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BTS-FR-82-181

MARCH 1982

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USER'S GUIDE FOR THE  
PRECISION RECURSIVE ESTIMATOR FOR  
EPHEMERIS REFINEMENT (PREFER)

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(NASA-CR-170506) USER'S GUIDE FOR THE  
PRECISION RECURSIVE ESTIMATOR FOR EPHEMERIS  
REFINEMENT (PREFER) (Business and  
Technological Systems, Inc.) 141 p  
HC A07/MF A01

CSSL 09B G3/61

Unclas  
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## 1.0 INTRODUCTION

PREFER is a recursive orbit determination program which is used to refine the ephemerides produced by a batch least squares program (e.g., GTDS). It is intended to be used primarily with GTDS and, thus, is compatible with some of the GTDS input/output files.

The input to PREFER consists of five disk (or tape) files and the card input. The satellite Orbit File contains the nominal satellite ephemerides and the state transition matrix as generated by GTDS. The ephemerides on this file should be accurate to within approximately 50 meters (to minimize linearization errors). PREFER interpolates from this file at the times given on the Measurement Data File. It processes these measurements in a Kalman filter to estimate the corrections to the nominal trajectory. The filter state also includes other parameters which have an effect upon the orbit determination (e.g., drag, perturbing gravitational accelerations, thrust, measurement biases and refraction parameters, etc.).

The measurement data types which PREFER can process include ground range and range rate measurements, TDRS relay measurements (range and range rate), GPSPAC pseudo range and pseudo delta-range measurements, NAVPAC range difference measurements and altimeter measurements. Processing of the ground measurements requires that earth motion be accurately modeled. The Solar/Lunar/Planetary (SLP) File supplies the data which is used in the true of date to 1950 coordinate transformations while a Time Coefficients File supplies data used for time system transformations and polar motion. A GPS Trajectory File supplies the ephemerides of the GPS satellites which are required to process the GPSPAC or NAVPAC measurements. TDRS ORBIT Files supply the required TDRS ephemerides.

After running the Kalman filter forward to the end of the Measurement Data File, PREFER performs optimal smoothing. A file created by the Kalman filter is read backward in time and the smoothed estimates are obtained by using the recursive formulation of Rauch-Tun-Streibel.

The combination of a Kalman filter and a smoother should result in greatly improved estimates of satellite ephemerides as compared to batch estimation. Batch estimation is subject to errors because of errors in the dynamic models (e.g., gravitational). A filter/smoothing which properly accounts for dynamic (state) noise should weight the data optimally and reduce the estimation errors. Smoothing will produce better estimates (in the middle of the data span) than just a forward filter because past and future data is used to estimate the state at each point in time (a filter uses only past data). Smoothing also tends to average out any dynamic modeling errors which remain.

It is suggested that the user carefully read Section 3.1 of this guide and the PREFER Mathematical Description before attempting to use the program. An understanding of the dynamic models and correct choice of state noise are essential to proper functioning of the program.

PREFER requires about 370K (base 10) bytes of storage on the IBM 360/95 for a run using only ground tracking. Since the core storage is dynamic, runs using TDRS or GPS tracking may require as much as 500K. Execution time will also vary drastically depending upon the data span and the number of adjusted parameters. It is expected that a one day solution containing 2200 measurements processed in 120 sec "mini-batches" will take less than 2 minutes of 360/95 CPU time and 5 minutes of I/O time. Approximately 60% of the CPU time is spent in filtering. The I/O charge will almost double when the option to output the smoothed covariance is used.

## 2.0 INPUT FILES

The following sections describe the PREFER input files mentioned in the introduction.

### 2.1 Satellite ORBIT File (Unit 50)

The satellite ORBIT File is generated by GTDS on unit 21. This file contains the ephemerides and matrix sums used to compute the state transition matrix (partials of current cartesian elements with respect to epoch elements) of the satellite. Although the file may contain partials with respect to many parameters, PREFER only uses the 6x6 matrix corresponding to the epoch orbital elements.

The ORBIT file consists of three types of records: two header records and the data records. The file is written on a tape (1600 BPI) using a record format of VS, a logical record length of 6664 bytes and a block size of 6668 bytes. The format of the individual records is given on the following pages.



RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
1	6660 bytes	1-8	SATNAM: Satellite name in EBCDIC
		9-16	AREA: Area of satellite (km <sup>2</sup> )
		17-24	SCMASS: Mass of satellite (kg)
		25-32	CSUBR: Satellite reflectivity constant
		33-40	CSUBDZ: Drag coefficient
		41-48	YMDOUT: YYMMDD. of start date
		49-56	HMSOUT: HHMMSS.SSSS of start date
		57-64	YMDFN: YYMMDD. of end date
		65-72	HMSFN: HHMMSS.SSSS of end date
		73-80	YMDIC: YYMMDD. of epoch date
		81-88	HMSIC: HHMMSS.SSSS of epoch date
		89-96	YMDREF: YYMMDD. of reference line for time coordinate system
		97-104	EGHA: Greenwich hour angle at epoch (rad)
		105-112	EJED: Julian ephemeris date of epoch
		113-160	AEINT(K): K=1,6 Keplerian elements in coordinate system of integration
161-208	SPINT(L): K=1,6 Spherical elements in coordinate system of integration		
209-256	PVINT(K): K=1,6 Position and velocity of satellite of integration		

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
1	6660 bytes	257-368	<b>OBLINT(L):</b> L=1,14 Auxiliary orbital elements in coordinate system of integration:  L=1, Eccentric anomaly 2, Period 3, Time derivative of period 4, Mean motion 5, True anomaly 6, Perifocal height 7, Apofocal height 8, Time derivative of argument of perigee 9, Time derivative of ascending node 10, Velocity at apogee 11, Velocity at perigee 12, Latitude 13, Longitude 14, Height
		369-376	<b>OBSYMD:</b> YYMMDD. of start of fitted data span for element set
		377-384	<b>OBSHMS:</b> HHMMSS.SSSS of start fitted span for element set
		385-392	<b>OBEYMD:</b> YYMMDD. of end of fitted data span for element
		393-400	<b>OBEHMS:</b> HHMMSS.SSSS of end of fitted data span for element set
		401-408	<b>WRMS:</b> Weighted RMS of fit for element set
		409-576	<b>COVMAT(I):</b> I=1,21 Upper triangle of state covariance matrix
		577-584	<b>AZERO:</b> Difference between A.1 time and UTC at epoch
		585-592	<b>TZER01:</b> Time from beginning of year in seconds
		593-600	<b>DEPOCH:</b> Julian date of epoch (A.1 system)

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
1	6660 bytes	601-608	SPARE Spare location
		609-612	IDSAT: Satellite number
		613-616	NBRRUN: Run number
		617-620	NBRELS: Element set number
		621-624	I50: Inertial coordinate system reference indicator. 1=1950, 2=TOD
		625-1024	INDSEC (I,J): I=1,20; J=1,5 Force model indicators
		1025-1048	MCDWF(K): K=1,6 Model identifiers
		1049-1052	NBROBS: Number of observations in fitted data span for elements sets
		1053-1056	NSTATE: Number of state partials
		1057-1080	KSTATE(K): K=1,6 Label numbers of state unknowns
		1081-1084	IPART: Partial indicator =1 partials on data record =2 no partials on data record
		1085-1088	ICENT Central body indicator
		1089-1092	IND(1) Orbit generator indicator = 1, time-regularized_Cowell orbit generator = 2, Cowell orbit generator
		1093-6660	Spare
2	6660 bytes	1-8	DTIM Dummy time word for internal retrieval use ( $\pm 99999999.0$ )
		9-16	ZERO Zero word for internal retrieval use
		17-104	GM(I): I = 1,11 Gravitational constant times the mass of body ( $\text{km}^3/\text{sec}^2$ )

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
2	6660 bytes	105-144	SECMOD(36,I): I = 1,5 Time regularized exponent of satellite radius for Section I
		145-384	COEF1(I,J): I = 1,10; J = 1,3 Time conversion coefficients; I indicates date interval
		385-408	SAE(I): I = 1,3 Drag coefficient times area of spacecraft surfaces I = 1, sphere or end of cylinder I = 2, sides of cylinder I = 3, paddles
		409-608	SPARE Spare locations
		609-612	IND(40) State partials indicator 1 = yes, 2 = no
		613-616	IND(41) Drag partials indicator 1 = yes, 2 = no
		617-620	IND(42) Solar radiation partials indicator 1 = yes, 2 = no
		621-624	IND(43) Potential partials indicator 1 = yes, 2 = no
		625-628	IND(44) Thrust partials indicator 1 = yes, 2 = no
		629-632	NTAB Time conversion table index
		633-672	JARG1(I): I = 1,10 Julian dates which define date intervals for time conversion
		673-676	KONFIG S/C configuration switch 0 = spherical 1 = cylindrical 2 = cylindrical with paddles
677-680	NEQ Number of variational equations to be integrated		

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
2	6660 bytes	681-684	NCNM Number of $C_{N,M}$ to be estimated
		685-688	NSNM Number of $S_{N,M}$ to be estimated
		689-768	NDEG(I): I = 1,20 N indices (for $C_{N,M}$ and $S_{N,M}$ )
		769-848	MORD(I): I = 1,20 M indices (for $C_{N,M}$ and $S_{N,M}$ )
		849-868	INDY(I): I = 1,5 I = 1, array location for drag partials in the integrator I = 2, array location for drag radiation partials in the integrator I = 3, array location for drag potential partials in the integrator  I=4, array location for thrust partials in the integrator 5, spare
		869-872	IND(39) Transformation Partials required 1 = Partial of state with respect to initial state elements 2 = Partial of state with respect to Keplerian state elements 3 = Partial of state with respect to spherical state elements 4 = Partial of state with respect to DODS state elements
		873-6660	SPARES

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
All others	6660 bytes	1-8	TN: Time (from epoch in seconds) of last acceleration in XDD
		9-16	H: Integrator stepsize, in seconds
		17-280	XDD(I,J): I=K-10,K; J=1,3 Satellite acceleration vectors K = acceleration array indicator
		281-368	TREG(I): I=K-10,K Time corresponding to acceleration array
		369-392	SX1(I): I=1,3 First sum vector of satellite acceleration
		393-416	SX2(I): I=1,3 Second sum vector of satellite acceleration
		417-5696	XVDD(J1,J2,J3): J1=K-10,K; J2=1,3; J3=1,20 Array of acceleration partials K = acceleration array indicator
		5697-6176	SV1(I,J): I=1,3; J=1,20 1st sum matrices for acceleration partials
		6177-6656	SV2(I,J): I=1,3; J=1,20 2nd sum matrices for acceleration partials
		6657-6660	NSECTN Current section number

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2.2 GPS Trajectory File (Unit 40)

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The GPS Trajectory File contains the positions and velocities (in ECI) of the GPS satellites. The number of satellites on the file is given on the header record and may vary from 1 to 24.

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
1	180 bytes	1-4	NB: Record Number = 1
		5-12	YEAR: Year of epoch of trajectory (2 digit)
		13-20	DAY: Day of epoch of trajectory
		21-28	SEC: Seconds of epoch of trajectory (UTC time)
		29-36	TVE-T0: Time of vernal equinox minus epoch of the trajectory
		37-44	DT: Interval at which trajectory is written (sec.)
		45-52	TLST: Last time on trajectory (sec. from epoch)
		53-60	STEP: Integration interval used when creating the trajectory (sec.)
		61-64	IFLOW: Kind of trajectory = 4, 5, 6 or 7 (Not Used)
		65-68	I50: Indicates if trajectory was made using epoch of date = 1 or epoch of 1950 = 0
		69-72	ICYC: Improvement cycle number (Not Used)
		73-80	DATE: Time clock value when trajectory was made (A8)
		81-84	NGPS: number of GPS satellites
		85-88	JGPS(1): Satellite number of 1st satellite (SV number)
89-92	JGPS(2): Satellite number of 2nd satellite		
.	.	.	.
177-180	.	JGPS(24): Satellite number of 24th satellite	

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.		
All others	212 to 1500	1-4	NB: Consecutive record number = 2, 3, n		
		5-12	TI: Seconds from epoch		
		13-20	X(1,1): X	} Inertial components of satellite #1 position at time TI (km)	
		21-28	X(2,1): Y		
		29-36	X(3,1): Z		
		37-44	XD(1,1): X	} Inertial components of satellite #1 velocity at time TI (km/sec.)	
		45-52	XD(2,1): Y		
		53-60	XD(3,1): Z		
		61-68	TB(1): Timing bias for satellite #1 (secs.) (TB1 = clock - truth time)		
		69-76	X(1,2): X	} Satellite #2 position	
		77-84	X(2,2): Y		
		85-92	X(3,2): Z		
		93-100	XD(1,2): X	} Satellite #2 velocity	
		101-108	XD(2,2): Y		
		109-116	XD(3,2): Z		
		117-124	TB(2): Timing bias for satellite #2		
				.	
				.	
				XD(1,NGPS): X	} Satellite # NGPS velocity
				XD(2,NGPS): Y	
		XD(3,NGPS): Z			
12+56•NGPS	TB(NGPS): Timing bias for satellite # NGPS				
		ABCD(1,1):	} Earth Centered Inertial (1950) to Earth Centered Fixed Transformation		
		ABCD(2,1):			
		.			
		ABCD(3,3):			
		ABDCD(1,1):	} Transformation of Velocities $(\dot{x}_{ECI} = (ABDCD)^T \cdot \dot{x}_{EF})$		
		ABDCD(2,1):			
		.			
156+56•NGPS		ABDCD(3,3):			



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2.3 Measurement Data File (Unit 9)

The measurement data file input to PREFER is created by GTDS as the Observation Save File (GTDS Unit 46). This file contains all the information necessary to process the observations (e.g. station positions, refraction corrections, etc.).

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
1	7200 bytes	1-4	NSET: Number of observation sets contained in data set
		5-144	IPOINT (I,J): I = 1,5; J = 1,7 Pointer array of set related information  IPOINT (1,J) = Type indicator for set J J = 1, tracking data = 2, telemetry data = 3, PCE data = 4, relay data = 5, landmark data =6 or 7, spare  IPOINT (2,J) = pointer to header record for set J IPOINT (3,J) = pointer to starting block for data from set J IPOINT (4,J) = pointer to starting record within indicated block for data from set J IPOINT (5,J) = Number of observations in set J
		145-164	IPOINT (I,8): I = 1,5 Pointer array of set related information (spare set)
		165-284	IMTYPE(I): I = 1,30 Array of external observation types to be used with input from this data set. Internal observation types 1-30 correspond with IMTYPE(1) to IMTYPE(30).

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
1	7200	285-298	Spare
		289-432	ISPRES (I): I = 2,37 Spare locations
		433-480	ISPRES (I): I = 38,49 Spare locations
		481-576	RHDR1 (I): I = 1,24 Header information for first observation set
		577-720	RHDR1 (I): I = 25,420 Header information for first observation set
		721-864	RHDR2 (I): I = 1,396 Header information for second observation set
		865-960	RHDR2 (I): I = 397,420 Header information for second observation set
		961-1008	RHDR3 (I): I = 1,12 Header information for third observation set
		1009-1152	RHDR3 (I): I = 13,408 Header information for third observation set
		1153-1200	RHDR3 (I): I = 409,420 Header information for third observation set
		1201-1296	RHDR4 (I): I = 1,24 Header information for fourth observation set
		1297-1440	RHDR4 (I): I = 25,420 Header information for fourth observation set
		1441-7200	Spare

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
2	7200	1-144	RHDR5 (I): I = 1,420 RHDR6 (I): I = 1,420 RHDR7 (I): I = 1,420 RHDR8 (I): I = 1,396 Headers for observation sets 5 through 6
		145-240	RHDR8 (I): I = 397,420 Header information for observation set 8 (continued)
		241-7200	Spare
			For a description of header information for an observation set, see data set layout for GTDS Observation Tape, FORTRAN logical unit 29[4].
			<b>*NOTE:</b> Record 2 exists in this format only if there are more than four observation sets on the file. If there are four or less, record 2 is formatted like records 3-N (data records).

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RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
ALL (data)	7200	1-8	TOBYMD: Corrected observation time tag (YYMMDD.)
		9-16	TOBHMS: Corrected observation time tag (HHMMSS.SSS)
		17-24	OM1: Uncorrected observation measurement No. 1
		25-32	Doppler Count Interval (sec.)
		33-40	SIG1: Standard deviation of data reduction fit
		41-48	OM1A: Corrected observation measurement No. 1
		49-56	IBIT(8): Validity flags
		57-64	DMR: Observation refraction correction
		65-72	TOBSC: TOBYMD and TOBHMS converted to A.1 seconds from Jan. 1,; DC closes file zero hour of epoch year
		73-80	DAMTD: Sum of antenna mount and transponder delay correction
		81-88	JBIT(8): Identification flags
		89-96	TCOR: TOBSC corrected for bias and light time (in ET seconds from epoch). <u>or</u>
			FREF: For TDRS data, primary frequency (MHz).
97-100	NOBS: Working file observation number		
101-104	IGATE: Range-Gating indicator		
105-108	MTYPE: Observation type indicator		

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
ALL (data)	7200	105-108* (TDRS Data only)	MTYPE: Packed indicator = uplink ID * 1000000. + ground transponder number * 10000. + downlink ID * 100. + MTYPE (ID is 2-digit referenced to 60 byte format)
		109-110	ISOU: Observation source indicator
		111	IBF: Doppler Bias Frequency indicator for SST data. Not used for TDRS data.
		112	IPFO: Primary Frequency Offset indicator for SST data. Not used for TDRS data.
		113-116	IEDIT: Edit flag
		117-120	IBIAS: Bias type indicator
		121-124	ISTA: Station geodetic indicator
		125-128	IUPDTE: Record update indicator <u>or</u> 100*ISTAAT +ISTAA: (TDRS only) ISTAAT = Ground transponder internal index (1, 2, 3 ...) ISTAA = Transmit station internal index (1, 2, 3 ...)
		129-132	IFGP(I): I=1,4; Flags indicating corrections made prior to GTDS/ODS processing
		133-136	WORD10: WORD 10 of 60 byte record
		137-140	IFGB(I): I=1,4; Flags indicating corrections made during GTDS/ODS processing
		141-144	WORD9: Word 9 of 60 byte record
		145-7200	49 additional observations containing duplication of bytes 1-144 definition

#### 2.4 Solar/Lunar/Planetary (SLP) (Unit 20 and 22)

There are two SLP files available to PREFER on the GSFC 360/95. One uses mean of 1950.0 coordinates (Unit 20) while the other uses true-of-date coordinates (Unit 22). PREFER automatically selects the correct file to match the satellite ORBIT file. The current names of the two SLP files are: ORBIT.GTDS.SLP1950.DATA and ORBIT.GTDS.SLPTOD.DATA.

#### 2.5 Time Coefficients File (Unit 21)

The time coefficients file contains information on the time system transformations and polar motion. The current name of the file on the GSFC 360/95 is ORBIT.GTDS.TIMCOF.DATA.

#### 2.6 TDRS ORBIT Files (Units 41, 42, 43)

When TDRS relay measurements are processed, the TDRS ephemerides are obtained from three, direct access, ORBIT files on the GSFC 360/95. The format of these files is identical to that of the Satellite ORBIT File (Unit 50) except for the difference between sequential and direct access. There is no unique relationship between the unit number (41, 42 or 43) and the individual TDRS: PREFER determines this relationship from the 7-digit satellite identifier on the header of the TDRS ORBIT files and on the TDRID cards.

It is important that the TDRS ephemeris coordinate system (1950 or true-of-date) match the coordinate system on the Satellite ORBIT file. If they do not match, the PREFER job will terminate.

PREFER does not actually use the TDRS ORBIT files when processing measurements. At the beginning of the job, PREFER Interpolates the ORBIT files (at a rate determined by the STEP card) and copies the ephemerides to a file (also on unit 40) with the same format as a GPS Trajectory file. This is the file used to process the measurements.

### 3.0 CARD INPUT

All card input to PREFER consists of 72-column keyword cards which have seven variables per card and are read using IBM's free form input (except for the keyword):

<u>Variable</u>	<u>Type</u>
1	Alphanumeric keyword (this <u>must</u> be located in columns 1-8, left justified)
2	Integer
3	Integer
4	Real
5	Real
6	Real
7	Real

The last six variables may be located anywhere in columns 9-72 since blanks or commas are used to separate the fields. The order of the variables is important and thus unused variables must still be input (a zero or a double comma is suggested). See the IBM Fortran (extended) manual for further information.

There are two general classifications for card types. Run control cards are used to input constants required for the run. Run initialization cards are used to set *a priori* standard deviations, state noise standard deviations and time constants of Markov processes. These cards also determine the parameters to be included in the state vector.

With the exception of the STEP card, any field which is blank will be read as a zero and will override the default values (if any). There are no restrictions on the order in which cards are read.

Before describing the format of the individual cards, it is necessary to discuss the dynamic models and the requirements for the card input.

