math Symbol	Data Dimensions or Units	Definition
I	P	NR,NC			Covariance matrix.
I	NR				Number of rows of P.
I	NC				Number of columns of P.

Common storages used: INPCØM/C(700)/WCØM/IW(550),CW(1450)

Subroutines required: TIMES

Subroutine: SBEVB

Purpose: SBEVB creates a chronologically ordered array of those times when the lunar beacon comes into view and goes out of view of earth-based tracking stations. This subroutine is specifically designed for the EBTLB* program. It is similar to SBEV with these exceptions: SBEVB considers occulting by earth only, is concerned with earth-based tracking stations only, and looks for one lunar beacon thereby requiring subroutine BEAK rather than the trajectory subroutine PCON.

Calling Sequence: CALL SBEVB(TI,TIM,ISS,SECR,ISEE,ISTIM,STIME,MB)

Input and Output

I/Ø	Symbolic Name or Location	Program Dimensions	Math Symbol	Data Dimensions or Units	Definition
I	TI	2		Days	Date in whole and fractional days from 1950.0.
I	TIM	2		Seconds	Minimum and maximum times (from epoch) of interest defining interval of investigation.
I	ISS	12			Numbers of stations or beacons to be considered. ISS(J) = 0 terminates list of numbers.
Ø	SECR	12		Seconds	Time (from epoch) to make observations for stations given in corresponding ISS.
Ø	ISEE	12			In view indicator for station given in corresponding ISS. Set -1 out of view, 0 in view.
Ø	ISTIM	50			Event indicator, in conjunction with STIME times. +, station into view -1, station out of view
Ø	STIME	50		Seconds	Ordered array of times (from epoch) at which ISTIM critical events occur.
Ø	MB				KKK = total number of critical events times STIME computed.

Common storages used: INPCOM/C(700)/WCOM/IW(550),CW(1450)

Subroutines required: BEAK,CRITO,PARAB,QUARTC,SORDR,STAT,TFRAC,VTRN,VTRT

* EBTLB: Earth-based tracking of a lunar beacon.

COMMON

HEAD	LOCATION	PROGRAM NAME	DIMENSION	DESCRIPTION
INPCOM	C(7)	RSPMSD		Reciprocal seconds per mean solar day = 1/86400.
	C(10)	DELTX		SBEVB step size in seconds (set to 3600. or 1 hour by Block Data).
	C(11) to C(90)	BODC(I,J)	10,8	J^{th} body constant for body number I. (Refer to BLOCK DATA/INPCOM/ description).
	C(200) to C(475)	S(I,J)	23,12	I data item for station number J.
WCOM	CW(1) to CW(3)	BECRK	3	Selenographic coordinates of the lunar beacon, latitude and longitude in radians, altitude in Km.