### 3.1 Discussion of Models and Card Input

PREFER has the capability to solve for the following set of parameters

- 1 satellite x-position at epoch
- 2 satellite y-position at epoch
- 3 satellite z-position at epoch
- 4 satellite x-velocity at epoch
- 5 satellite y-velocity at epoch
- 6 satellite z-velocity at epoch
- 7 satellite drag coefficient
- 8 perturbing gravitational acceleration (vertical)
- 9 perturbing gravitational acceleration (cross-track)
- 10 perturbing gravitational acceleration (along-track)
- 11 acceleration of 1st thrust segment (vertical)
- 12 acceleration of 1st thrust segment (cross-track)
- 13 acceleration of 1st thrust segment (along-track)
- 14 acceleration of 2nd thrust segment (vertical)
- 15 acceleration of 2nd thrust segment (cross-track)
- 16 acceleration of 2nd thrust segment (along-track)
- 17 host satellite clock timing error
- 18 host satellite clock drift rate
- 19 altimeter bias
- 20 ground station measurement bias 1
- 21 ground station measurement bias 2
- 22 ground station refraction parameter
- 23 ground station position error (x)
- 24 ground station position error (y)
- 25 ground station position error (z)
- 26 GPS satellite position error (H)
- 27 GPS satellite position error (C)
- 28 GPS satellite position error (L)
- 29 GPS satellite clock timing error



All the parameters (except the first six) are optional. That is, the user may elect to solve for almost any subset of these parameters in a given run. The only restrictions are that parameters which appear in groups of three (e.g., gravitation, thrust, ground station positions and GPS positions) will be treated as a group (all three will be adjusted or none will be adjusted).

The first nineteen of these parameters are called dynamic parameters because their values may change with time. This may happen simply because they have a non-identity transition matrix or because the parameters are driven by some random process (i.e., they have state noise). Of these nineteen parameters, six (drag, gravitation, clock drift and altimeter bias) are assumed to be first order Markov processes; i.e., if  $x$  represents one of these parameters, then

$$\dot{x} = -\frac{1}{\tau}x + u$$

where

- $\tau$  = the correlation time
- $u$  = zero mean white noise .

For these six parameters, it is necessary for the user to input three separate quantities: the standard deviation of the error in the *a priori* parameter estimate, the standard deviation of the process output ( $\sigma_x$ ) and the correlation time. For all the other parameters, only the *a priori* standard deviation and the state noise spectral density are required.

Determination of the appropriate values for the *a priori* sigma and the correlation time is usually not difficult. However, calculation of the state noise is frequently done with a bit of hand waving. In fact, the bias that some people have against Kalman filtering is often the result of their misunderstanding of the meaning of state noise (and, consequently, their inappropriate choice of values). This is somewhat understandable

since few books elaborate on this subject. The primary purpose of state noise is to account for errors in the dynamic model.

In the PREFER program, the spectral density of  $u$  is computed internally from the state noise sigma that the user inputs. That is, the user specifies the standard deviation of  $x$  (in the previous equation). The standard deviation on  $x$  that results from integration of the first-order Markov process is related to  $\sigma_u$  by the equation

$$\sigma_x = \sqrt{\frac{\tau}{2}} \sigma_u \quad .$$

Therefore,  $\sigma_u = \sqrt{\frac{2}{\tau}} \sigma_x$  will be computed internally by the program.

For the orbital elements and thrust accelerations, (the non-Markov processes), the input quantity for state noise is the expected standard deviation of the time derivative of the parameter. In this case, the standard deviation of the parameter will grow as  $\sigma_u \sqrt{t}$  where  $t$  is the integration time. Since the thrusting times will generally be short, it should not be necessary to input any state noise for thrust. However, the use of a very small value may help minimize numerical problems.

A similar situation also exists for the orbital elements. If no other force model parameters were adjusted, then it would be necessary to include state noise on the orbital elements (particularly the velocity terms). However, if the gravitation and/or other parameters are adjusted, then the state noise on the orbital elements should just be large enough to alleviate numerical problems.

Notice that no provision was made for specifying state noise on the host clock timing error. This was done because the error is really in the clock frequency (drift rate) and, thus, errors in the clock time can be obtained exactly by integrating the drift rate.

All the remaining parameters are related to the measurements and are not part of the dynamic model. They are all assumed to be constant (identity

state transition matrix) and also have no state noise. For these reasons, they come under the general heading of "measurement biases".

These parameters are treated differently than dynamic parameters in several aspects but the most significant difference is their use as "pass parameters". That is, parameters for a particular station or satellite do not actually enter the filter until measurements from that station (satellite) are processed. Once the pass is over, the parameters are dropped from the filter. This procedure has been shown to produce the same results for the common parameters as if all parameters were carried throughout the run (assuming that all pass parameters are independent between passes).

In the case of station position errors, pass independence is not a valid assumption. Thus, the assumption of pass independence means that some information is not being used and the filter is slightly suboptimal. However, the filter estimate will not be biased because of this assumption.

It should be noted that the original design of PREFER did not attempt to solve for station and GPS position errors and GPS timing errors; they were carried as "consider" parameters. However, problems in implementing a smoother with consider parameters forced their inclusion as adjusted parameters. At this time, it is not known how severe the numerical problems are going to be when many pass parameters are simultaneously adjusted. It was assumed that a maximum of four ground stations and 15 GPS satellites\* could be simultaneously observable. If all possible parameters were adjusted, this would result in a state dimension of 99 (PREFER allows for 100 states). Numerical problems should not be unexpected with a state vector of this size.

The user should also be wary of runs which simultaneously adjust the drag coefficient and gravitational accelerations. If the orbit is nearly circular, the drag acceleration will probably not be distinguishable from the along-track gravitational acceleration (unless the correlation times are significantly different).

---

\* PREFER also has a total limit of 50 ground stations and 24 GPS satellites in a run.

The description of the STEP card (Section 3.2.10) uses the expression "mini-batch measurement processing". In order to reduce the program running time and disk storage, measurements are processed in small batches, during which time (typically 120 seconds), the dynamic model errors are assumed to be negligible. State noise is included only when the filter proceeds from one mini-batch to the next.

The processing of TDRS relay measurements is handled somewhat differently than that for GPSPAC measurements. First, it is not possible to estimate the TDRS ephemeris errors using the current version of PREFER. Secondly, it is necessary for the user to establish a unique relationship (using the TDRID card) between the TDRS and ground tracking stations. It is assumed that each of these ground stations tracks only one TDRS and nothing else. Thus the deletion of the station position errors and measurement biases (pass parameters) from the state vector is determined by the visibility of the user satellite as viewed from the TDRS (see the ELCUT card description for details).

### 3.2 Run Control Cards

All the following cards are optional.

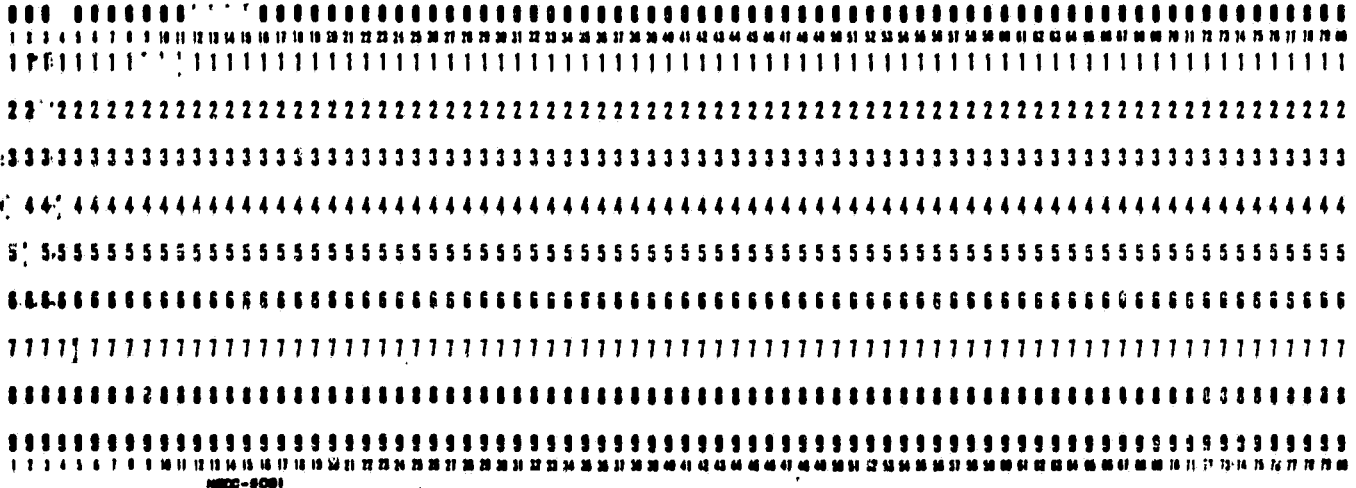
<u>Keyword</u>	<u>Description</u>
3.2.1 DEBUG	Turns on debug print
3.2.2 DRAGCON	Coefficients used for atmospheric density modelling
3.2.3 EARTH	Earth ellipsoid parameters, $G_m$ and speed of light
3.2.4 ELCUT	Measurement elevation cutoffs
3.2.5 MEDIT	Editing thresholds
3.2.6 MSIG	Overrides measurement sigmas on measurement file
3.2.7 PRINT	Printout options
3.2.8 SMR	Satellite area to mass ratio
3.2.9 STAPOS	Ground station positions
3.2.10 STEP	Mini-batch step size, stop time and integration step size
3.2.11 TORID	Defines the relationships between TDRS identifiers and ground tracking stations
3.2.12 THRTIM	Times of thrust events

3.2.1 DEBUG

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The DEBUG card turns on the debug printout for specified subroutines.

**DEBUG** 1110000 . . . . .



<u>Variable</u>	<u>Digit</u>	<u>Type</u>	<u>Description</u>
1		Alphanumeric (A8)	Keyword DEBUG.
2	1	7 digit integer	1 in this digit will turn on the debug print for subroutine FILTER.
	2		1 in this digit will turn on the debug print for subroutine MEAS.
	3		1 in this digit will turn on the debug print for subroutine CARD.
	4		1 in this digit will turn on the debug print for subroutine DYNAM.
	5		1 in this digit will turn on the debug print for subroutine SNOISE.
	6		1 in this digit will turn on the debug print for subroutines GETHDR and INTERG.
	7		1 in this digit will turn on the debug print for subroutine EVAL and EARTH.

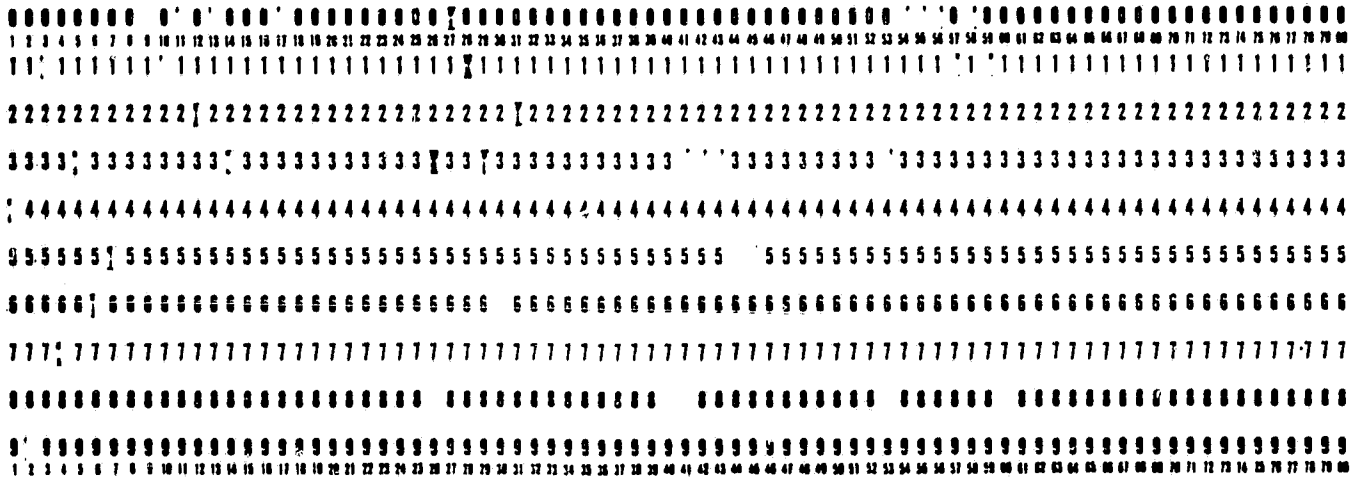
- Notes: (1) The default is no debug print.
- (2) A brief description of the debug printout is given in the Appendix. In general, it would be necessary to have a Fortran listing of PREFER to interpret the output.

3.2.2 DRAGCON

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The DRAGCON card allows the user to input the five coefficients which  
are used to model the density of the earth's atmosphere.

DRAGCON 010203 0 .01362 -0.3355 .0001018 ,,



Variable	Digit	Type	Description
1		Alphanumeric (A8)	Keyword DRAGCON.
2	1-2	Integer	Index (i) of first coefficient on card.
	3-4	Integer	Index (j) of second coefficient on card.
	5-6	Integer	Index (k) of third coefficient on card.
3		Integer	Not used.
4		Real	Coefficient corresponding to number in digits 1-2 ( $d_i$ ).
5		Real	Coefficient corresponding to number in digits 3-4 ( $d_j$ ).
6		Real	Coefficient corresponding to number in digits 5-6 ( $d_k$ ).



Note: The five coefficients are used in the equation

$$\rho = \exp(d_1 h - d_2 - \sqrt{d_3 h^2 + d_4 h - d_5})$$

where  $h$  is the altitude in kilometers and  $\rho$  is density in  $\text{kg}/\text{km}^3$ .  
The defaults for  $d_1 - d_5$  are shown on the sample card. The numbers in  
columns 9-10 and 11-12 should not be zero (or blank).

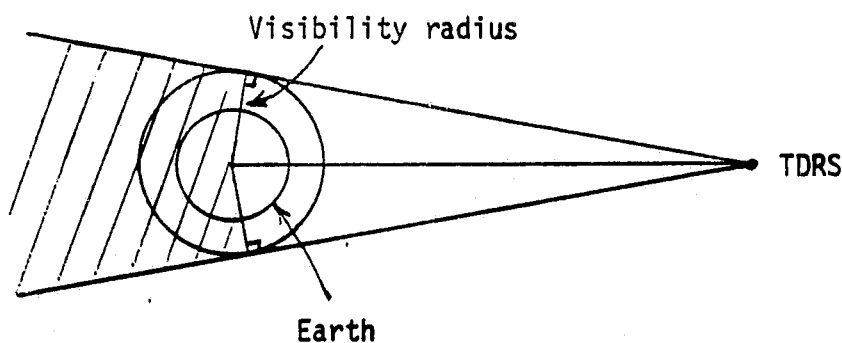
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<u>Variable</u>	<u>Type</u>	<u>Description</u>
6	Real	Radius of sphere surrounding earth which is used to determine whether a user satellite is "visible" to a TDRS (See note 2). Default = 6778.0 km. This visibility test determines when pass parameters associated with TDRS tracking (e.g. station biases, position errors, etc.) are deleted from the filter state.

- Notes: 1) The formula for computing refraction effects will blow up if elevation is less than or equal to zero. Therefore, the elevation cut-off should be greater than zero.
- 2) The shaded area in the figure is not "visible" from the TDRS.





3.2.6 MSIG

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The MSIG card is used to override the measurement standard deviations (as given on the measurement tape) for particular stations, GPS satellites or satellite altimetry.

**MSIG            101   2                    0.001                    0.0            ,,,**

```

0 0000000000 0000000000 0 0000000000 0 0000000000 0000000000 0000000000 0000000000 0000000000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
MSIG-6001

```

<u>Variable</u>	<u>Type</u>	<u>Description</u>
1	Alphanumeric (A8)	Keyword MSIG.
2	Integer	Station or satellite number (maximum of 5 digits and must be positive).
3	Integer	Source of measurement. 1 = GPS satellite 2 = Ground station 3 = Altimeter
4	Real	Measurement standard deviation (kilometers or dimensionless) for the <u>first</u> measurement from a station, satellite or altimeter. Default = SIG1 on Measurement Data File (see page 15).

<u>Variable</u>	<u>Type</u>	<u>Description</u>
5	Real	Measurement standard deviation (kilometer or km/sec) for the second measurement from a satellite which has a pair of measurements. This only applies to the psuedo-delta range from GPS satellites and range rate for ground stations (including TDRS relay measurements). Default = SIG1 on Measurement Data File.

Note: Measurements processed in pairs are:

	<u>Measurement 1:</u>	<u>Measurement 2</u>
Ground range and range rate:	range	range rate
GPSPAC	psuedo range	psuedo delta-range
TDRS	range	range rate

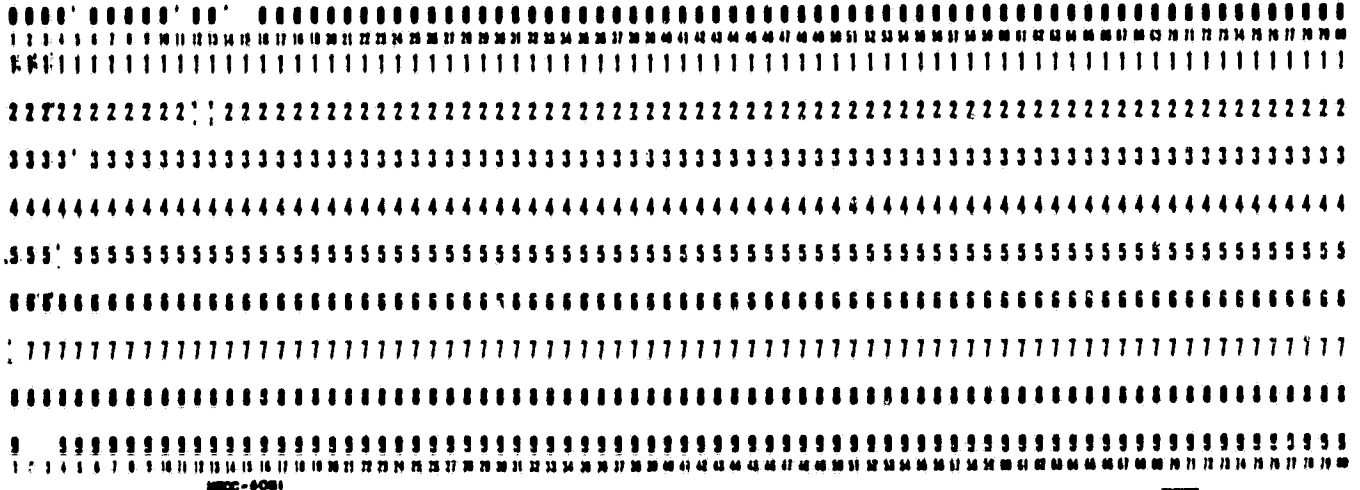
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3.2.7 PRINT

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The PRINT card defines the printout options.

**PRINT 02200 33333**



<u>Variable</u>	<u>Digit</u>	<u>Type</u>	<u>Description</u>
1		Alphanumeric (A8)	Keyword PRINT.
2		Integer	5 digit integer.
	1		Defines coordinate system of printed and plotted output: 0 = HCL, 1 = ECI. Default = 0.
	2		Controls filter print: 0 = no state output, 1 = orbital elements only, 2 = full printout. Default = 2.
	3		Controls smoother print: 0 = no state output, 1 = orbital elements only, 2 = full printout. Default = 2.
	4		Controls generation of the smoother covariance (ECI coordinates) on unit 71. 0 = no output, 1 = output. Default = 0.

NOTE: The computer I/O charges will approximately double when using this option.



---

<u>Variable</u>	<u>Digit</u>	<u>Type</u>	<u>Description</u>
2	5	Integer	Controls plotting of filter/smoothen standard deviations on position. 0 = no plots, 1 = filter plot only, 2 = smoothen plot only, 3 = filter and smoothen plots. Default = 0.





- (2) The conversion of geodetic position to earth-fixed cartesian coordinates is

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$$x = (\rho_g + h) \cos \phi \cos \lambda$$

$$y = (\rho_g + h) \cos \phi \sin \lambda$$

$$z = ((1 - e^2) \rho_g + h) \sin \phi$$

where

$$\rho = a / \sqrt{1 - e^2 \sin^2 \phi}$$

a = earth's semi-major axis

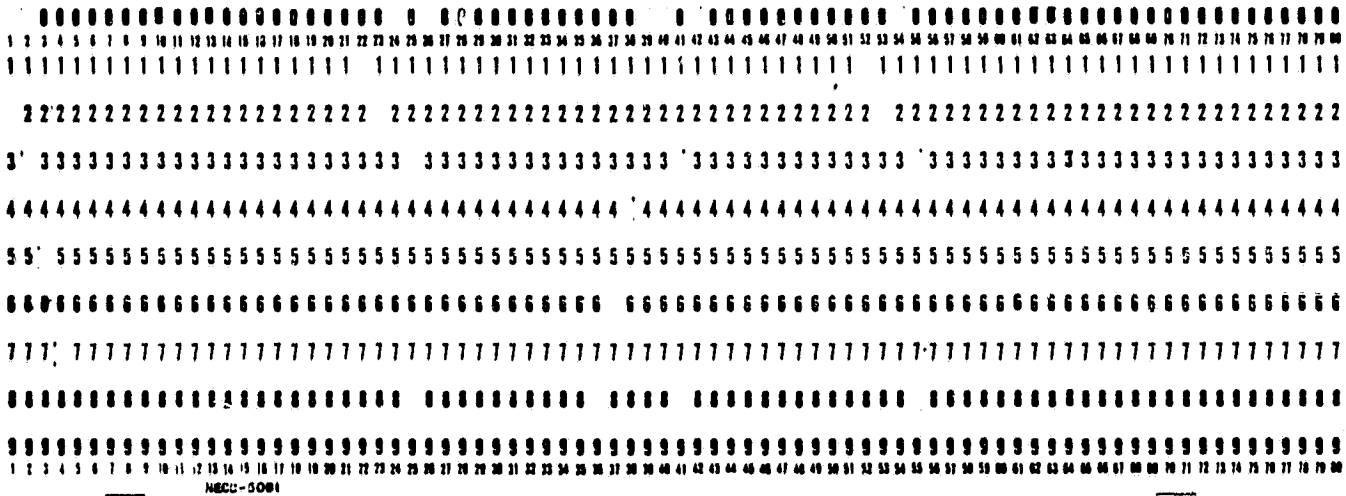
e = earth's eccentricity

3.2.10 STEP

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The STEP card controls the step size used for filter/smoothing output and also controls the stop time of the run.