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$IBFTC MC13EB  NOREF,M94,NODD,XR3                                              SBVB0010
CMC13EB  SBEVB  FOR EARTH BASED TRACKING OF A LUNAR BEACON                     SBVB0020
      SUBROUTINE SBEVB(TI,TIM,ISS,SECR,ISEE,ISTIM,STIME,MB)                    SBVB0030
C                                                                              SBVB0040
C     SUBROUTINES REQUIRED                                                     SBVB0050
C          BEAK       CRITO      PARAB      QUARTC     SORDR      STAT        SBVB0060
C          TFRAC      VTRN,VTRT                                               SBVB0070
C                                                                              SBVB0080
      COMMON/INPCOM/C(700)/WCOM/IW(550),CW(1450)                               SBVB0090
      DIMENSION    AA(2),     AP(3,3),    APD(3,3)                            SBVB0100
     1,            BB(2),     BECRK(3),  BODC(10,8),          BRAD(2)        SBVB0110
     2,            DUM(3),    EN(3,3),    ST(2)                              SBVB0120
     3,            IMAX(12),  ISC(12),   ISEE(12),  ISEK(12)                 SBVB0130
     4,            ISS(12),   ISTIM(50)                                      SBVB0140
     5,            R(9),      RS(3),      RT(3)                              SBVB0150
     6,            S(23,12),  SC(5),      SECR(12),  STIME(50),STOR(3,12)    SBVB0160
     7,            TDUM(3),   TI(2),      TIM(2),    TST(3)                  SBVB0170
     8,            XX(9)                                                     SBVB0180
      EQUIVALENCE  (C(7),RSPMSD), (C(10),DELTX), (C(11),BODC)                  SBVB0190
     1,            (C(200),S)                                                SBVB0200
      EQUIVALENCE  (CW(1),BECRK)                                               SBVB0210
      TW=TI(1)                                                                 SBVB0220
      TF=TI(2)                                                                 SBVB0230
      TSECO=TIM(1)                                                             SBVB0240
      NN=-2                                                                    SBVB0250
      TSTP=TSECO                                                               SBVB0260
      TSEC=TSECO                                                               SBVB0270
      FLTIM=TIM(2)                                                             SBVB0280
      DELTY=(FLTIM - TSECO)/3.3                                                SBVB0290
      IF(DELTY.GT.DELTX) DELTY=DELTX                                           SBVB0300
      DO 3 I=1,12                                                              SBVB0310
      IF(ISS(I)) 4,4,2                                                         SBVB0320
2     ISC(I)=ISS(I)                                                            SBVB0330
3     CONTINUE                                                                 SBVB0340
      I=13                                                                     SBVB0350
4     NKK=I-1                                                                  SBVB0360
      DO 17 I=1,NKK                                                            SBVB0370
17    IMAX(I)=1                                                                SBVB0380
      BRAD(1)=BODC(1,3)                                                        SBVB0390
      BRAD(2)=BODC(1,4)                                                        SBVB0400
      KKK=0                                                                    SBVB0410
      NHEAD=1                                                                  SBVB0420
10    CONTINUE                                                                 SBVB0430
      TDELT=(TSTP-TSEC)*RSPMSD                                                 SBVB0440
      CALL TFRAC(TW,TF,TDELT)                                                  SBVB0450
      CALL BEAK(TW,TF,BECRK, R,GHAN,OMGM,AP,APD)                               SBVB0460
      TSEC=TSTP                                                                SBVB0470
      TSTP=TSTP+DELTY                                                          SBVB0480
      NN=NN+1                                                                  SBVB0490
      TST(3)=TST(2)                                                            SBVB0500
      TST(2)=TST(1)                                                            SBVB0510
      TST(1)=TSEC                                                              SBVB0520
      DO 80 II=1,NKK
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      NST=ISC(II)                                                        SBVB0530
      IF(NST) 80,80,21                                                   SBVB0540
21    CONTINUE                                                           SBVB0550
      CALL STAT(S(3,NST),GHAN,EN,RT,SC,BRAD)                             SBVB0560
      DO 22 I=1,3                                                        SBVB0570
22    RT(I)=R(I)-RT(I)                                                   SBVB0580
      CALL VTRT(EN,RT,RS)                                                SBVB0590
      EL=ATAN(-RS(3)/SQRT(RS(1)*RS(1)+RS(2)*RS(2)))-S(6,NST)             SBVB0600
      STOR(3,II)=STOR(2,II)                                              SBVB0610
      STOR(2,II)=STOR(1,II)                                              SBVB0620
      STOR(1,II)=EL                                                      SBVB0630
      IF(NN) 25,80,40                                                    SBVB0640
25    IF(EL) 29,29,28                                                    SBVB0650