STEP 0 0 120.0 86400.0 120. 600.



<u>Variable</u>	<u>Type</u>	<u>Description</u>
1	A6	Keyword STEP.
2	Integer	Not used.
3	Integer	Not used.
4	Real	Step size (seconds) for mini-batch measurement processing. All filter/smoothing output will use this interval (see note 1) Default is 120 sec.
5	Real	Stop time (seconds) from epoch of host trajectory tape. The default is 86400 seconds but the program will stop at the end of either the host trajectory tape or the measurement tape.

<u>Variable</u>	<u>Type</u>	<u>Description</u>
6	Real	Maximum step size for use in the Taylor series integrator. Default = 120 sec.
7	Real	Step size used in copying TDRS ORBIT files to a TDRS trajectory file. Default = 600 sec.

- Notes:
- (1) This step size should be chosen so that dynamic modelling errors are negligible during the interval because the filter assumes that state noise is zero.
  - (2) If zeroes or blanks are input on this card, the program will use the default value.
  - (3) There is an additional restriction that the stop time divided by the mini-batch step size is less than 999. This restriction is imposed because PREFER must have sufficient core storage to store the pointers used in the random-access disk I/O.







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3.3 Run Initialization Cards

All the following cards are optional but it may be unreasonable to make runs without initializing certain parameters.

Because the cards may be read in any order, it is important that the CLOCK and CLOCKQ cards have the same number for variable 3.

	<u>Keyword</u>	<u>Description</u>
3.3.1	ALTIM	<i>a priori</i> $\sigma$ for altimeter bias
3.3.2	ALTIMQ	state noise for altimeter bias
3.3.3	ALTIMT	de-correlation time for altimeter bias
3.3.4	CLOCK	<i>a priori</i> $\sigma$ for host clock timing bias and clock drift rate
3.3.5	CLOCKQ	state noise for host clock timing bias and clock drift rate
3.3.6	CLOCKT	de-correlation time for clock drift rate
3.3.7	CSTA	<i>a priori</i> $\sigma$ for station position errors
3.3.8	DRAG	<i>a priori</i> $\sigma$ for drag coefficient
3.3.9	DRAGQ	state noise for drag coefficient
3.3.10	DRAGT	de-correlation time for drag coefficient
3.3.11	GPSP	<i>a priori</i> $\sigma$ for GPS position errors
3.3.12	GPST	<i>a priori</i> $\sigma$ for GPS timing errors
3.3.13	GRAV	<i>a priori</i> $\sigma$ for perturbing gravitational accelerations
3.3.14	GRAVQ	state noise for perturbing gravitational accelerations
3.3.15	GRAVT	de-correlation time for perturbing gravitational accelerations
3.3.16	MBIAS	<i>a priori</i> $\sigma$ for station biases
3.3.17	REFRAC	<i>a priori</i> $\sigma$ for refraction parameters
3.3.18	STATE1	<i>a priori</i> $\sigma$ for first three orbital elements
3.3.19	STATE1Q	state noise for first three orbital elements
3.3.20	STATE2	<i>a priori</i> $\sigma$ for orbital elements 4-6
3.3.21	STATE2Q	state noise for orbital elements 4-6

<u>Keyword</u>	<u>Description</u>
3.3.22 THRUST1	<i>a priori</i> $\sigma$ for acceleration of first thrust segment
3.3.23 THRUST1Q	state noise for acceleration of first thrust segment
3.3.24 THRUST2	<i>a priori</i> $\sigma$ for acceleration of second thrust segment
3.3.25 THRUST2Q	state noise for acceleration of second thrust segment.

Because certain parameters require more than one input card (e.g., GRAV, GRAVQ, GRAVT), it is possible to have unusual errors occur if the deck is not correctly set up. For example, suppose that the GRAVQ card was input but no GRAV card was provided. The presence of the GRAVQ card tells PREFER that gravitational parameters are to be adjusted. However, the *a priori* variances will default to zero because no GRAV card was supplied. This will obviously result in problems for the filter.





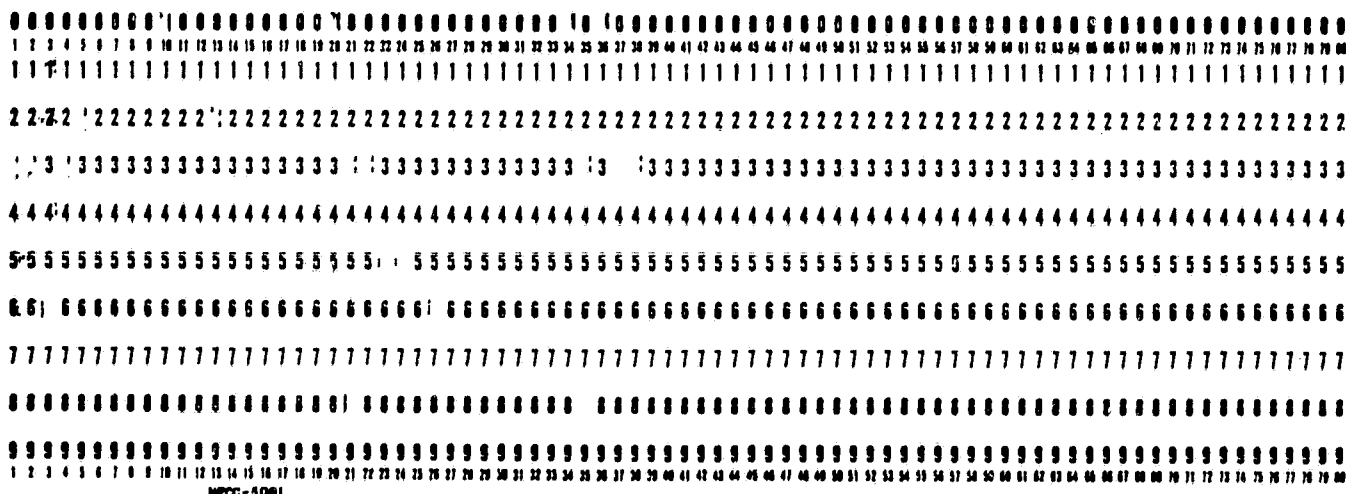


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3.3.4 CLOCK

The CLOCK card is used to initialize the standard deviations for the host clock timing error and drift rate. If omitted, the clock errors will not be adjusted.

CLOCK 0 2 0.35E-6 0.033 , , ,



<u>Variable</u>	<u>Type</u>	<u>Description</u>
1	Alphanumeric (A8)	Keyword CLOCK.
2	Integer	Not used.
3	Integer	Number of parameters: 1 = adjust clock drift rate only (e.g. NAVPAC). 2 = adjust clock timing error plus drift rate (e.g. GPSPAC rate).
4	Real	A <i>priori</i> standard deviation for host clock drift rate (milliseconds/second). No default.
5	Real	A <i>priori</i> standard deviation for host clock timing bias (milliseconds). No default, but this number is not used if column 15 is 1.









Note: (1) If it is desired to use the same sigmas for all stations but one or two, then use one card with no station number and the other cards with station numbers.









- Note: (1) Note (1) on the CSTA card also applies.  
(2) GPS position errors are treated as "pass" parameters.











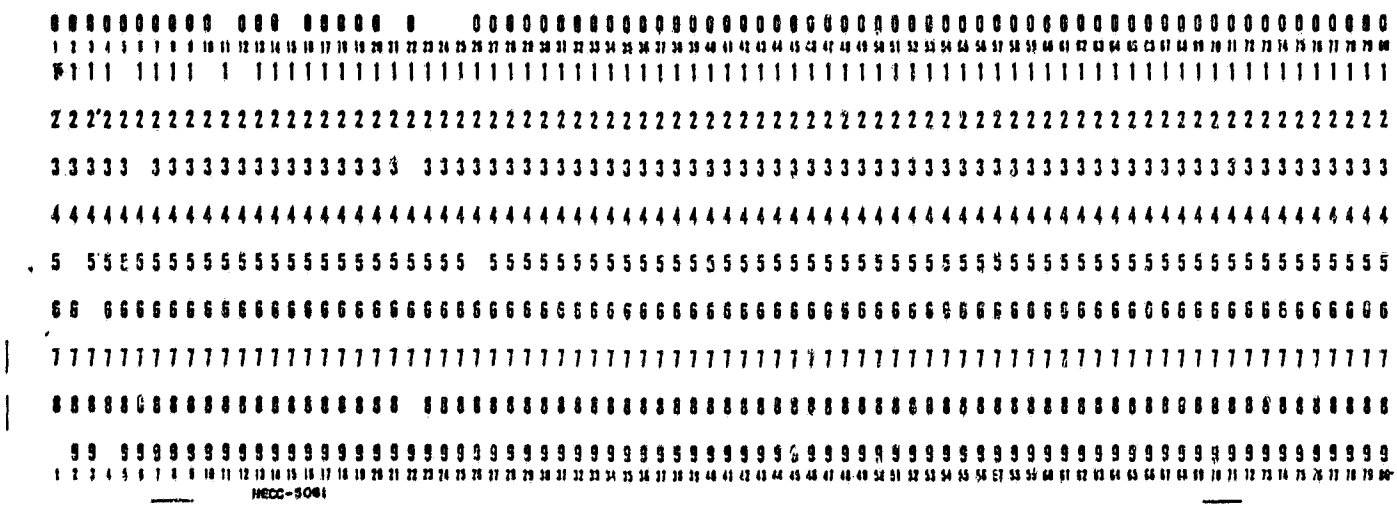


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3.3.17 REFRAC

The REFRAC card is used to initialize the standard deviations for station refraction parameters. If omitted, no refraction parameters will be adjusted.

REFRAC 101 0 0.0005 , , , ,



<u>Variable</u>	<u>Type</u>	<u>Description</u>
1	Alphanumeric (A8)	Keyword REFRAC.
2	Integer	Station number (if 0, this card will apply to all stations).
3	Integer	If this number is greater than 0 on <u>any</u> REFRAC card, then the program will use the refraction correction on the measurement tape as the multiplier of the refraction parameter. Default = 0.
4	Real	A <i>priori</i> standard deviation for the measurement refraction parameter (see Note 2). No default.

- Note: (1) Note (1) on the CSTA card also applies.  
(2) If variable 3 is zero for all REFRAC cards, then the residual refraction error is assumed to be of the form:

$$K/\sin E \quad (\text{range})$$

$$K\left(\frac{1}{\sin E_j} - \frac{1}{\sin E_{j-1}}\right)/DT \quad (\text{range rate})$$

where  $K$  is the refraction parameter and  $E$  is the elevation of the ray. Thus the *a priori* sigma on  $K$  has units of kilometers. If variable 3 is greater than zero for any REFRAC card, then  $K$  will be treated as the multiplier of the total refraction correction which is available on the measurement tape for each measurement. Thus  $K$  is dimensionless.



















#### 4.0 PROGRAM OUTPUT

The printed output from PREFER consists of the filter estimates at the end of each mini-batch, a summary of the measurement residual statistics for each mini-batch, the smoother estimates at the corresponding times, and optional printer plots of the filter and smoother position standard deviations. PREFER also produces an ORBI File (smoother output) on unit 70 and an optional file (unit 71) containing the smoother covariance matrix in ECI coordinates.

The filter summary includes output in both earth-centered inertial or local coordinates at the current time and epoch elements (cartesian, Keplerian or spherical). The ECI/HCL output consists of the nominal trajectory, the estimated correction and the estimated total. The filter output for the epoch elements is the estimated correction to the nominal elements. Also printed are the estimates for the remaining state parameters and the computed standard deviation for the estimate.

The measurement residual statistics for each mini-batch are printed before the corresponding filter summary. Two lines are printed for measurements which occur in pairs (e.g., GPSPAC, or ground range and range rate). The first line for each GPS satellite lists the statistics for the pseudo range measurements while the second line corresponds to the pseudo delta-range measurements. Ground tracking can be easily distinguished from satellite-to-satellite tracking because GPS satellite numbers are printed as negative. Included in the residual statistics is the "WEIGHTED SIGMA". This is computed

as  $\sqrt{\frac{n}{\sum_i (z_i^2 / \sigma_{z_i}^2)}}$  where  $\sigma_{z_i}$  is the residual sigma ( $\sigma_{z_i} = \sqrt{HPH^T + R}$ )

as computed by the filter. If all the filter models are correct, the expected value of the WEIGHTED SIGMA should be approximately equal to 1 and the deviation from 1 should be approximately  $1/\sqrt{2n}$ .

Between the filter summaries may be other messages which indicate when pass parameters are added or removed. Also, any measurement residuals which exceed the editing or printing thresholds will be printed.

A summary of the measurement residual statistics is printed at the end of the filter printout. The following five quantities are printed:

(a) Total number of measurements:  $n$

(b) Weighted sigma:  $\sqrt{\frac{n}{\sum_i (z_i^2 / \sigma_{z_i}^2)}} / n$

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(c)  $\sum_{i=1}^n z_i^2 / \sigma_{z_i}^2$

(d)  $\sum_{i=1}^n \ln(\sigma_{z_i}^2)$

(e)  $-\frac{1}{2} \sum_{i=1}^n (z_i^2 / \sigma_{z_i}^2 + \ln \sigma_{z_i}^2)$

The sum of weighted residuals (quantity c) should be chi-square distributed with a mean of  $n$  and a standard deviation of  $\sqrt{2n}$ . If the value printed deviates greatly from  $n \pm \sqrt{2n}$ , then modeling errors are suspected. Quantity d is the sum of the natural logarithm of the analytically computed residual variances. Quantity e is the log likelihood function (plus a bias) and is computed as the negative of one-half the sum of quantities c and d. This is the quantity which would be maximized in a maximum likelihood estimation program [3]. Thus, the log likelihood can be used as a metric to compare runs made with different model assumptions. Notice that this procedure attempts to minimize the sum of weighted residuals and the residual variances: it is not acceptable to minimize just the sum of weighted residuals since this can be done by making  $\sigma_{z_i}$  large.



The smoother output is printed backward in time after the filtering is completed. The smoother summary is very similar to the filter summary and also includes the filter estimate at each point.

All output is in units of kilometers, km/sec, km/sec<sup>2</sup>, radians, milliseconds, Hz/megahertz or dimensionless.

4.1 Format of ORB1 File (Unit 70)

The smoothed ECI positions and velocities are written on Unit 70 in the format of a GTDS ORB1 File. This will be generated in the same coordinate system (TOD or 1950) as the input ORBIT file. The starred quantities are not actually written on the file.

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
1 ORB1 header	2800 bytes	1-8	TITLE(1): ORB1 identifier = 76796291.
		9-16	IDSAT: Satellite ID number
		17-24	Not used
		25-32	STORB1(1): Start time of ephemeris (YYMMDD.)
		33-40	TITLE(5): Day count of year for start of ephemeris
		41-48	TITLE(6): Seconds of day for start of ephemeris
		49-56	ETORB1(1): End time of ephemeris (YYMMDD.)
		57-64	TITLE(8): Day count of year for end of ephemeris
		65-72	TITLE(9): Seconds of day for end of ephemeris
		73-80	TITLE(10): Time interval between ephemeris points (sec.)
81-152	HEADER (I,1): I=1,9 Title of current run		
153-160	ICENT: Central body indicator		

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
1 ORB1 header	2800 bytes	161-208	Spares
		209-216	YMDREF: Year, month, and day of referenced time of true system
		217-224	TITLE(28): Day count of year for reference date
		225-232	GHA: Greenwich hour angle at epoch
		233-632	Spares
		633-640	CSUBDZ: Drag coefficient
		641-648	AREA: Area of spacecraft in cm <sup>2</sup>
		649-656	SCMASS: Mass of spacecraft in grams
		657-800	Spares
		801-808	TITLE(101): Time of epoch from reference date in seconds/806.81242
		809-816*	TITLE(102): Ratio of semimajor axis to mean equatorial radius
		817-824*	AEINT(2): Eccentricity
		825-832*	OBLINT(5): True anomaly at $t_0$ : rad.
		833-880	PVINT(1): I=1,6 Cartesian elements for integration initialization
		881-888	SPINT(5): Magnitude of radius vector (km)
		889-896	SPINT(6): Magnitude of velocity vector (km/sec)
		897-904*	TITLE(113): Sum of mean anomaly and argument of perifocus
		905-912*	AEINT(6): Mean anomaly
		913-920	Spare
		921-928*	AEINT(5): Augment of perifocus
929-936*	AEINT(3): Inclination		
937-944*	AEINT(4): Longitude of ascending node		

RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
1 ORB1 header	2800 bytes	945-952*	TITLE(119): Vertical flight path angle minus $\pi/2$
		953-960*	OBLINT(4): Mean motion at $t_0$ : rad./DUT sec.
		961-968*	OBLINT(1): Eccentric anomaly at $t_0$ : rad.
		969-976*	OBLINT(8): Time rate of change of argument of perigee at $t_0$ : rad./DUT sec.
		977-984*	OBLINT(9): Time rate of change of right ascension of ascending node at $t_0$ : rad./DUT sec.
		985-992*	OBLINT(2): Period at $t_0$ : DUT sec.
		993-1000*	OBLINT(6): Perigee height at $t_0$ : km
		1001-1008*	OBLINT(7): Apogee height at $t_0$ : km
		1009-1520	Spare
		1521-1528	EY: Year of elements epoch
		1529-1536	EM: Month of elements epoch
		1537-1544	ED: Day of elements epoch
		1545-1552	EH: Hour of elements epoch
		1553-1560	EMN: Minute of elements epoch
		1561-1568	ESC: Seconds of elements epoch
		1569-1592	Spare
		1593-1600	TITLE (200): Orbit theory indicator = 2, Cowell or time-regularized Cowell = 3, all others
1601-2800	Spare		

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RECORD	RECORD SIZE	BYTES	NAME, DESCRIPTION, ETC.
All except first and last two  ORB1 data	2800 bytes	1-8	DATA(1): Date of first ephemeris point (YYMMDD.)
		9-16	DATA(2): Day count of year for first ephemeris point
		17-24	DATA(3): Seconds of day for first ephemeris point
		25-32	DATA(4): Time interval between data points (sec.)
		33-40	DATA(5): Day count of year for epoch
		41-86	PVINT(I): I = 1,6; first position vector (km) and velocity vector (km/sec)
		87-2440	PVINT(I): I = 1,6; J = 2,50 Position and velocity vector sets for data points 2-50. For less than 50 points, the first invalid set is .9999999999999999 x 10 <sup>16</sup> (units km and km/sec)
		2441-2800	Spares
Last two ORB1 and sentinels	2800 bytes	1-2800	ESNINE(I) I = 1,350 End of file sentinels, with the value 0.9999999999999999 x 10 <sup>16</sup>

4.2 Format of Smoother ECI Covariance File (Unit 71)

If requested, the entire smoother covariance matrix is written on unit 71 where the entries corresponding to the orbital elements are transformed from epoch osculating elements to current ECI cartesian elements. This file consists of two types of records which are repeated until the end of the trajectory is reached. Notice that the first record (in a pair) contains a variable which defines the length of the second record.

Record Type 1

Word	No.	Type	Description
	1-2	Double Precision	Time from epoch (sec).
	3	Integer	Number of adjusted states (n) at current time.
	4	Integer	Length of covariance matrix $(\frac{n(n+1)}{2})$
	5	Integer	Numeric label of 1st state.
	6	Integer	Numeric label of 2nd state.
	.	.	.
	.	.	.
	.	.	.
	.	.	.
	.	.	.
	104	Integer	Numeric label of 100th state.

Record Type 2

This contains the ECI smoother covariance matrix stored as upper triangular by columns.

<u>Word</u>	<u>Type</u>	<u>Description</u>
<u>No.</u>		
1-2	Double Precision	Variance of 1st state.
3-4	Double Precision	Covariance between 1st and 2nd states.
.	.	.
.	.	.
.	.	.
(n <sup>o</sup> (n+1)-1)	Double Precision	Variance of nth state.
-(n <sup>o</sup> (n+1))		

- Notes: (1) Because of numerical problems, it is possible for the state variances to become negative.
- (2) The numeric labels of the states are defined as:

<u>Label</u>	<u>Description</u>
1-6	state orbital elements (ECI)
7	drag coefficient
8	perturbing gravitational accelerations (HCL)
9	acceleration of first thrust segment (HCL)
10	acceleration of second thrust segment (HCL)
11	host clock timing error (msec)
12	host clock drift rate (msec/sec)
13	altimeter bias
100000	station bias
200000	station refraction parameter
300000	station position error (ECI)
400000	GPS position error (HCL)
500000	GPS timing error (msec)

The last 5 digits in each number are reserved for the station or satellite number.

5.0 EXAMPLE (LANDSAT)

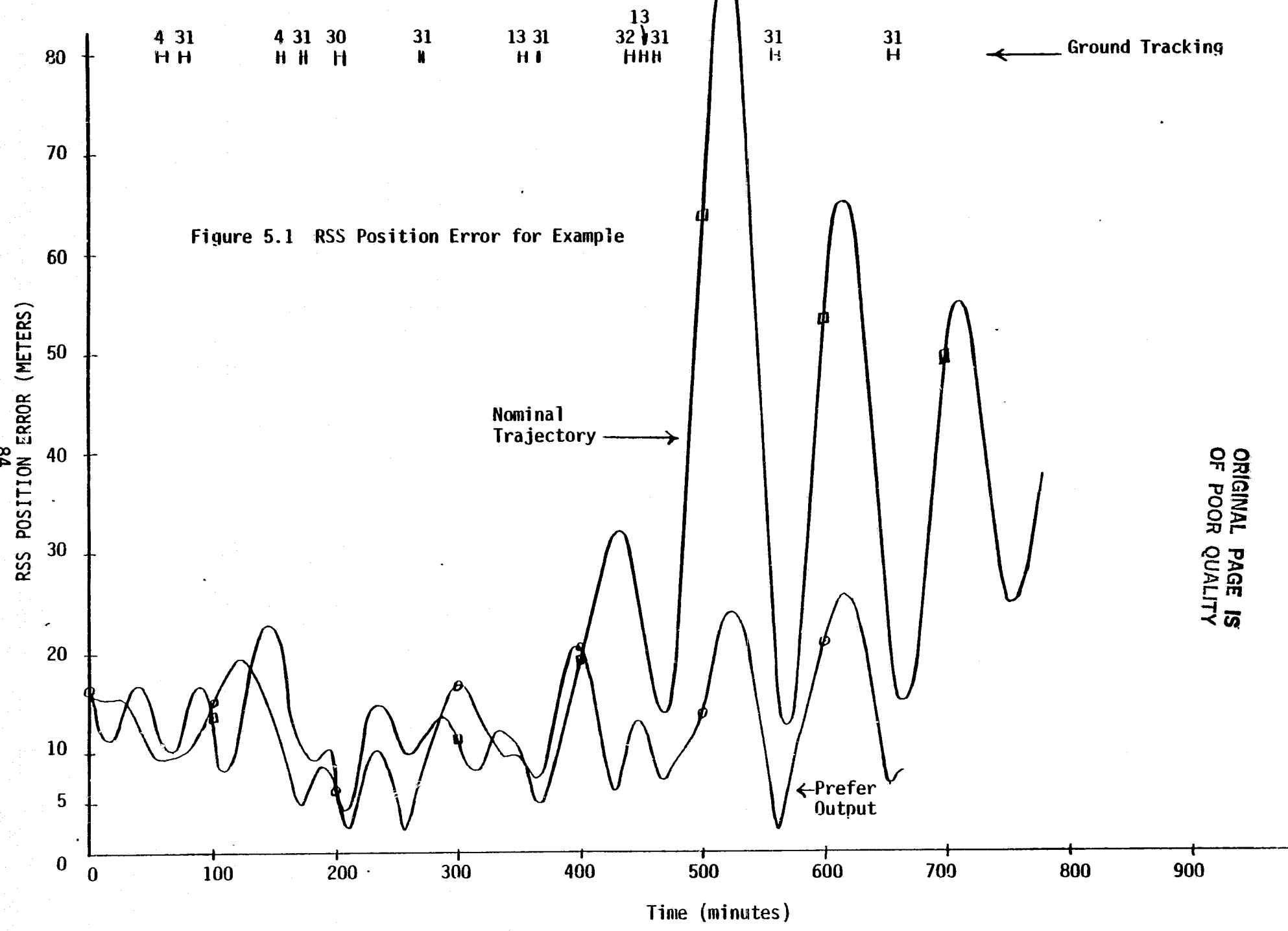
Orbit - 700 km altitude,  $e = .0001$ ,  $98.3^\circ$  inclination, 720 minutes  
(7.3 revolutions)

Simulated Tracking Data - 5 ground stations measuring range and  
integrated range rate. See Table 5.1 for error parameters.

Nominal Trajectory - Obtained by using GTDS to least squares fit the  
simulated tracking data over 12 hours. See Table 5.1 for  
differences between models used in simulating data and models  
used in batch orbit determination.

Table 5.1 Error Parameters of Example

Parameter	Model Description	
	Simulated Data	Batch Orbit Determination
data noise (range)	1 meter	1 meter (weighting)
data noise (range rate)	0.1 cm/sec	0.1 cm/sec (weighting)
gravitational field	GEM9 (20,20)	WGS72 (16,16)
measurement bias (R)	5 meters	---
measurement bias ( $\dot{R}$ )	0.1 cm/sec	---
station position errors	$\pm 5m$ each component	---
drag coefficient	2.0	1.5
density model	Flux table #150	Flux table #150
solar radiation pressure	yes	no
refraction-tropospheric	yes	yes
refraction-ionospheric	yes	yes
polar motion modeled	no	yes



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A priori standard deviations used in PREFER

- x,y,z - 20 meters
- $\dot{x}, \dot{y}, \dot{z}$  - 2 cm/sec
- gravitational acceleration -  $2.4 \times 10^{-6}$  (H),  $0.7 \times 10^{-6}$  (C),  $1.0 \times 10^{-6}$  (L)  
m/sec<sup>2</sup>
- station measurement biases - 5 meter (range), 0.1 cm/sec (range rate)
- station refraction - 50 cm @ zenith
- station position errors - 5 meters (each component)

State noise spectral density - none on orbital elements

Markov process standard deviations

- gravitational accelerations -  $2.4 \times 10^{-6}$  (H),  $0.7 \times 10^{-6}$  (C),  $1.0 \times 10^{-6}$  (L)  
m/sec<sup>2</sup>

Time constants of Markov processes

- gravitational acceleration - 1200 (H), 200 (C), 200 (L) seconds

Results - See Figure 5.1 and Table 5.2

Table 5.2 Position Errors for Smoothed Trajectory

component	RMS	maximum
radial	3.8	8.1
crosstrack	7.0	13.1
alongtrack	11.4	24.9
total	13.9	26.0

The nominal trajectory has large errors (e.g. 89 meters) in the data gaps near the end of the orbit. This occurs when only one station (#31) is tracking. In the periods when two or more stations are tracking, the error in the nominal trajectory is less than 32 meters.

The smoothed output of PREFER has errors which are less than 21 meters during the period when two or more stations are tracking. In the last data gap at the end of the trajectory, the peak error is 26 meters (mostly alongtrack). Notice that the total error in the PREFER output tends to be relatively smooth while the error in the nominal trajectory (GTDS output) fluctuates wildly; there are 4 short periods of time when the nominal trajectory is more accurate than the PREFER output but the PREFER output is generally much superior.

These results for PREFER were obtained from one of the best runs in a series of runs in which *a priori* variances, state noise variances, time constants, and the selection of adjusted parameters were varied. Several other runs yielded likelihood functions and ephemeris errors similar to those of the run listed. It was found that the results are not very sensitive to the exact form of the gravitational acceleration model if the parameters of that model are reasonable. Maximization of the likelihood function can generally be relied upon to select the run with the optimum model.

\*\*\*\*\*

THE PRECISION RECURSIVE ESTIMATOR FOR EPHEMERIS REFINEMENT (PREFER) VERSION (IBM) 82.001

OUTPUT FROM ORBIT FILE FOR SATELLITE LS-D

EPOCH DATE/TIME = 811001. 195500.0000

START DATE/TIME = 811001. 195500.0000      END DATE/TIME = 811002. 200000 0000

SATELLITE AREA = 20.000 M\*\*2, MASS = 1700.00 KG, CD = 1.500

ORBIT FILE WAS CREATED USING 1950      COORDINATES

EPOCH KEPLERIAN ELEMENTS =    7078.032    0.000099    1.714872    5.846084    0.520692    2.620901

EPOCH CARTESIAN ELEMENTS =    -6413.078    2996.587    -0.687    0.45640    0.97591    -7.42596

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LISTING OF CARD INPUT

PRINT	2203	0	.0	.0	.0	0
EARTH	0	0	6378.1660	298.30000	398600.64	.299790*06
STEP	0	0	120.00000	43200.000	120.00000	.0
ELCUT	0	0	2.0000000	.0	.0	.0
STATE1	0	0	.200000000-01	.200000000-01	.200000000-01	.0
STATE2	0	0	.200000000-04	.200000000-04	.200000000-04	.0
GRAV	0	0	.240000000-08	.700000000-09	.100000000-08	.0
GRAVO	0	0	.240000000-08	.700000000-09	.100000000-08	.0
GRAVT	0	0	1200.0000	200.00000	200.00000	.0
MBIAS	0	2	.500000000-02	.100000000-05	.0	.0
REFRAC	0	0	.500000000-03	.0	.0	.0
CSTA	0	0	.500000000-02	.500000000-02	.500000000-02	.0
MSIG	4	2	.100000000-02	.100000000-05	.0	.0
MSIG	13	2	.100000000-02	.100000000-05	.0	.0
MSIG	30	2	.100000000-02	.100000000-05	.0	.0
MSIG	31	2	.100000000-02	.100000000-05	.0	.0
MSIG	32	2	.100000000-02	.100000000-05	.0	.0

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## SUMMARY OF CARD INPUT

NUMBER OF DYNAMIC PARAMETERS= 9 (ALSO EQUALS INITIAL NUMBER OF STATES)

MINI-BATCH STEP SIZE= 120.00 SECONDS

MAXIMUM INTEGRATION STEP SIZE= 120.00 SECONDS

INPUT RUN STOP TIME= 43200.00 SECONDS ACTUAL STOP TIME MAY BE LESS THAN THIS

STEP SIZE FOR CREATING TDRS TRAJECTORY FILE = 600.00

SATELLITE AREA TO MASS RATIO= .1176D-07 KM\*\*2/KG

CONSTANTS USED IN THE ATMOSPHERIC DENSITY MODELING= .13620D-01 -8.3355 .10180D-03 1.0830 89.390

EARTH SEMI-MAJOR AXIS = 6378.166 EARTH ECCENTRICITY SQUARED = .6693422D-02

EARTH GRAVITATIONAL CONSTANT = 398600.64 KM\*\*3/SEC.\*\*2

SPEED OF LIGHT = 299792.4562 KM/SEC

MEASUREMENT ELEVATION CUTOFFS	GROUND MEASUREMENTS:	2.000 DEGREES
	GPS MEASUREMENTS:	0.0 DEGREES
	TDRS MEASUREMENTS:	0.0 KILOMETERS

## PRINTOUT OPTIONS

- 1) FILTER/SMOOTHER OUTPUT AND PLOTS WILL BE IN HCL COORDINATES
- 2) FILTER OUTPUT - ALL
- 3) SMOOTHER OUTPUT - ALL
- 5) PLOTS OF POSITION SIGMAS - FILTER+SMOOTHER

SUMMARY OF STATE PARAMETERS							
	LABEL	LABEL	UNITS	A PRIORI SIGMA	SQRT(SPECTRAL DEN.)	TIME CONSTANT	NOISE SIGMA
1	1	X	KM.	.20000-01	.0		
2	2	Y	KM.	.20000-01	.0		
3	3	Z	KM.	.20000-01	.0		
4	4	XDDT	KM/SEC	.20000-04	.0		
5	5	YDDT	KM/SEC	.20000-04	.0		
6	6	ZDDT	KM/SEC	.20000-04	.0		
7	8	GRAV	KM/S**2	.24000-08	.97980-10	1200.	24000-08
8	8	GRAV	KM/S**2	.70000-09	.70000-10	200.0	70000-09
9	8	GRAV	KM/S**2	.10000-08	.10000-09	200.0	.10000-08
10	100000	MBIAS 1	KM.	.50000-02	.0		
11	200000	MBIAS 2	KM/S	.10000-05	.0		
12	300000	REFRACT	KM., -	.50000-03	.0		
13	400000	STA POS	KM.	.50000-02	.0		
14	400000	STA POS	KM.	.50000-02	.0		
15	400000	STA POS	KM.	.50000-02	.0		

NOTE: FOR A FIRST ORDER MARKOV PROCESS, OUTPUT SIGMA = SQRT(INPUT SPECTRAL DENSITY\*TIME CONSTANT/2)

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## SUMMARY OF GROUND STATIONS ( 5)

	STATION NO.	STATION POSITION(EFC)		
		X	Y	Z
1	4	4847.8243	-353.3178	4117.1445
2	31	-2282.4958	-1453.3850	5756.7222
3	30	-4447.4906	2676.8624	-3295.2795
4	13	1129.8039	-4833.1549	3992.2086
5	32	1263.4446	-6255.0397	-68.8004

## INPUT MEASUREMENT SIGMAS

SIGMA1	SIGMA2
.10000-02	.10000-05
.10000-02	.10000-05
.10000-02	.10000-05
.10000-02	.10000-05
.10000-02	.10000-05

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NOTES ON RESIDUAL STATISTICS

- 1) IF ALL MODELS ARE CORRECT, THE WEIGHTED RESIDUAL RMS SHOULD EQUAL 1. WITH A SIGMA OF 1./SQRT(2\*N)
- 2) UNITS OF RESIDUALS ARE KM. (ALL TYPES EXCEPT DOPPLER) OR DIMENSIONLESS (DOPPLER)

APPROXIMATE REGION SIZE = 383216 BYTES (ASSUMING TWO 7294-BYTE BUFFERS ARE USED FOR UNITS 70 AND 71)

REGION SPECIFIED FOR THIS JOB = 405504 ARRAYS REQUIRE 26360 BYTES

NOTE: PREFER WILL USE ALL THE CORE ALLOCATED FOR THE JOB. IGNORE REGION PRINTED IN SYSTEM MESSAGES

5288 4496 6040 5288 5288 79689 78351 76429 75081 73545

```

.....
FILTER OUTPUT AT TIME 120.00
NOMINAL TRAJECTORY (ECI) = -6306.5691 3089.1352 -889.3853 1.31634 0.56448 -7.36562
ESTIM. TOTAL (ECI) = -6306.5691 3089.1352 -889.3853 1.31634 0.56448 -7.36562
ESTIM. CORRECTION (HCL) = 0.0 0.0 0.0 0.0 0.0 0.0
ESTIM. SIGMA (HCL) = 0.02045 0.01998 0.02001 0.00002 0.00002 0.00002

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0
FILTER STATE (EPOCH) = 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FILTER SIGMAS (EPOCH) = 0.02000001 0.02000000 0.02000000 0.00002000 0.00002000 0.00002000 0.00000000 0.00000000 0.00000000
.....

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.....
FILTER OUTPUT AT TIME 240.00
NOMINAL TRAJECTORY (ECI) = -6098.0154 3131.6999 -1763.6533 2.15483 0.14399 -7.18580
ESTIM. TOTAL (ECI) = -6098.0154 3131.6999 -1763.6533 2.15483 0.14399 -7.18580
ESTIM. CORRECTION (HCL) = 0.0 0.0 0.0 0.0 0.0 0.0
ESTIM. SIGMA (HCL) = 0.02161 0.01993 0.02021 0.00002 0.00002 0.00002

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0
FILTER STATE (EPOCH) = 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FILTER SIGMAS (EPOCH) = 0.02000009 0.02000003 0.02000001 0.00002001 0.00002000 0.00002000 0.00000000 0.00000000 0.00000000
.....

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.....
FILTER OUTPUT AT TIME 360.00
NOMINAL TRAJECTORY (ECI) = -5790.8142 3123.6042 -2609.3150 2.95823 -0.27871 -6.88950
ESTIM. TOTAL (ECI) = -5790.8142 3123.6042 -2609.3150 2.95823 -0.27871 -6.88950
ESTIM. CORRECTION (HCL) = 0.0 0.0 0.0 0.0 0.0 0.0
ESTIM. SIGMA (HCL) = 0.02313 0.01985 0.02107 0.00003 0.00002 0.00002

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0
FILTER STATE (EPOCH) = 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FILTER SIGMAS (EPOCH) = 0.02000044 0.02000013 0.02000007 0.00002001 0.00002000 0.00002000 0.00000000 0.00000000 0.00000000
.....