29    CONTINUE                                                           SBVB0660
      ISEK(II)=1                                                         SBVB0670
      GO TO 30                                                           SBVB0680
28    CONTINUE                                                           SBVB0690
      ISEK(II)=2                                                         SBVB0700
      IF(EL.GT.S(7,NST)-S(6,NST))GO TO 296                               SBVB0710
      ISEE(II)=0                                                         SBVB0720
      SECR(II)=TSEC                                                      SBVB0730
      KSW=2                                                              SBVB0740
      GO TO 31                                                           SBVB0750
296   IMAX(II)=2                                                         SBVB0760
30    CONTINUE                                                           SBVB0770
      ISEE(II)=-1                                                        SBVB0780
      KSW=1                                                              SBVB0790
31    CONTINUE                                                           SBVB0800
      EL=EL+S(6,NST)                                                     SBVB0810
      CALL CRITO(TST(1),S(1,NST),KSW,RS,EL,6,NHEAD)                      SBVB0820
      GO TO 80                                                           SBVB0830
40    CONTINUE                                                           SBVB0840
      CALL PARAB(TST,STOR(1,II),AA)                                      SBVB0850
      AD=0.                                                              SBVB0860
      JJ=ISEK(II)                                                        SBVB0870
      KSAV=IMAX(II)                                                      SBVB0880
      IF(JJ.EQ.2) AD=S(7,NST)-S(6,NST)                                   SBVB0890
41    CONTINUE                                                           SBVB0900
      CALL QUARTC(STOR(2,II),AD,AA,DT,KK)                                SBVB0910
      IF(KK) 42,44,44                                                    SBVB0920
42    CONTINUE                                                           SBVB0930
      IF(JJ+KSAV.EQ.3) GO TO 43                                          SBVB0940
      IF(JJ.EQ.3.AND.AA(1).GT.0.) JJ=2                                   SBVB0950
      GO TO 79                                                           SBVB0960
43    JJ=3                                                               SBVB0970
      AD=0.                                                              SBVB0980
      GO TO 41                                                           SBVB0990
44    CONTINUE                                                           SBVB1000
      GO TO(445,440,445),JJ                                              SBVB1010
440   IF(STOR(2,II).LT.0..AND.KSAV.EQ.1) GO TO 43                        SBVB1020
445   CONTINUE                                                           SBVB1030
      DELT=TST(2)-TST(3)                                                 SBVB1040
      DTEST=DT(2)                                                        SBVB1050
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      IF(JJ+KSAV.EQ.4) DTEST=DT(1)                                      SBVB1060
      IF(DTEST) 45,45,79                                                SBVB1070
45    CONTINUE                                                          SBVB1080
      IF(DELT+DTEST.LT.0.) GO TO 42                                     SBVB1090
      IF(JJ.EQ.2) DSAV=DT(1)                                            SBVB1100
48    CONTINUE                                                          SBVB1110
      DUM(1)=STOR(2,II)                                                 SBVB1120
      DUM(3)=STOR(3,II)                                                 SBVB1130
      TDUM(1)=TST(2)- TST(1)                                            SBVB1140
      TDUM(2)=TDUM(1) + DTEST                                           SBVB1150
      TDUM(3)=TST(3)- TST(1)                                            SBVB1160
      NJAZ=1                                                            SBVB1170
49    CONTINUE                                                          SBVB1180
      NJAZ=NJAZ+1                                                       SBVB1190
      TDELT=TDUM(2)*RSPMSD                                              SBVB1200
      CALL TFRAC(TW,TF,TWX,TFX,TDELT)                                   SBVB1210
      CALL BEAK(TWX,TFX,BECRK,XX,GHAM,OMGM,AP,APD)                      SBVB1220
      CALL STAT(S(3,NST),GHAM,EN,RT,SC,BRAD)                            SBVB1230
      DO 54 I=1,3                                                       SBVB1240
54    RT(I)=XX(I)-RT(I)                                                 SBVB1250
      CALL VTRT(EN,RT,RS)                                               SBVB1260
      EL=ATAN(-RS(3)/SQRT(RS(1)*RS(1)+RS(2)*RS(2)))-S(6,NST)            SBVB1270
      CON=.002                                                          SBVB1280
      IF(ABS(EL-AD)-CON) 61,56,56                                       SBVB1290
56    CONTINUE                                                          SBVB1300
      IF(NJAZ.GT.10) GO TO 61                                           SBVB1310
      DUM(2)=EL                                                         SBVB1320
      CALLPARAB(TDUM,DUM,BB)                                            SBVB1330
      CALL QUARTC(DUM(2),AD,BB,DT,KK)                                   SBVB1340
      IF(KK) 42,57,57                                                   SBVB1350