```

```

.....
FILTER OUTPUT AT TIME 480.00
NOMINAL TRAJECTORY (ECI) = -5389.9667 3064.9966 -3412.6691 3.71349 -0.69674 -6.48164
ESTIM. TOTAL (ECI) = -5389.9667 3064.9966 -3412.6691 3.71349 -0.69674 -6.48164
ESTIM. CORRECTION (HCL) = 0.0 0.0 0.0 0.0 0.0 0.0
ESTIM. SIGMA (HCL) = 0.02455 0.01975 0.02319 0.00003 0.00002 0.00003

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0
FILTER STATE (EPOCH) = 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FILTER SIGMAS (EPOCH) = 0.02000135 0.02000041 0.02000027 0.00002003 0.00002001 0.00002000 0.00000000 0.00000000 0.00000000
.....

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FILTER SIGMAS (EPOCH)= 0.02026998 0.02022877 0.02228970 0.00002218 0.00002064 0.00002038 0.00000000 0.00000000 0.00000000

FILTER OUTPUT AT TIME 2880.00

NOMINAL TRAJECTORY (ECI)= 6421.1216 -2899.1272 -601.8361 0.13095 -1.24688 7.40645  
ESTIM. TOTAL (ECI) = 6421.1216 -2899.1272 -601.8361 0.13095 -1.24688 7.40645  
ESTIM. CORRECTION (HCL) = 0.0 0.0 0.0 0.0 0.0 0.0  
ESTIM. SIGMA (HCL) = 0.07318 0.03457 0.26920 0.00018 0.00018 0.00013

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0  
FILTER STATE (EPOCH) = 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
FILTER SIGMAS (EPOCH)= 0.02028040 0.02025262 0.02271158 0.00002248 0.00002073 0.00002040 0.00000000 0.00000000 0.00000000

FILTER OUTPUT AT TIME 3000.00

NOMINAL TRAJECTORY (ECI)= 6384.6691 -3024.8148 289.4234 -0.73767 -0.84507 7.42769  
ESTIM. TOTAL (ECI) = 6384.6691 -3024.8148 289.4234 -0.73767 -0.84507 7.42769  
ESTIM. CORRECTION (HCL) = 0.0 0.0 0.0 0.0 0.0 0.0  
ESTIM. SIGMA (HCL) = 0.12520 0.03706 0.26953 0.00020 0.00021 0.00007

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0  
FILTER STATE (EPOCH) = 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
FILTER SIGMAS (EPOCH)= 0.02028880 0.02027626 0.02316704 0.00002280 0.00002081 0.00002041 0.00000000 0.00000000 0.00000000

FILTER OUTPUT AT TIME 3120.00

NOMINAL TRAJECTORY (ECI)= 6244.5604 -3101.3954 1175.9713 -1.59429 -0.42955 7.32803  
ESTIM. TOTAL (ECI) = 6244.5604 -3101.3954 1175.9713 -1.59429 -0.42955 7.32803  
ESTIM. CORRECTION (HCL) = 0.0 0.0 0.0 0.0 0.0 0.0  
ESTIM. SIGMA (HCL) = 0.17785 0.07287 0.25298 0.00020 0.00024 0.00003

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0  
FILTER STATE (EPOCH) = 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
FILTER SIGMAS (EPOCH)= 0.02029544 0.02029941 0.02365182 0.00002312 0.00002090 0.00002042 0.00000000 0.00000000 0.00000000

FILTER OUTPUT AT TIME 3240.00

NOMINAL TRAJECTORY (ECI)= 6003.0835 -3127.6322 2043.3788 -2.42483 -0.00716 7.10915  
ESTIM. TOTAL (ECI) = 6003.0835 -3127.6322 2043.3788 -2.42483 -0.00716 7.10915  
ESTIM. CORRECTION (HCL) = 0.0 0.0 0.0 0.0 0.0 0.0  
ESTIM. SIGMA (HCL) = 0.22597 0.11701 0.21887 0.00018 0.00026 0.00010

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0  
FILTER STATE (EPOCH) = 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
FILTER SIGMAS (EPOCH)= 0.02030071 0.02032182 0.02416100 0.00002347 0.00002099 0.00002043 0.00000000 0.00000000 0.00000000

NEW PASS PARAMETERS ADDED AT TIME 3420.00, STATION/SAT 4, N = 15

\$\$\$ RESIDUAL STATISTICS FOR TIME 3300.00 TO 3420.00

FILTER OUTPUT AT TIME 3360.00

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NOMINAL TRAJECTORY (ECI)= 5664.1891 -3103.1151 2877.5419 -3.21570 0.41519 6.77470  
 ESTIM. TOTAL (ECI) = 5664.1860 -3103.1131 2877.5292 -3.21570 0.41519 6.77471  
 ESTIM. CORRECTION (HCL) = 0.00373 0.00244 -0.01243 -0.00000 -0.00000 0.00001  
 ESTIM. SIGMA (HCL) = 0.00989 0.01951 0.01065 0.00001 0.00002 0.00002

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0 4  
 FILTER STATE (EPOCH) = 0.00053431 0.00150118-0.00377666-0.00000354 0.00000254 0.00000171-0.00000000-0.00000000 0.00000000-0.00002852  
 FILTER SIGMAS (EPOCH)= 0.01611228 0.01901381 0.02153840 0.00002093 0.00001928 0.00001360 0.00000000 0.00000000 0.00000000 0.00499854

PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
 STATION/SATELLITE = 4 4 4 4 4 4  
 FILTER STATE =-0.00000000 0.00002852-0.00001858 0.00002447 0.00014427  
 FILTER SIGMAS = 0.00000100 0.00049182 0.00499965 0.00499940 0.00497917

RESIDUAL STATISTICS FOR TIME 3420.00 TO 3540.00  
 STATION 4 TYPE 10 N= 12. MEAN= .7496D-07 SIGMA= .2206D-05 WEIGHTED SIGMA= 1.044  
 STATION 4 TYPE 13 N= 12. MEAN= -.1770D-03 SIGMA= .7846D-03 WEIGHTED SIGMA= .6928

FILTER OUTPUT AT TIME 3480.00  
 NOMINAL TRAJECTORY (ECI)= 5233.4212 -3028.2663 3664.9082 -3.95398 0.83056 6.33031  
 ESTIM. TOTAL (ECI) = 5233.4172 -3028.2577 3664.8985 -3.95398 0.83056 6.33031  
 ESTIM. CORRECTION (HCL) = 0.00160 -0.00063 -0.01052 -0.00001 0.00000 0.00000  
 ESTIM. SIGMA (HCL) = 0.00839 0.01071 0.00528 0.00001 0.00001 0.00002

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0 4  
 FILTER STATE (EPOCH) = 0.00338635 0.00278143 0.02288501-0.00000241 0.00000423-0.00000009 0.00000000-0.00000000 0.00000000-0.00125162  
 FILTER SIGMAS (EPOCH)= 0.01444120 0.01652870 0.02153933 0.00002060 0.00001751 0.00001337 0.00000000 0.00000000 0.00000000 0.00401336

PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
 STATION/SATELLITE = 4 4 4 4 4 4  
 FILTER STATE = 0.00000011 0.00006394 -0.00011810 0.00015171 0.00021890  
 FILTER SIGMAS = 0.00000099 0.00009330 0.00498390 0.00496892 0.00494967

RESIDUAL STATISTICS FOR TIME 3540.00 TO 3660.00  
 STATION 4 TYPE 10 N= 12. MEAN= .4470D-06 SIGMA= .1270D-05 WEIGHTED SIGMA= .8684  
 STATION 4 TYPE 13 N= 12. MEAN= .2795D-03 SIGMA= .1125D-02 WEIGHTED SIGMA= 1.046

FILTER OUTPUT AT TIME 3600.00  
 NOMINAL TRAJECTORY (ECI)= 4717.8187 -2904.3301 4392.7114 -4.62769 1.23220 5.78336  
 ESTIM. TOTAL (ECI) = 4717.8106 -2904.3358 4392.7041 -4.62770 1.23220 5.78336  
 ESTIM. CORRECTION (HCL) = -0.00329 -0.00302 -0.01140 -0.00000 0.00001 -0.00000  
 ESTIM. SIGMA (HCL) = 0.00496 0.00877 0.00377 0.00003 0.00001 0.00002

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0 4  
 FILTER STATE (EPOCH) = 0.00926432 0.00488644-0.00270946-0.00000097 0.00000750-0.00000351 0.00000000-0.00000000 0.00000000 0.00566759  
 FILTER SIGMAS (EPOCH)= 0.01290821 0.01590341 0.02207023 0.00002083 0.00001696 0.00001296 0.00000000 0.00000000 0.00000000 0.00136934

PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
 STATION/SATELLITE = 4 4 4 4 4 4  
 FILTER STATE =-0.00000011 0.00002649 -0.00029671 0.00037350 0.00026544  
 FILTER SIGMAS = 0.00000093 0.00007315 0.00497750 0.00495770 0.00494365

RESIDUAL STATISTICS FOR TIME 3660.00 TO 3780.00  
 STATION 4 TYPE 10 N= 12. MEAN= .1396D-06 SIGMA= .1081D-05 WEIGHTED SIGMA= .8436  
 STATION 4 TYPE 13 N= 12. MEAN= .3965D-03 SIGMA= .1192D-02 WEIGHTED SIGMA= 1.113

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 FILTER OUTPUT AT TIME 3720.00  
 NOMINAL TRAJECTORY (ECI)= 4125.7936 -2733.3490 5049.1735 -5.22598 1 61358 5 14293  
 ESTIM. TOTAL (ECI) = 4125.7845 -2733.3557 5049.1667 -5.22596 1 61359 5.14293  
 ESTIM. CORRECTION (HCL) = -0.00334 -0.00397 -0.01213 -0.00000 0.00001 -0.00001  
 ESTIM. SIGMA (HCL) = 0.00425 0.00675 0.00284 0.00001 0.00001 0.00001

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 4  
 FILTER STATE (EPOCH) = 0.01062389 0.00554910 -0.00243990 -0.00000032 0.00000829 -0.00000442 0.00000000 -0.00000000 0.00000000 0.00621968  
 FILTER SIGMAS (EPOCH) = 0.00847158 0.01395388 0.02186394 0.00002117 0.00001695 0.00000756 0.00000000 0.00000000 0.00000000 0.00080044

PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
 STATION/SATELLITE = 4 4 4 4 4  
 FILTER STATE = -0.00000071 0.00003685 -0.00034057 0.00042868 0.00030179  
 FILTER SIGMAS = 0.00000078 0.00006413 0.00497694 0.00495532 0.00491235

.....  
 \$\$\$ RESIDUAL STATISTICS FOR TIME 3780.00 TO 3900.00  
 STATION 4 TYPE 10 N= 11. MEAN= .2635D-06 SIGMA= .0715D-06 WEIGHTED SIGMA= .9014  
 STATION 4 TYPE 13 N= 11. MEAN= -.3911D-03 SIGMA= .1004D-02 WEIGHTED SIGMA= .9356

.....  
 FILTER OUTPUT AT TIME 3840.00  
 NOMINAL TRAJECTORY (ECI)= 3466.9873 -2518.1269 5623.6951 -5.73923 1 96856 4.41958  
 ESTIM. TOTAL (ECI) = 3466.9770 -2518.1306 5623.6885 -5.73924 1 96857 4.41957  
 ESTIM. CORRECTION (HCL) = -0.00080 -0.00167 -0.01326 0.00000 0.00001 -0.00001  
 ESTIM. SIGMA (HCL) = 0.00454 0.00665 0.00310 0.00001 0.00001 0.00001

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 4  
 FILTER STATE (EPOCH) = 0.91119814 0.00398565 -0.00366589 -0.00000089 0.00000747 -0.00000547 -0.00000000 -0.00000000 0.00000000 0.00571648  
 FILTER SIGMAS (EPOCH) = 0.00707678 0.01360885 0.02231765 0.00002163 0.00001703 0.00000581 0.00000000 0.00000000 0.00000000 0.00062654

PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
 STATION/SATELLITE = 4 4 4 4 4  
 FILTER STATE = -0.00000031 0.00003789 -0.00030894 0.00036995 0.00020514  
 FILTER SIGMAS = 0.00000067 0.00005586 0.00497669 0.00495474 0.00490711

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 \$\$\$ RESIDUAL STATISTICS FOR TIME 3900.00 TO 4020.00  
 STATION 4 TYPE 10 N= 3. MEAN= -.1289D-05 SIGMA= .2100D-05 WEIGHTED SIGMA= 1.455  
 STATION 4 TYPE 13 N= 3. MEAN= .2952D-03 SIGMA= .8231D-05 WEIGHTED SIGMA= 6638

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 FILTER OUTPUT AT TIME 3960.00  
 NOMINAL TRAJECTORY (ECI)= 2752.1069 -2262.1794 6107.0271 -6.15931 2 29143 3.62514  
 ESTIM. TOTAL (ECI) = 2752.0951 -2262.1790 6107.0187 -6.15932 2 29144 3.62514  
 ESTIM. CORRECTION (HCL) = 0.00244 0.00151 -0.01410 0.00000 0.00001 -0.00001  
 ESTIM. SIGMA (HCL) = 0.00488 0.00728 0.00438 0.00001 0.00001 0.00001

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 4  
 FILTER STATE (EPOCH) = 0.00747069 0.00299259 -0.00381694 -0.00000222 0.00000586 -0.00000280 0.00000000 0.00000000 0.00000000 0.00515358  
 FILTER SIGMAS (EPOCH) = 0.00664277 0.01362552 0.02291802 0.00002210 0.00001714 0.00000548 0.00000000 0.00000000 0.00000000 0.00054260

PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
 STATION/SATELLITE = 4 4 4 4 4  
 FILTER STATE = -0.00000024 -0.00003459 -0.00018796 0.00022862 0.00020588  
 FILTER SIGMAS = 0.00000064 0.00003997 0.00497624 0.00495414 0.00490696

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AT TIME 4080.00, PARAMETER 10, LABEL 100004 DELETED FROM STATE  
 AT TIME 4080.00, PARAMETER 10, LABEL 200004 DELETED FROM STATE  
 AT TIME 4080.00, PARAMETER 10, LABEL 300004 DELETED FROM STATE  
 AT TIME 4080.00, PARAMETER 10, LABEL 400004 DELETED FROM STATE  
 AT TIME 4080.00, PARAMETER 10, LABEL 400004 DELETED FROM STATE  
 AT TIME 4080.00, PARAMETER 10, LABEL 400004 DELETED FROM STATE

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 FILTER OUTPUT AT TIME 4080.00  
 NOMINAL TRAJECTORY (ECI) = 1992.7473 -1969.6734 6491.4027 -6.47558 2.57706 2.77256  
 ESTIM. TOTAL (ECI) = 1992.7342 -1969.6718 6491.3937 -6.47959 2.57707 2.77255  
 ESTIM. CORRECTION (HCL) = 0.00480 0.00193 -0.01516 0.00001 0.00001 -0.00001  
 ESTIM. SIGMA (HCL) = 0.00511 0.00829 0.00592 0.00001 0.00001 0.00001

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = 0.00746728 0.00299403 -0.00380972 -0.0000223 0.00000586 -0.00000280 0.00000000 0.00000000 0.00000000  
 FILTER SIGMAS (EPOCH) = 0.0054855 0.01365153 0.02351439 0.00002257 0.00001727 0.00000548 0.00000000 0.00000000 0.00000000  
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 FILTER OUTPUT AT TIME 4200.00  
 NOMINAL TRAJECTORY (ECI) = 1201.2029 -1645.3574 6770.6657 -6.69503 2.82090 1.87562  
 ESTIM. TOTAL (ECI) = 1201.1884 -1645.3545 6770.6555 -6.69504 2.82091 1.87561  
 ESTIM. CORRECTION (HCL) = 0.00789 0.00213 -0.01598 0.00001 0.00001 -0.00001  
 ESTIM. SIGMA (HCL) = 0.00525 0.00949 0.00734 0.00001 0.00001 0.00001

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = 0.00746450 0.00299476 -0.00380600 -0.00000223 0.00000586 -0.00000280 0.00000000 0.00000000 0.00000000  
 FILTER SIGMAS (EPOCH) = 0.00665892 0.01367380 0.02409559 0.00002303 0.00001739 0.00000549 0.00000000 0.00000000 0.00000000  
 .....

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 FILTER OUTPUT AT TIME 4320.00  
 NOMINAL TRAJECTORY (ECI) = 390.2692 -1294.4844 6940.3567 -6.80232 3.01909 0.94881  
 ESTIM. TOTAL (ECI) = 390.2535 -1294.4801 6940.3448 -6.80233 3.01911 0.94879  
 ESTIM. CORRECTION (HCL) = 0.01166 0.00203 -0.01625 0.00002 0.00001 -0.00001  
 ESTIM. SIGMA (HCL) = 0.00544 0.01081 0.00849 0.00001 0.00001 0.00001

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = 0.00746213 0.00299513 -0.00380134 -0.00000223 0.00000586 -0.00000279 0.00000000 0.00000000 0.00000000  
 FILTER SIGMAS (EPOCH) = 0.00667557 0.01369326 0.02465691 0.00002349 0.00001751 0.00000550 0.00000000 0.00000000 0.00000000  
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 FILTER OUTPUT AT TIME 4440.00  
 NOMINAL TRAJECTORY (ECI) = -426.9611 -922.7269 6997.7791 -6.79984 3.16852 0.00699  
 ESTIM. TOTAL (ECI) = -426.9777 -922.7210 6997.7653 -6.79985 3.16853 0.00697  
 ESTIM. CORRECTION (HCL) = 0.01598 0.00160 -0.01567 0.00002 0.00000 -0.00001  
 ESTIM. SIGMA (HCL) = 0.00583 0.01220 0.00926 0.00001 0.00001 0.00001

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = 0.00746004 0.00299535 -0.00379656 -0.00000224 0.00000587 -0.00000279 0.00000000 0.00000000 0.00000000  
 FILTER SIGMAS (EPOCH) = 0.00669897 0.01371054 0.02519511 0.00002394 0.00001764 0.00000552 0.00000000 0.00000000 0.00000000  
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FILTER STATE (EPOCH) = -0.01196459 0.00155851 0.01372915 -0.00001392 0.00000734 0.00001233 -0.00000000 0.00000000 0.00000000 -0.00572779  
FILTER SIGMAS (EPOCH) = 0.00709953 0.02355629 0.16470665 0.00015902 0.00007499 0.00000475 0.00000000 0.00000000 0.00000000 0.00051518

PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
STATION/SATELLITE = 31 31 31 31 31  
FILTER STATE = 0.00000134 -0.00009739 0.00337072 -0.00143922 -0.00383002  
FILTER SIGMAS = 0.00000068 0.00004192 0.00389016 0.00481491 0.00419323

\$\$\$\$ RESIDUAL STATISTICS FOR TIME 39660.00 TO 39780.00  
STATION 31 TYPE 10 N= 12. MEAN= -.13900-06 SIGMA= .82170-06 WEIGHTED SIGMA= .6941  
STATION 31 TYPE 13 N= 12. MEAN= .25090-03 SIGMA= .12660-02 WEIGHTED SIGMA= 1.189

FILTER OUTPUT AT TIME 39720.00  
NOMINAL TRAJECTORY (ECI) = 1289.7009 -1668.0161 6748.8733 -6.69912 2.75112 1.96254  
ESTIM. TOTAL (ECI) = 1289.7066 -1668.0199 6748.8689 -6.69912 2.75111 1.96256  
ESTIM. CORRECTION (HCL) = 0.00341 -0.00637 0.00379 -0.00002 0.00000 0.00000  
ESTIM. SIGMA (HCL) = 0.00225 0.00259 0.00216 0.00000 0.00000 0.00000

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1  
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 31  
FILTER STATE (EPOCH) = -0.01191212 0.00195711 0.01112740 -0.00001062 0.00000559 0.00001239 0.00000000 -0.00000000 0.00000000 -0.00539561  
FILTER SIGMAS (EPOCH) = 0.00724170 0.02345464 0.16543332 0.00015942 0.00007507 0.00000398 0.00000000 0.00000000 0.00000000 0.00036306

PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
STATION/SATELLITE = 31 31 31 31 31  
FILTER STATE = 0.00000090 -0.00009307 0.00256003 -0.00112262 -0.00340266  
FILTER SIGMAS = 0.00000057 0.00004095 0.00368938 0.00478503 0.00412870

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\$\$\$\$ RESIDUAL STATISTICS FOR TIME 39780.00 TO 39900.00  
STATION 31 TYPE 10 N= 7. MEAN= .56920-06 SIGMA= .11010-05 WEIGHTED SIGMA= .9007  
STATION 31 TYPE 13 N= 7. MEAN= .46660-03 SIGMA= .15010-02 WEIGHTED SIGMA= 1.365

FILTER OUTPUT AT TIME 39840.00  
NOMINAL TRAJECTORY (ECI) = 477.5626 -1325.3116 6929.1433 -6.81828 2.95292 1.03798  
ESTIM. TOTAL (ECI) = 477.5681 -1325.3157 6929.1406 -6.81828 2.95291 1.03799  
ESTIM. CORRECTION (HCL) = 0.00114 -0.00575 0.00442 -0.00002 0.00000 0.00000  
ESTIM. SIGMA (HCL) = 0.00220 0.00265 0.00228 0.00000 0.00000 0.00000

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1  
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 31  
FILTER STATE (EPOCH) = -0.01028879 -0.00360944 0.04112749 -0.00004005 0.00001975 0.00000865 -0.00000000 -0.00000000 0.00000000 -0.00524538  
FILTER SIGMAS (EPOCH) = 0.00739320 0.02360592 0.16738533 0.00016126 0.00007591 0.00000342 0.00000000 0.00000000 0.00000000 0.00032576

PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
STATION/SATELLITE = 31 31 31 31 31  
FILTER STATE = 0.00000052 -0.00005719 0.00221876 -0.00090583 -0.00338876  
FILTER SIGMAS = 0.00000052 0.00002683 0.00363468 0.00478566 0.00412166

SUMMARY OF RESIDUAL STATISTICS FOR 1082. MEASUREMENTS  
WEIGHTED SIGMA = 1.0160 . SUM(RES\*\*2/RVAR) = 1116.8 . SUM(ALOG(RVAR)) = -21929. . ALOG LIKELIHOOD = 10406.

## SMOOTHER OUTPUT AT TIME 39720.00

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PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0 0 0 31
FILTER STATE (EPOCH) = -0.01191212 0.00195711 0.01112740 -0.00001062 0.00000559 0.00001239 0.00000000 -0.00000000 0.00000000 -0.00539568
SMOOTHER STATE(EPOCH) = -0.01039022 -0.00384667 0.04291335 -0.00004176 0.00002055 0.00000865 -0.00000000 -0.00000000 0.00000000 -0.00524538
SMOOTHER SIGMAS(EPOCH) 0.00719138 0.02323254 0.16449102 0.00015650 0.00007463 0.00000339 0.00000000 0.00000000 0.00000000 0.00032576

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PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS
STATION/SATELLITE = 31 31 31 31 31
FILTER STATE = 0.00000090 -0.00009307 0.00256003 -0.00112262 -0.00340266
SMOOTHER STATE = 0.00000052 -0.00005719 0.00221876 -0.00090583 -0.00338876
SMOOTHER SIGMAS 0.00000052 0.00002683 0.00363468 0.00478666 0.00412166

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NOMINAL TRAJECTORY (ECI) = 1289.7009 -1668.0161 6748.8733 -6.69912 2.75112 1.96254
SMOOTHER TOTAL (ECI) = 1289.7065 -1668.0197 6748.8687 -6.69912 2.75111 1.96256
FILTER ESTIM. (HCL) = 0.0034109 -0.0063667 0.0037916 -0.0000196 0.0000027 0.0000045
SMOOTHER ESTIM. (HCL) = 0.0036475 -0.0061407 0.0036228 -0.0000162 0.0000013 0.0000032
SMOOTHER SIGMA (HCL) = 0.0022143 0.0025912 0.0021084 0.0000040 0.0000030 0.0000025

```

## SMOOTHER OUTPUT AT TIME 39600.00

```

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0 0 0 31
FILTER STATE (EPOCH) = -0.01196459 0.00155251 0.01372915 -0.00001392 0.00000734 0.00001233 -0.00000000 -0.00000000 0.00000000 -0.00572779
SMOOTHER STATE(EPOCH) = -0.01048145 -0.00404558 0.04442501 -0.00004320 0.00002122 0.00000866 -0.00000000 -0.00000000 0.00000000 -0.00524538
SMOOTHER SIGMAS(EPOCH) 0.00699729 0.02283163 0.16142531 0.00015558 0.00007327 0.00000337 0.00000000 0.00000000 0.00000000 0.00032576

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PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS
STATION/SATELLITE = 31 31 31 31 31
FILTER STATE = 0.00000134 -0.00009739 0.00337072 -0.00143922 -0.00383002
SMOOTHER STATE = 0.00000052 -0.00005719 0.00221876 -0.00090583 -0.00338876
SMOOTHER SIGMAS 0.00000052 0.00002683 0.00363468 0.00478666 0.00412166

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NOMINAL TRAJECTORY (ECI) = 2081.0206 -1983.7978 6459.3856 -6.47175 2.50479 2.85583
SMOOTHER TOTAL (ECI) = 2081.0262 -1983.8006 6459.3791 -6.47175 2.50479 2.85584
FILTER ESTIM. (HCL) = 0.0068244 -0.0065368 0.0014804 -0.0000193 0.0000007 0.0000069
SMOOTHER ESTIM. (HCL) = 0.0060435 -0.0062858 0.0021863 -0.0000161 -0.0000000 0.0000061
SMOOTHER SIGMA (HCL) = 0.0024619 0.0025332 0.0018484 0.0000339 0.0000030 0.0000028

```

## SMOOTHER OUTPUT AT TIME 39480.00

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PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0 0 0 31
FILTER STATE (EPOCH) = -0.01230410 0.00525684 -0.00826364 0.00000937 -0.00000419 0.00001339 0.00000000 0.00000000 -0.00000000 -0.00506149
SMOOTHER STATE(EPOCH) = -0.01056495 -0.00422756 0.04581033 -0.00004452 0.00002183 0.00000867 -0.00000000 -0.00000000 0.00000000 -0.00524538
SMOOTHER SIGMAS(EPOCH) 0.00680871 0.02241107 0.15823161 0.00015255 0.00007185 0.00000336 0.00000000 0.00000000 0.00000000 0.00032576

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PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS
STATION/SATELLITE = 31 31 31 31 31
FILTER STATE = 0.00000017 -0.00010301 0.00162578 -0.00079411 -0.00286710
SMOOTHER STATE = 0.00000052 -0.00005719 0.00221876 -0.00090583 -0.00338876
SMOOTHER SIGMAS 0.00000052 0.00002683 0.00363468 0.00478666 0.00412166

```

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NOMINAL TRAJECTORY (ECI) = 2838.7295 -2267.5407 6065.3029 -6.13967 2.21784 3.70344
SMOOTHER TOTAL (ECI) = 2838.7348 -2267.5428 6065.2944 -6.13966 2.21784 3.70345
FILTER ESTIM. (HCL) = 0.0081388 -0.0064660 0.0006029 -0.0000192 -0.0000025 0.0000130

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SMOOTHER ESTIM. (HCL) = 0.0081972 -0.0061156 0.0001315 0.0000155 -0.0000017 0.0000091  
SMOOTHER SIGMA (HCL) = 0.0028091 0.0024538 0.0015978 0.0000037 0.0000029 0.0000032

SMOOTHER OUTPUT AT TIME 39360.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV BIAS 1  
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 31  
FILTER STATE (EPOCH) = -0.01410669 0.00027669 0.02812465 -0.00002710 0.00001280 0.00001384 0.00000000 -0.00000000 -0.00000000 -0.00017022  
SMOOTHER STATE (EPOCH) = -0.01063542 -0.00437357 0.04693069 -0.00004558 0.00002233 0.00000868 -0.00000000 -0.00000000 -0.00000000 -0.00524538  
SMOOTHER SIGMAS (EPOCH) = 0.00662439 0.02197792 0.15495235 0.00014944 0.00007040 0.00000336 0.00000000 0.00000000 0.00000000 0.00032576  
PARAMETER LABELS = BIAS 2 REFRACT STA POS STA POS STA POS  
STATION/SATELLITE = 31 31 31 31 31  
FILTER STATE = 0.00000000 -0.00019862 0.00135949 -0.00064712 -0.00243527  
SMOOTHER STATE = 0.00000052 -0.00005719 0.00221876 -0.00090583 -0.00338876  
SMOOTHER SIGMAS = 0.00000052 0.00002683 0.00363468 0.00478666 0.00412166  
NOMINAL TRAJECTORY (ECI) = 3550.5578 -2514.6368 5572.8383 -5.70807 1.89483 4.49164  
SMOOTHER TOTAL (ECI) = 3550.5628 -2514.6380 5572.9278 -5.70807 1.89482 4.49165  
FILTER ESTIM. (HCL) = 0.0001577 -0.0025187 -0.0048125 -0.0000160 -0.0000025 0.0000120  
SMOOTHER ESTIM. (HCL) = 0.0099593 -0.0055595 -0.0024915 -0.0000141 -0.0000038 0.0000121  
SMOOTHER SIGMA (HCL) = 0.0031416 0.0023383 0.0015530 0.0000034 0.0000029 0.0000036

SMOOTHER OUTPUT AT TIME 39240.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0  
FILTER STATE (EPOCH) = -0.01265382 0.00701380 -0.01826674 0.00001396 -0.00000672 0.00001497 -0.00000000 -0.00000000 -0.00000000  
SMOOTHER STATE (EPOCH) = -0.01067324 -0.00442226 0.04734736 -0.00004596 0.00002250 0.00000870 -0.00000000 -0.00000000 -0.00000000  
SMOOTHER SIGMAS (EPOCH) = 0.00644052 0.02155520 0.15172483 0.00014639 0.00006898 0.00000337 0.00000000 0.00000000 0.00000000  
NOMINAL TRAJECTORY (ECI) = 4204.9572 -2721.0618 4990.2020 -5.18379 1.54090 5.20758  
SMOOTHER TOTAL (ECI) = 4204.9617 -2721.0621 4990.1895 -5.18378 1.54089 5.20759  
FILTER ESTIM. (HCL) = 0.0282220 -0.0138232 -0.0101672 -0.0000231 -0.0000122 0.0000338  
SMOOTHER ESTIM. (HCL) = 0.0111706 -0.0045501 -0.0055869 -0.0000120 -0.0000063 0.0000147  
SMOOTHER SIGMA (HCL) = 0.0033816 0.0021811 0.0018784 0.0000030 0.0000030 0.0000040

SMOOTHER OUTPUT AT TIME 39120.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
STATION/SATELLITE = 0 0 0 0 0 0 0 0 0  
FILTER STATE (EPOCH) = -0.01265457 0.00701294 -0.01825917 0.00001395 -0.00000672 0.00001497 -0.00000000 -0.00000000 -0.00000000  
SMOOTHER STATE (EPOCH) = -0.01068227 -0.00438753 0.04715851 -0.00004577 0.00002241 0.00000872 -0.00000000 -0.00000000 -0.00000000  
SMOOTHER SIGMAS (EPOCH) = 0.00625964 0.02114227 0.14855694 0.00014341 0.00006759 0.00000340 0.00000000 0.00000000 0.00000000  
NOMINAL TRAJECTORY (ECI) = 4791.2909 -2883.4429 4326.4809 -4.57516 1.16175 5.83953  
SMOOTHER TOTAL (ECI) = 4791.2945 -2883.4422 4326.4663 -4.57515 1.16174 5.83955  
FILTER ESTIM. (HCL) = 0.0291601 -0.0107151 -0.0184131 -0.0000157 -0.0000184 0.0000373  
SMOOTHER ESTIM. (HCL) = 0.0116737 -0.0030324 -0.0090038 -0.0000090 -0.0000092 0.0000168  
SMOOTHER SIGMA (HCL) = 0.0034797 0.0019970 0.0025013 0.0000026 0.0000032 0.0000044

SMOOTHER OUTPUT AT TIME 39000.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV

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SMOOTHER OUTPUT AT TIME 34320.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = -0.01288091 0.00667978 -0.01551303 0.00001107 -0.00000539 0.00001506 -0.00000000 -0.00000000 -0.00000000  
 SMOOTHER STATE(EPOCH) = -0.01392362 -0.00775946 0.07764766 -0.00007836 0.00003731 0.00001060 -0.00000000 -0.00000000 -0.00000000  
 SMOOTHER SIGMAS(EPOCH) = 0.00493206 0.01242826 0.08935511 0.00008583 0.00004028 0.00000221 0.00000000 0.00000000 0.00000000  
 NOMINAL TRAJECTORY (ECI) = -2223.5573 -52.8471 6713.8066 -6.41486 3.27666 -2.09260  
 SMOOTHER TOTAL (ECI) = -2223.5492 -52.8539 6713.9084 -6.41486 3.27666 -2.09258  
 FILTER ESTIM. (HCL) = -0.0089958 -0.0045663 0.0057511 -0.0000201 0.0000098 -0.0000152  
 SMOOTHER ESTIM. (HCL) = -0.0068559 -0.0053091 0.0062154 -0.0000159 0.0000082 -0.0000134  
 SMOOTHER SIGMA (HCL) = 0.0031333 0.0028263 0.0014741 0.0000037 0.0000026 0.0000015

SMOOTHER OUTPUT AT TIME 34200.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = -0.01292766 0.00666988 -0.01531427 0.00001087 -0.00000530 0.00001510 -0.00000000 -0.00000000 -0.00000000  
 SMOOTHER STATE(EPOCH) = -0.01410321 -0.00762837 0.07735176 -0.00007815 0.00003717 0.00001082 -0.00000000 0.00000000 -0.00000000  
 SMOOTHER SIGMAS(EPOCH) = 0.00480205 0.01244604 0.08908353 0.00008555 0.00004017 0.00000222 0.00000000 0.00000000 0.00000000  
 NOMINAL TRAJECTORY (ECI) = -1437.9158 -444.5628 6910.0647 -6.66154 3.24315 -1.17230  
 SMOOTHER TOTAL (ECI) = -1437.5068 -444.5683 6910.0639 -6.66155 3.24314 -1.17227  
 FILTER ESTIM. (HCL) = -0.0055320 -0.0062105 0.0078919 -0.0000227 0.0000093 -0.0000112  
 SMOOTHER ESTIM. (HCL) = -0.0038383 -0.0067623 0.0079470 -0.0000188 0.0000081 -0.0000104  
 SMOOTHER SIGMA (HCL) = 0.0027318 0.0026839 0.0014850 0.0000034 0.0000027 0.0000018

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SMOOTHER OUTPUT AT TIME 34080.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = -0.01297605 0.00667141 -0.01518205 0.00001073 -0.00000524 0.00001515 -0.00000000 -0.00000000 -0.00000000  
 SMOOTHER STATE(EPOCH) = -0.01425524 -0.00742048 0.07648873 -0.00007737 0.00003677 0.00001105 -0.00000000 0.00000000 -0.00000000  
 SMOOTHER SIGMAS(EPOCH) = 0.00467897 0.01246169 0.08881470 0.00008530 0.00004007 0.00000223 0.00000000 0.00000000 0.00000000  
 NOMINAL TRAJECTORY (ECI) = -629.0865 -829.1093 6994.4987 -6.80080 3.15733 -0.23302  
 SMOOTHER TOTAL (ECI) = -629.0767 -829.1155 6994.4953 -6.80081 3.15733 -0.23300  
 FILTER ESTIM. (HCL) = -0.0015608 -0.0078040 0.0090308 -0.0000250 0.0000086 -0.0000070  
 SMOOTHER ESTIM. (HCL) = -0.0003089 -0.0081892 0.0088358 -0.0000215 0.0000076 -0.0000069  
 SMOOTHER SIGMA (HCL) = 0.0023868 0.0025538 0.0014495 0.0000031 0.0000027 0.0000022

PARAMETER RECONSTRUCTION. NO = 9 N = 15  
 OLD LABELS = 1 2 3 4 5 6 8 8 8  
 NEW LABELS = 1 2 3 4 5 6 8 8 8 100031 200031 300031 400031 400031 400031

SMOOTHER OUTPUT AT TIME 33960.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV BIAS 1  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 31  
 FILTER STATE (EPOCH) = -0.01302252 0.00669649 -0.01520233 0.00001074 -0.00000526 0.00001520 -0.00000000 -0.00000000 -0.00000000 -0.00516155  
 SMOOTHER STATE(EPOCH) = -0.01436812 -0.00710705 0.07485697 -0.00007583 0.00003601 0.00001128 -0.00000000 0.00000000 -0.00000000 -0.00505704  
 SMOOTHER SIGMAS(EPOCH) = 0.00456801 0.01247485 0.08856004 0.00008507 0.00003997 0.00000226 0.00000000 0.00000000 0.00000000 0.00047105  
 PARAMETER LABELS = BIAS 2 REFRACT STA PDS STA PDS STA PDS  
 STATION/SATELLITE = 31 31 31 31 31  
 FILTER STATE = 0.00000097 -0.00013497 -0.00657906 0.00014390 -0.00368113



SMOOTHER STATE = 0.00000058-0.00012990-0.00740535 0.00008527-0.00344118  
 SMOOTHER SIGMAS 0.00000050 0.00003847 0.00411089 0.00499719 0.00338917

NOMINAL TRAJECTORY (ECI)= 189.8874 -1200.2840 6965.8335 -6.83039 3.02058 0.71017  
 SMOOTHER TOTAL (ECI) = 189.8978 -1200.2898 6965.8272 -6.83039 3.02057 0.71020  
 FILTER ESTIM. (HCL) = 0.0027560 -0.0092531 0.0090843 -0.0000268 0.0000076 -0.0000024  
 SMOOTHER ESTIM. (HCL) = 0.0035906 -0.0094970 0.0087669 -0.0000238 0.0000068 -0.0000027  
 SMOOTHER SIGMA (HCL) = 0.0021466 0.0024374 0.0013534 0.0000028 0.0000028 0.0000025

SMOOTHER OUTPUT AT TIME 33840.00

PARAMETER LABELS	X	Y	Z	XDOT	YDOT	ZDOT	GRAV	GRAV	GRAV	MBIAS 1
STATION/SATELLITE	0	0	0	0	0	0	0	0	0	31
FILTER STATE (EPOCH)	-0.01025805	-0.00352851	0.03989700	-0.00003869	0.00002027	0.00000879	-0.00000000	0.00000000	0.00000000	-0.00420297
SMOOTHER STATE(EPOCH)	-0.01443920	-0.00670008	0.07251688	-0.00007359	0.00003493	0.00001150	-0.00000000	0.00000000	0.00000000	-0.00505704
SMOOTHER SIGMAS(EPOCH)	0.00447487	0.01248474	0.08833056	0.00004487	0.00003989	0.00000230	0.00000000	0.00000000	0.00000000	0.00047105

PARAMETER LABELS	MBIAS 2	REFRACT	STA POS	STA POS	STA POS
STATION/SATELLITE	31	31	31	31	31
FILTER STATE	0.00000099	0.00008011	-0.00238554	0.00012084	-0.00111765
SMOOTHER STATE	0.00000058	-0.00012990	-0.00740535	0.00008527	-0.00344118
SMOOTHER SIGMAS	0.00000050	0.00003847	0.00411089	0.00499719	0.00338917

NOMINAL TRAJECTORY (ECI)= 1005.7564 -1552.0961 6824.5052 -6.74978 2.83505 1.64218  
 SMOOTHER TOTAL (ECI) = 1005.8072 -1552.1013 6824.4959 -6.74978 2.83504 1.64221  
 FILTER ESTIM. (HCL) = 0.0035039 -0.0096903 0.0069416 -0.0000208 0.0000023 0.0000033  
 SMOOTHER ESTIM. (HCL) = 0.0076911 -0.0105755 0.0076408 -0.0000255 0.0000055 0.0000020  
 SMOOTHER SIGMA (HCL) = 0.0020379 0.0023340 0.0012256 0.0000027 0.0000028 0.0000026

SMOOTHER OUTPUT AT TIME 33720.00

PARAMETER LABELS	X	Y	Z	XDOT	YDOT	ZDOT	GRAV	GRAV	GRAV	MBIAS 1
STATION/SATELLITE	0	0	0	0	0	0	0	0	0	31
FILTER STATE (EPOCH)	-0.01173550	-0.00031796	0.02422561	-0.00002062	0.00001225	0.00001148	-0.00000000	-0.00000000	-0.00000000	-0.00317798
SMOOTHER STATE(EPOCH)	-0.01454938	-0.00648348	0.07147197	-0.00007257	0.00003443	0.00001169	-0.00000000	-0.00000000	-0.00000000	-0.00505704
SMOOTHER SIGMAS(EPOCH)	0.00439642	0.01248467	0.08806834	0.00008464	0.00003980	0.00000234	0.00000000	0.00000000	0.00000000	0.00047105

PARAMETER LABELS	MBIAS 2	REFRACT	STA POS	STA POS	STA POS
STATION/SATELLITE	31	31	31	31	31
FILTER STATE	-0.00000033	0.00007278	-0.00029536	-0.00002773	0.00050737
SMOOTHER STATE	0.00000058	-0.00012990	-0.00740535	0.00008527	-0.00344118
SMOOTHER SIGMAS	0.00000050	0.00003847	0.00411089	0.00499719	0.00338917

NOMINAL TRAJECTORY (ECI)= 1805.4718 -1878.8608 6572.7555 -6.56017 2.60367 2.54806  
 SMOOTHER TOTAL (ECI) = 1805.4829 -1878.8654 6572.7431 -6.56017 2.60367 2.54809  
 FILTER ESTIM. (HCL) = 0.0041293 -0.0097481 0.0052776 -0.0000215 -0.0000013 0.0000094  
 SMOOTHER ESTIM. (HCL) = 0.0117773 -0.0112952 0.0053870 -0.0000264 0.0000035 0.0000074  
 SMOOTHER SIGMA (HCL) = 0.0020560 0.0022404 0.0011324 0.0000028 0.0000030 0.0000026

SMOOTHER OUTPUT AT TIME 33600.00

PARAMETER LABELS	X	Y	Z	XDOT	YDOT	ZDOT	GRAV	GRAV	GRAV	MBIAS 1
STATION/SATELLITE	0	0	0	0	0	0	0	0	0	31
FILTER STATE (EPOCH)	-0.01084261	-0.00333562	0.04032661	-0.00003641	0.00001992	0.00000948	-0.00000000	-0.00000000	0.00000000	-0.00320249
SMOOTHER STATE(EPOCH)	-0.01464689	-0.00625672	0.07034010	-0.00007145	0.00003387	0.00001187	-0.00000000	-0.00000000	-0.00000000	-0.00505704
SMOOTHER SIGMAS(EPOCH)	0.00432628	0.01246784	0.08770679	0.00008433	0.00003966	0.00000239	0.00000000	0.00000000	0.00000000	0.00047105

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PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
 STATION/SATELLITE = 31 31 31 31 31  
 FILTER STATE = 0.0000001 0.00010116-0.00022424 0.00001401 0.00047121  
 SMOOTHER STATE = 0.00000058-0.00012990-0.00740535 0.00008527-0.00344118  
 SMOOTHER SIGMAS = 0.00000050 0.00003847 0.00411089 0.00499719 0.00338917

NOMINAL TRAJECTORY (ECI)= 2575.9927 -2175.2889 6214.6000 -6.26450 2.33011 3.41322  
 SMOOTHER TOTAL (ECI) = 2576.0037 -2175.2926 6214.5843 -6.26449 2.33010 3.41325  
 FILTER ESTIM. (HCL) = 0.0071108 -0.0094902 0.0028559 -0.0000184 -0.0000036 0.0000115  
 SMOOTHER ESTIM. (HCL) = 0.0155920 -0.0115129 0.0019852 -0.0000262 0.0000008 0.0000131  
 SMOOTHER SIGMA (HCL) = 0.0021656 0.0021503 0.0011745 0.0000030 0.0000029 0.0000027

SMOOTHER OUTPUT AT TIME 33480.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV MBIAS 1  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0 31  
 FILTER STATE (EPOCH) = -0.01185935-0.00676767 0.06460779-0.00006069 0.00003149 0 00000923-0.00000000-0.00000000 0.00000000 0.00015798  
 SMOOTHER STATE (EPOCH) = -0.01469780-0.00593218 0.06844481-0.00006959 0.00003298 0 00001204-0.00000000 0.00000000-0.00000000-0.00050704  
 SMOOTHER SIGMAS (EPOCH) 0.00425662 0.01243498 0.08722282 0.00008390 0.00003947 0.00000245 0.00000000 0.00000000 0.00000000 0.00047105

PARAMETER LABELS = MBIAS 2 REFRACT STA POS STA POS STA POS  
 STATION/SATELLITE = 31 31 31 31 31  
 FILTER STATE = -0.00000002-0.00000051 0.00020439 0.00002857 0.00137975  
 SMOOTHER STATE = 0.00000058-0.00012990-0.00740535 0.00008527-0.00344118  
 SMOOTHER SIGMAS = 0.00000050 0.00003847 0.00411089 0.00499719 0.00338917

NOMINAL TRAJECTORY (ECI)= 3304.8902 -2436.5711 5755.7709 -5.86736 2.01868 4.22368  
 SMOOTHER TOTAL (ECI) = 3304.9008 -2436.5736 5755.7518 -5.86735 2.01867 4.22371  
 FILTER ESTIM. (HCL) = 0.0084838 -0.0069912 -0.0018416 -0.0000154 -0.0000047 0.0000115  
 SMOOTHER ESTIM. (HCL) = 0.0188414 -0.0110819 -0.0025097 -0.0000246 -0.0000027 0.0000189  
 SMOOTHER SIGMA (HCL) = 0.0023157 0.0020543 0.0014257 0.0000031 0.0000028 0.0000029

SMOOTHER OUTPUT AT TIME 33360.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = -0.00809563 0.00226557-0.00269560 0.00000623 0.00000016 0 00000884 0.00000000 0.00000000 0.00000000  
 SMOOTHER STATE (EPOCH) = -0.01489549-0.00580487 0.06788934-0.00006898 0.00003268 0.00001217-0.00000000 0.00000000-0.00000000  
 SMOOTHER SIGMAS (EPOCH) 0.00418174 0.01238971 0.08662333 0.00008338 0.00003924 0.00000252 0.00000000 0.00000000 0.00000000

NOMINAL TRAJECTORY (ECI)= 3980.3483 -2658.4563 5203.6326 -5.37501 1.67436 4.96626  
 SMOOTHER TOTAL (ECI) = 3980.3581 -2658.4575 5203.6099 -5.37501 1.67435 4.96629  
 FILTER ESTIM. (HCL) = 0.0175172 -0.0141730 -0.0011385 -0.0000156 -0.0000136 0.0000245  
 SMOOTHER ESTIM. (HCL) = 0.0212109 -0.0098631 -0.0079489 -0.0000213 -0.0000071 0.0000240  
 SMOOTHER SIGMA (HCL) = 0.0024536 0.0019452 0.0018710 0.0000031 0.0000027 0.0000032

SMOOTHER OUTPUT AT TIME 33240.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = -0.00809529 0.00226591-0.00269871 0.00000623 0.00000016 0 00000884 0.00000000 0.00000000 0.00000000  
 SMOOTHER STATE (EPOCH) = -0.01489570-0.00581037 0.06823271-0.00006924 0.00003278 0.00001227-0.00000000 0.00000000-0.00000000  
 SMOOTHER SIGMAS (EPOCH) 0.00410578 0.01233420 0.08594364 0.00008279 0.00003898 0.00000260 0.00000000 0.00000000 0.00000000

NOMINAL TRAJECTORY (ECI)= 4591.3958 -2837.3228 4567.0704 -4.79528 1.30267 5.62882  
 SMOOTHER TOTAL (ECI) = 4591.4044 -2837.3225 4567.0442 -4.79526 1.30265 5.62885  
 FILTER ESTIM. (HCL) = 0.0188532 -0.0117729 -0.0069333 -0.0000103 -0.0000173 0.0000255

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SMOOTHER ESTIM. (HCL) = 0.0223922 -0.0077422 -0.0140761 -0.0000164 -0.0000121 0.0000282  
 SMOOTHER SIGMA (HCL) = 0.0025325 0.0018270 0.0024499 0.0000029 0.0000028 0.0000036

SMOOTHER OUTPUT AT TIME 33120.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = -0.00809495 0.00226631 -0.00270220 0.00000623 0.00000015 0.00000884 0.00000000 0.00000000 0.00000000  
 SMOOTHER STATE(EPOCH) = -0.01501208 -0.00589059 0.06906281 -0.00006995 0.00003310 0.00001235 -0.00000000 0.00000000 -0.00000000  
 SMOOTHER SIGMAS(EPOCH) 0.00403126 0.01226886 0.08520073 0.00008214 0.00003663 0.00000267 0.00000000 0.00000000 0.00000000

NOMINAL TRAJECTORY (ECI) = 5128.0876 -2970.2404 3856.3545 -4.13741 0.90958 6.20046  
 SMOOTHER TOTAL (ECI) = 5128.0944 -2970.2384 3856.3248 -4.13740 0.90957 6.20048  
 FILTER ESTIM. (HCL) = 0.0188020 -0.0086115 -0.0126916 -0.0000045 -0.0000209 0.0000251  
 SMOOTHER ESTIM. (HCL) = 0.0221167 -0.0046494 -0.0205240 -0.0000099 -0.0000175 0.0000307  
 SMOOTHER SIGMA (HCL) = 0.0025182 0.0017293 0.0030997 0.0000025 0.0000029 0.0000040

SMOOTHER OUTPUT AT TIME 33000.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = -0.00809462 0.00226678 -0.00270609 0.00000624 0.00000015 0.00000884 0.00000000 0.00000000 0.00000000  
 SMOOTHER STATE(EPOCH) = -0.01512492 -0.00601130 0.07013711 -0.00007087 0.00003353 0.00001241 -0.00000000 0.00000000 -0.00000000  
 SMOOTHER SIGMAS(EPOCH) 0.00395969 0.01219362 0.08440394 0.00008146 0.00003838 0.00000273 0.00000000 0.00000000 0.00000000

NOMINAL TRAJECTORY (ECI) = 5581.6721 -3055.0214 3082.8785 -3.41202 0.50148 6.67171  
 SMOOTHER TOTAL (ECI) = 5581.6766 -3055.0174 3082.9454 -3.41200 0.50146 6.67174  
 FILTER ESTIM. (HCL) = 0.0173428 -0.0047515 -0.0180432 0.0000014 -0.0000247 0.0000232  
 SMOOTHER ESTIM. (HCL) = 0.0201933 -0.0005754 -0.0268249 -0.0000023 -0.0000237 0.0000309  
 SMOOTHER SIGMA (HCL) = 0.0023996 0.0017192 0.0037561 0.0000022 0.0000033 0.0000041

SMOOTHER OUTPUT AT TIME 32880.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = -0.00809429 0.00226731 -0.00271041 0.00000624 0.00000015 0.00000884 0.00000000 0.00000000 0.00000000  
 SMOOTHER STATE(EPOCH) = -0.01522786 -0.00615128 0.07130482 -0.00007188 0.00003400 0.00001245 -0.00000000 0.00000000 -0.00000000  
 SMOOTHER SIGMAS(EPOCH) 0.00389226 0.01210838 0.08356013 0.00008074 0.00003805 0.00000279 0.00000000 0.00000000 0.00000000

NOMINAL TRAJECTORY (ECI) = 5944.7403 -3090.2596 2259.4758 -2.63086 0.08500 7.03474  
 SMOOTHER TOTAL (ECI) = 5944.7419 -3090.2535 2259.4397 -2.63083 0.08498 7.03476  
 FILTER ESTIM. (HCL) = 0.0145296 -0.0002952 -0.0226102 0.0000072 -0.0000271 0.0000197  
 SMOOTHER ESTIM. (HCL) = 0.0165448 0.0044148 -0.0324387 0.0000059 -0.0000283 0.0000285  
 SMOOTHER SIGMA (HCL) = 0.0022083 0.0018824 0.0043501 0.0000022 0.0000038 0.0000040

SMOOTHER OUTPUT AT TIME 32760.00

PARAMETER LABELS = X Y Z XDOT YDOT ZDOT GRAV GRAV GRAV  
 STATION/SATELLITE = 0 0 0 0 0 0 0 0 0 0  
 FILTER STATE (EPOCH) = -0.00809398 0.00226794 -0.00271521 0.00000625 0.00000015 0.00000884 0.00000000 0.00000000 0.00000000  
 SMOOTHER STATE(EPOCH) = -0.01531631 -0.00629638 0.07246483 -0.00007287 0.00003446 0.00001248 -0.00000000 0.00000000 -0.00000000  
 SMOOTHER SIGMAS(EPOCH) 0.00383015 0.01201316 0.08267573 0.00007999 0.00003771 0.00000283 0.00000000 0.00000000 0.00000000

NOMINAL TRAJECTORY (ECI) = 6211.3546 -3075.3575 1399.2162 -1.80665 -0.33305 7.28347

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```

.....
SMOOTHER OUTPUT AT TIME      0 0

PARAMETER LABELS      =  X      Y      Z      XDOT      YDOT      ZDOT      GRAV      GRAV      GRAV
STATION/SATELLITE     =
FILTER STATE (EPOCH)  =  0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
SMOOTHER STATE(EPOCH) = -0.00181402  0.00199352 -0.00173660 -0.00000111  0.00000421  0.00000391 -0.00000000  0.00000000 -0.00000000
SMOOTHER SIGMAS(EPOCH) 0.00390116  0.00372853  0.01237418  0.00001099  0.00000587  0.00000394  0.00000000  0.00000000  0.00000000

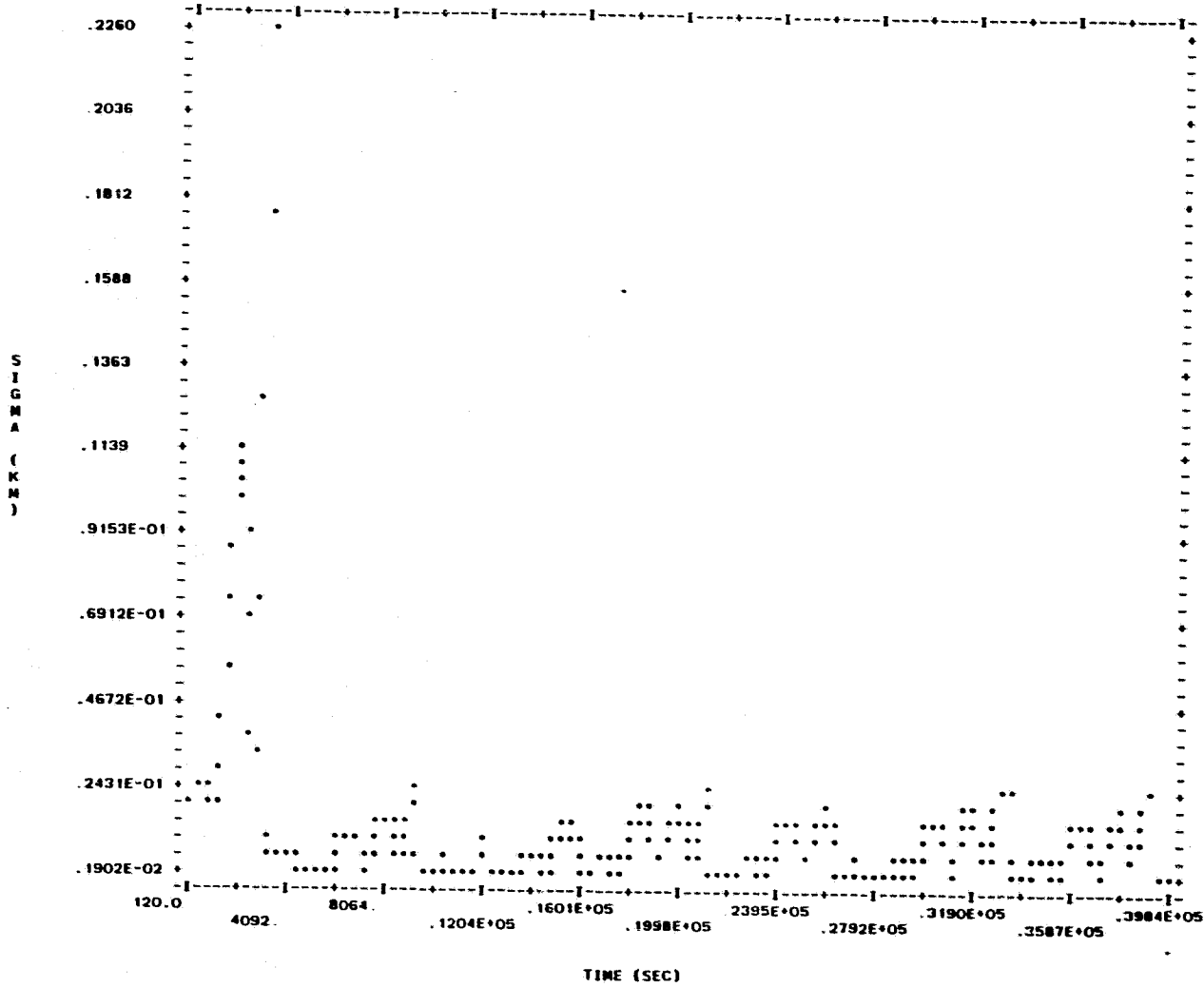
NOMINAL TRAJECTORY (ECI) = -6413.0778  2996.5868  -0.6872  0.45640  0 97591  -7.42596
SMOOTHER TOTAL (ECI)    = -6413.0796  2996.5888  -0.6890  0.45640  0 97592  -7.42596
FILTER ESTIM. (HCL)     =  0.0      0.0      0.0      0.0      0.0      0.0
SMOOTHER ESTIM. (HCL)  =  0.0023729  0.0007936  0.0020050  0.0000030  0.0000038  -0.0000033
SMOOTHER SIGMA (HCL)   =  0.0040975  0.0027677  0.0125615  0.0000120  0.0000029  0.0000043
.....