57    CONTINUE                                                          SBVB1360
      DTEST=DT(2)                                                       SBVB1370
      IF(JJ+KSAV.EQ.4) DTEST=DT(1)                                      SBVB1380
      K=1                                                               SBVB1390
      IF(DTEST.GT.0.) K=3                                               SBVB1400
      DUM(K)=DUM(2)                                                     SBVB1410
      TDUM(K)=TDUM(2)                                                   SBVB1420
      TDUM(2)=TDUM(2)+DTEST                                             SBVB1430
      GO TO 49                                                          SBVB1440
61    CONTINUE                                                          SBVB1450
      KKK=KKK+1                                                         SBVB1460
      STIME(KKK)=TST(1)+TDUM(2)                                         SBVB1470
      GO TO(62,65,68),JJ                                                SBVB1480
62    CONTINUE                                                          SBVB1490
      ISTIM(KKK) = II                                                   SBVB1500
      EL=EL+S(6,NST)                                                    SBVB1510
      CALL CRITO(STIME(KKK),S(1,NST),2,RS,EL,6,NHEAD)                   SBVB1520
      JJ=2                                                              SBVB1530
      IF(AA(2).GT.0.) GO TO 79                                          SBVB1540
      AD=S(7,NST)-S(6,NST)                                              SBVB1550
      GO TO 41                                                          SBVB1560
65    CONTINUE                                                          SBVB1570
      GO TO(66,75),KSAV                                                 SBVB1580
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66    ISTIM(KKK)=-II                                                          SBVB1590
      EL=EL+S(6,NST)                                                          SBVB1600
      CALL CRITO(STIME(KKK),S(1,NST),1,RS,EL,6,NHEAD)                         SBVB1610
      KSAV=2                                                                  SBVB1620
      IF(TST(2)+DSAV.LE.TDUM(2)+TST(1).OR.TST(2)+DSAV.GT.TST(1))GO TO 79      SBVB1630
      IF(DSAV.GT.0.) GO TO 67                                                 SBVB1640
      DTEST=DSAV                                                              SBVB1650
      GO TO 48                                                                SBVB1660
67    CONTINUE                                                                SBVB1670
      DUM(1)=STOR(1,II)                                                       SBVB1680
      DUM(3)=STOR(2,II)                                                       SBVB1690
      TDUM(1)=0.                                                              SBVB1700
      TDUM(3)=TST(2)-TST(1)                                                   SBVB1710
      TDUM(2)=TDUM(3)+DSAV                                                    SBVB1720
      GO TO 49                                                                SBVB1730
68    CONTINUE                                                                SBVB1740
      ISTIM(KKK)= -II                                                         SBVB1750
      EL=EL+S(6,NST)                                                          SBVB1760
      CALL CRITO(STIME(KKK),S(1,NST),1,RS,EL,6,NHEAD)                         SBVB1770
      JJ=1                                                                    SBVB1780
      IF(AA(2)) 79,79,41                                                      SBVB1790
75    CONTINUE                                                                SBVB1800
      KSAV=1                                                                  SBVB1810
      ISTIM(KKK) = II                                                         SBVB1820
      EL=EL+S(6,NST)                                                          SBVB1830
      CALL CRITO(STIME(KKK),S(1,NST),2,RS,EL,6,NHEAD)                         SBVB1840
      JJ=3                                                                    SBVB1850
      AD=0.                                                                   SBVB1860
      GO TO 41                                                                SBVB1870
79    CONTINUE                                                                SBVB1880
      ISEK(II)=JJ                                                             SBVB1890
      IMAX(II)=KSAV                                                           SBVB1900
80    CONTINUE                                                                SBVB1910
      IF(NN) 10,10,81                                                         SBVB1920
81    IF(TST(2).GE.FLTIM) GO TO 82                                            SBVB1930
      IF(KKK-38) 10,83,83                                                     SBVB1940
82    KKK=KKK+1                                                               SBVB1950
      STIME(KKK)=FLTIM + 99999.                                               SBVB1960
83    CONTINUE                                                                SBVB1970
      MB=KKK                                                                  SBVB1980
      CALL SORDR(STIME,ISTIM,KKK)                                             SBVB1990
      RETURN                                                                  SBVB2000
      END                                                                     SBVB2010
```

REFERENCES

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