```

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FILTER POSITION SIGMA (HCL)  
 • REPRESENTS X IN (ECI), H IN (HCL)  
 - REPRESENTS Y IN (ECI), C IN (HCL)  
 + REPRESENTS Z IN (ECI), L IN (HCL)



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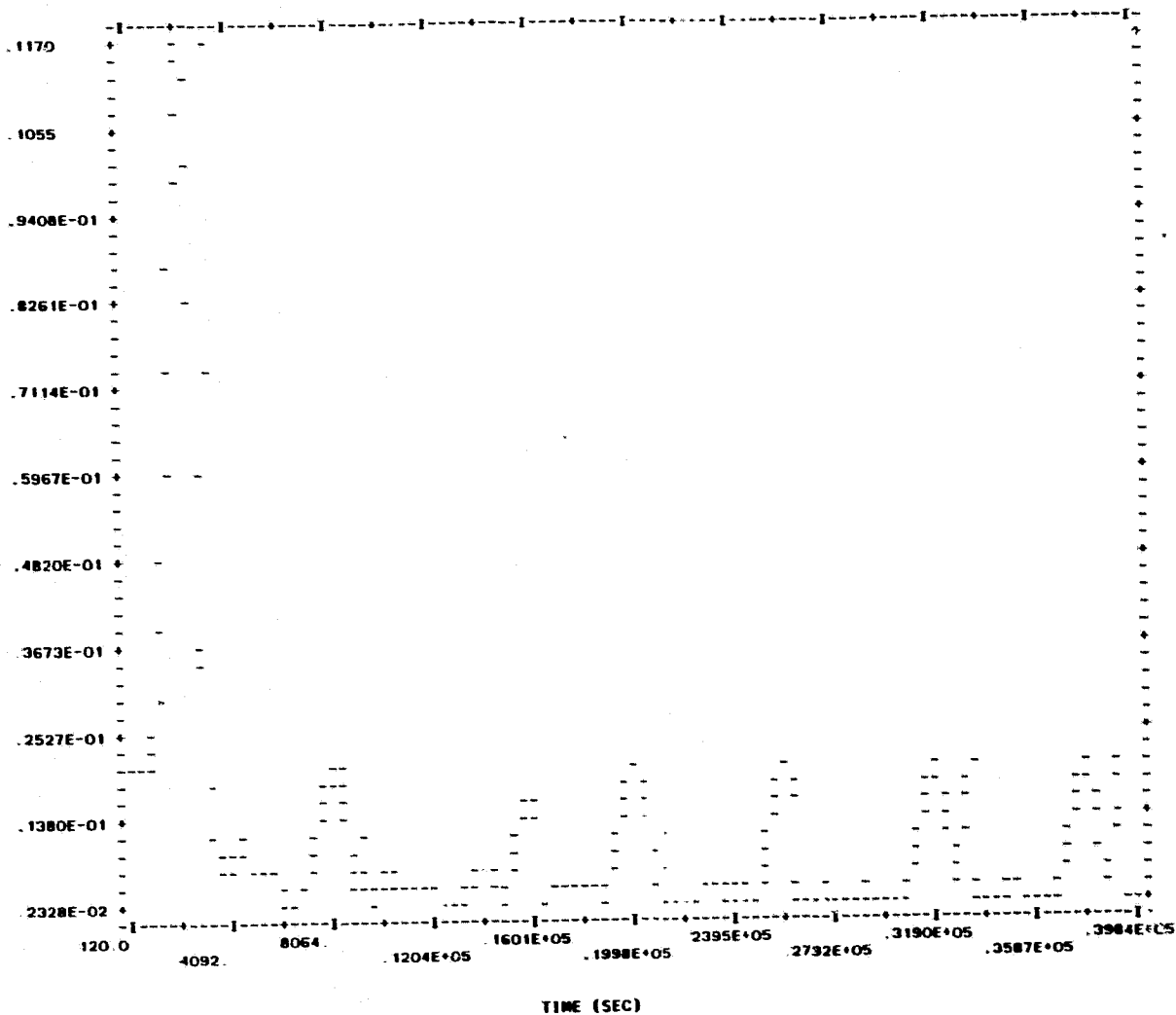
\* -- MEAN= .12951866E-01, SD= .22307243E-01, RMS= .25765587E-01

(USED 332 OF 332 POINTS WITHIN 10. SIGMA)

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FILTER POSITION SIGMA (HCL)  
• REPRESENTS X IN (ECI), H IN (HCL)  
- REPRESENTS Y IN (ECI), C IN (HCL)  
+ REPRESENTS Z IN (ECI), L IN (HCL)



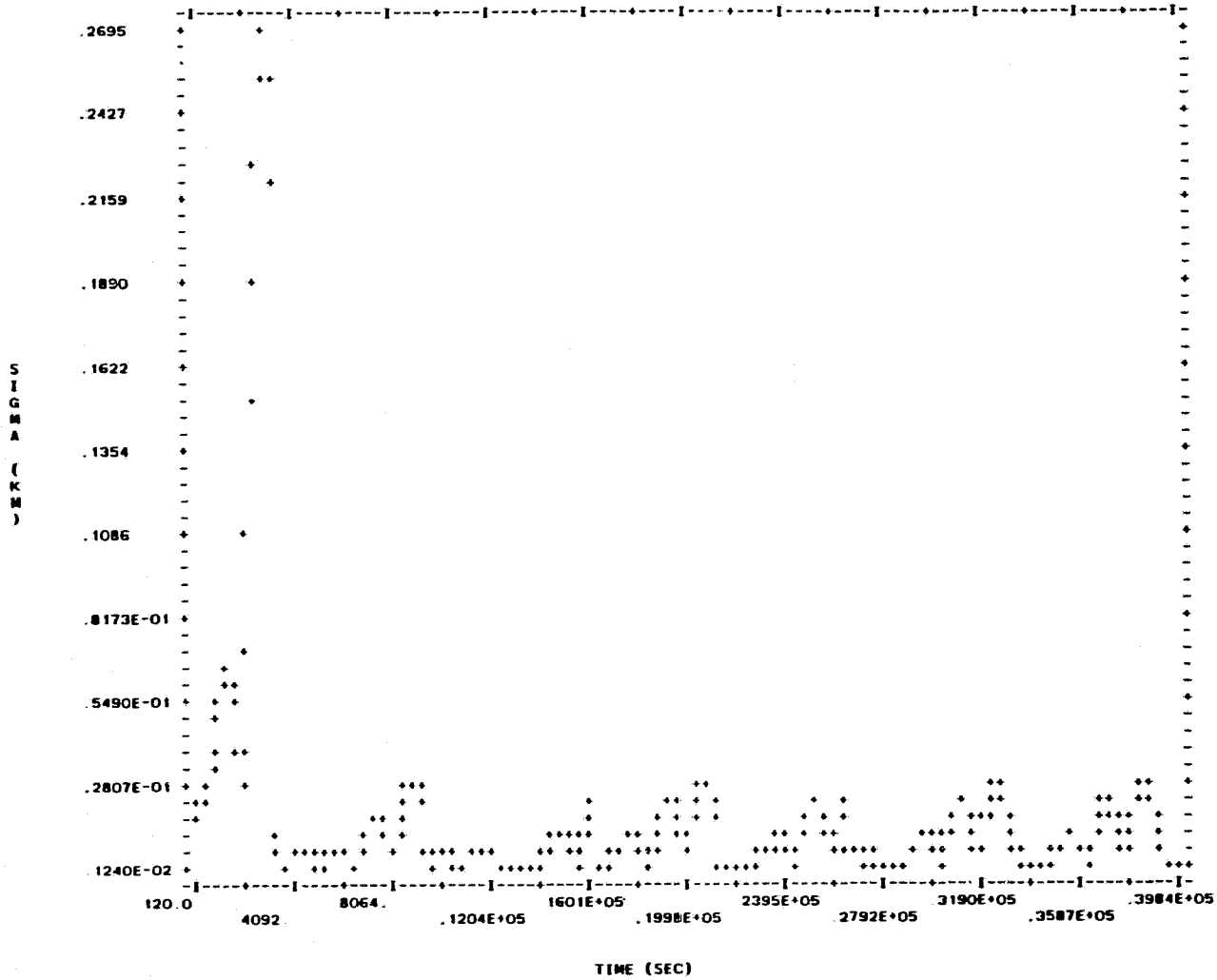
S I G M A

\* -- MEAN= .11350453E-01, SD= 1.261783E-01, RMS= .21478388E-01  
(USED 332 OF 332 POINTS WITHIN 10. SIGMA)

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FILTER POSITION SIGMA (INCL)  
 \* REPRESENTS X IN (ECI), H IN (HCL)  
 - REPRESENTS Y IN (ECI), C IN (HCL)  
 + REPRESENTS Z IN (ECI), L IN (HCL)



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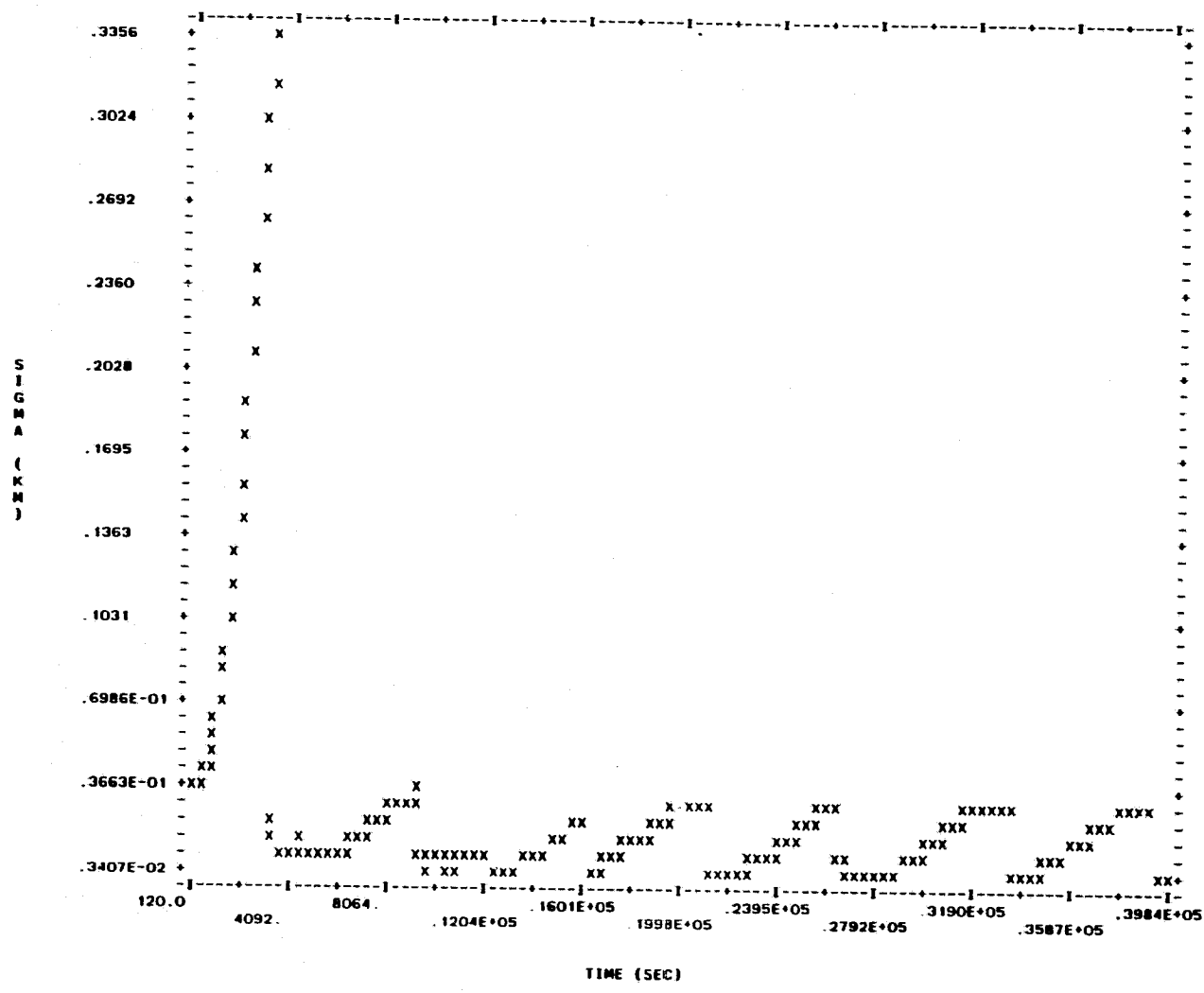
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• -- MEAN= .1692R244E-01. SD= .36083471E-01. RMS= .39807796E-01  
(USED 332 OF 332 POINTS WITHIN 10. SIGMA)

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FILTER POSITION SIGMA (HCL)  
 • REPRESENTS X IN (ECI), H IN (HCL)  
 - REPRESENTS Y IN (ECI), C IN (HCL)  
 + REPRESENTS Z IN (ECI), L IN (HCL)



111  
 SIGMA (KMM)

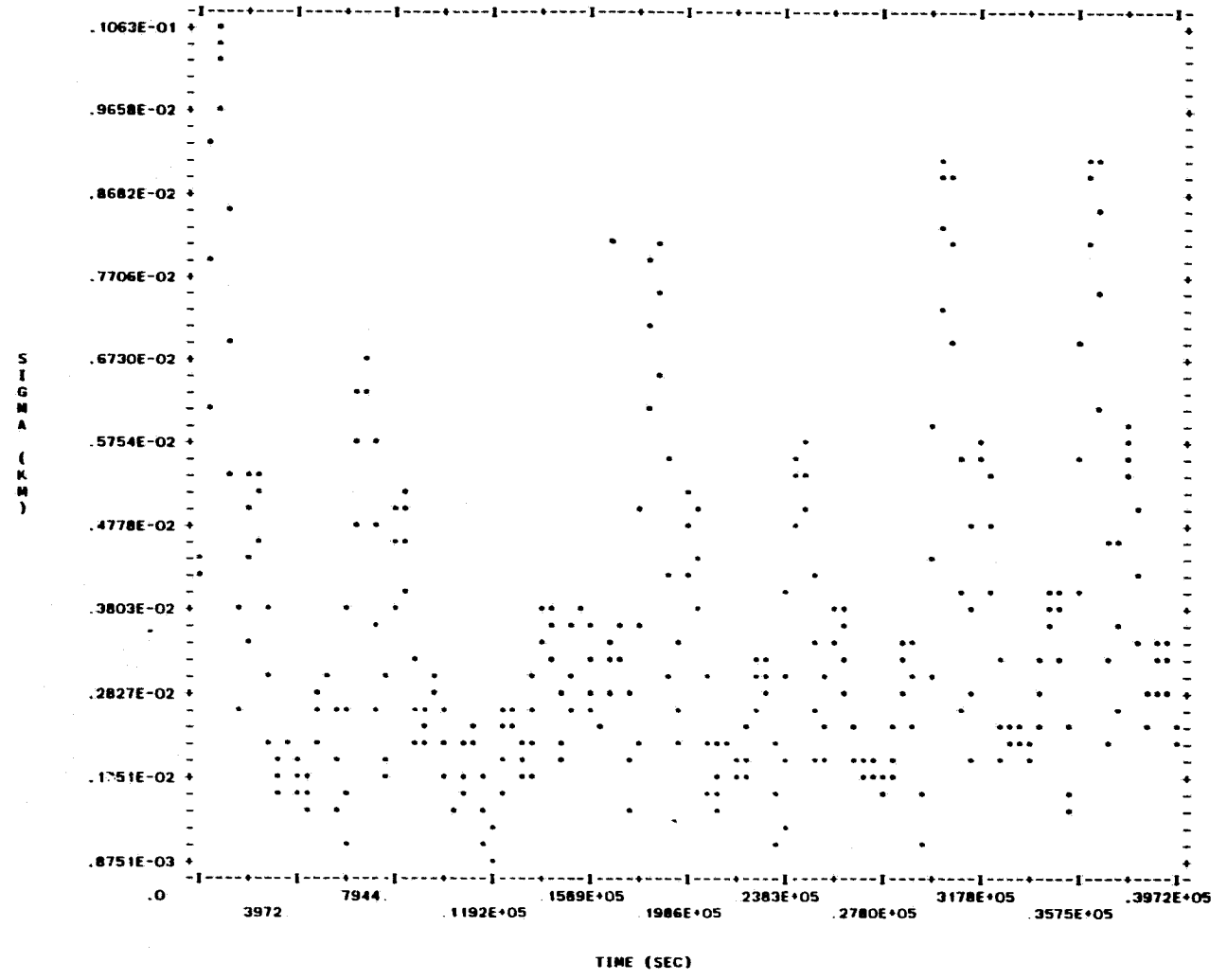
TIME (SEC)

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• -- MEAN= .26011597E-01, SD= .45162126E-01, RMS= .52058402E-01

(USED 332 OF 332 POINTS WITHIN 10. SIGMA)

SMOOTHER POSITION SIGMAS (HCL)  
• REPRESENTS X IN (ECI), H IN (HCL)  
- REPRESENTS Y IN (ECI), C IN (HCL)  
+ REPRESENTS Z IN (ECI), L IN (HCL)



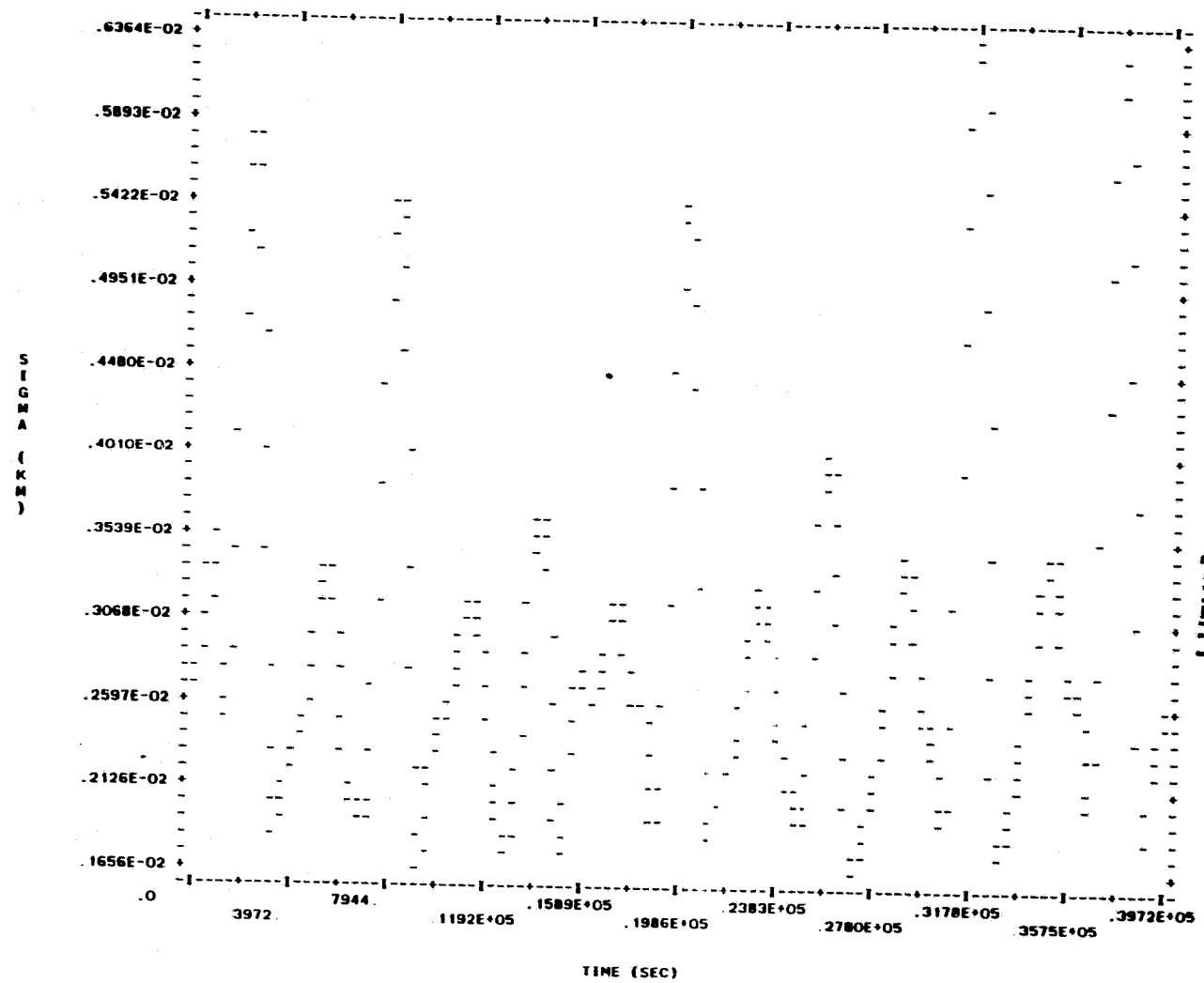
113

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\* -- MEAN= .35237661E-02. SD= .19338729E-02. RMS= .40181465E-02  
(USED 332 OF 332 POINTS WITHIN 10. SIGMA)

SMOOTHER POSITION SIGMAS (HCL)  
• REPRESENTS X IN (ECI), H IN (HCL)  
- REPRESENTS Y IN (ECI), C IN (HCL)  
• REPRESENTS Z IN (ECI), L IN (HCL)



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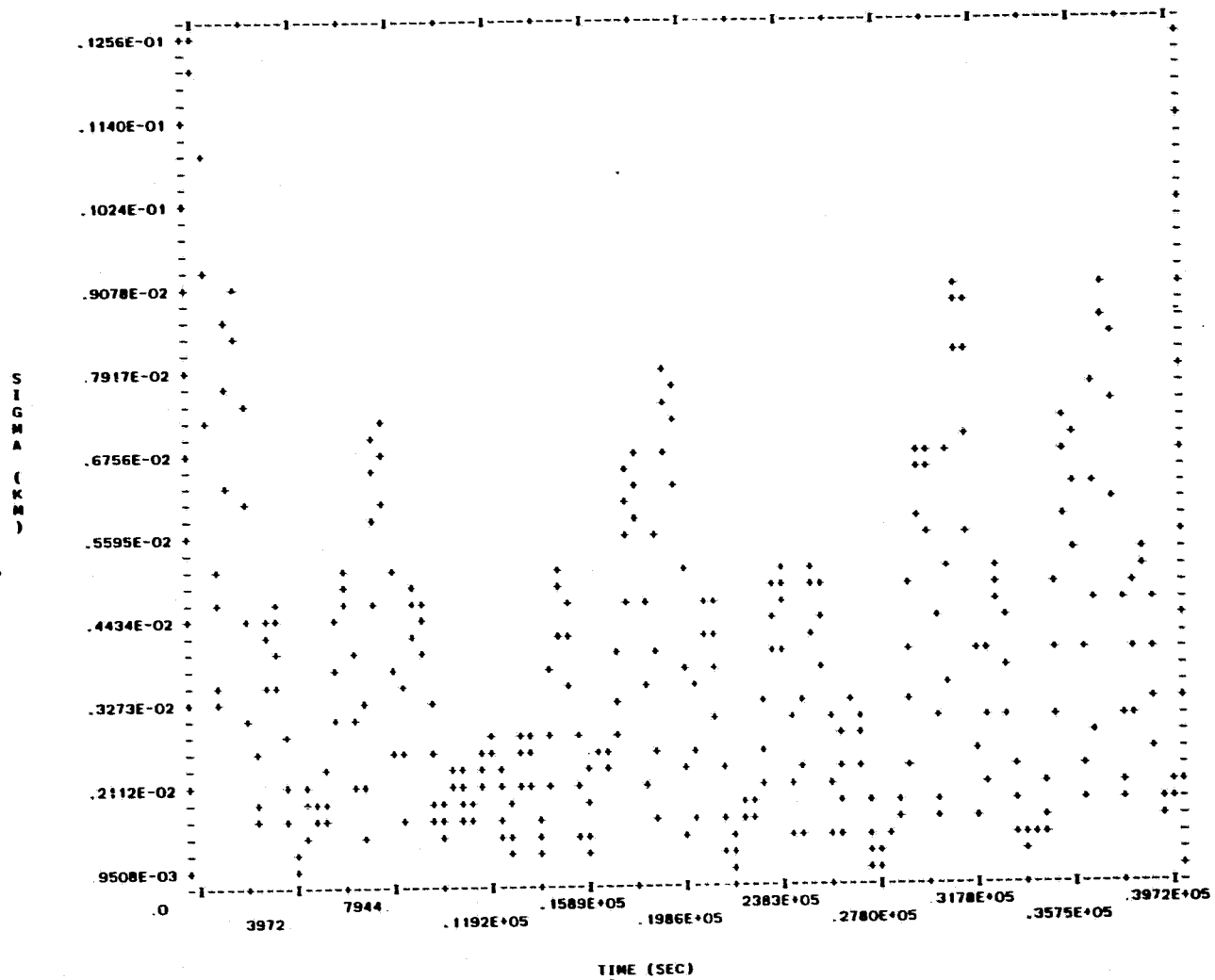
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\* -- MEAN= .29874777E-02, SD= .10701504E-02, RMS= .31728214E-02  
(USED 332 OF 332 POINTS WITHIN 10. SIGMA)

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SMOOTHER POSITION SIGMAS (HCL)  
 \* REPRESENTS X IN (ECI), H IN (HCL)  
 - REPRESENTS Y IN (ECI), C IN (HCL)  
 + REPRESENTS Z IN (ECI), L IN (HCL)



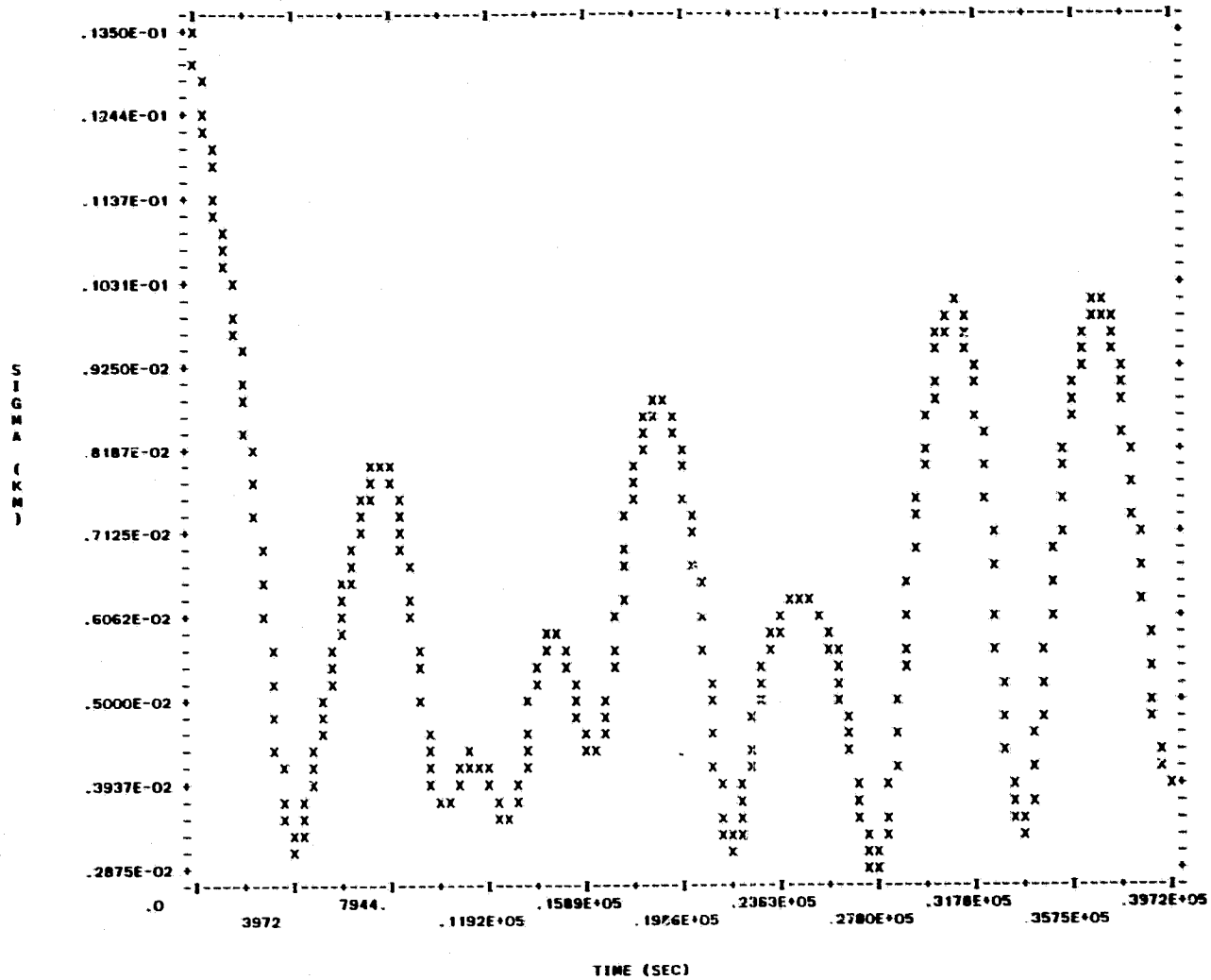
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\* -- MEAN= .62650368E-02, SD= .22927150E-02, RMS= .56701844E-02

(USED 332 OF 332 POINTS WITHIN 10 SIGMA)

SMOOTHER POSITION SIGMAS (HCL)  
 • REPRESENTS X IN (ECI), H IN (HCL)  
 - REPRESENTS Y IN (ECI), C IN (HCL)  
 + REPRESENTS Z IN (ECI), L IN (HCL)



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\* -- MEAN= .36805279E-02, SD= .21797807E-02, RMS= .42758106E-02  
(USED 332 OF 332 POINTS WITHIN 10. SIGMA)

6.0 JOB CONTROL LANGUAGEORIGINAL PAGE IS  
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The listing following this paragraph is an example of the JCL required to run PREFER on the IBM 360/95. The core required to run PREFER (without overlays) using the loader is approximately 370K. This will vary somewhat depending upon the program options (e.g. GPSPAC/TDRS measurements, plots, smoothed covariance file) and number of I/O buffers. The use of overlays would only reduce the storage by approximately 50K. When tracking from many GPS satellites is processed, it may be necessary to increase the region to 500K. Printout from the job will define (approximately) the actual region used by PREFER.

```
// EXEC LOADER, REGION.GO=370K, PARM='SIZE=370000, EP=MAIN'
//SYSLIN DD
//      DD DSN=%%OBJ, DISP=(OLD, DELETE)
//      DD DSN=YCBPG.GSPACE, OBJ, DISP=SHR
//      DD DSN=YCBPG.CDCIO, OBJ, DISP=SHR
//GO.FT09F001 DD UNIT=2400-9, VOL=SER=36493, LABEL=(3, NL, , IN),
// DCB=(RECFM=VBS, LRECL=7204, BLKSIZE=7208, BUFNO=1), DISP=(OLD, KEEP)
//GO.FT10F001 DD UNIT=DISK, DSN=%%MEAS, DISP=(NEW, DELETE),
// DCB=(RECFM=VBS, LRECL=7204, BLKSIZE=7208, BUFNO=1), SPACE=(CYL, (2, 1))
//GO.FT11F001 DD DUMMY, DCB=BLKSIZE=100
//GO.FT20F001 DD DSN=ORBIT.GTDS.SLP1950.DATA, DISP=SHR, DCB=BUFNO=1
//GO.FT21F001 DD DSN=ORBIT.GTDS.TIMCDF.DATA, DISP=SHR
//GO.FT22F001 DD DSN=ORBIT.GTDS.SLPTOD.DATA, DISP=SHR, DCB=BUFNO=1
//GO.FT30F001 DD UNIT=DISK, DSN=%%U30, DISP=(NEW, DELETE),
// DCB=(RECFM=VBS, LRECL=108, BLKSIZE=3244, BUFNO=1), SPACE=(TRK, (10, 2))
//GO.FT40F001 DD DUMMY, DCB=BLKSIZE=100
//GO.FT41F001 DD DUMMY, DCB=BLKSIZE=100
//GO.FT42F001 DD DUMMY, DCB=BLKSIZE=100
//GO.FT43F001 DD DUMMY, DCB=BLKSIZE=100
//GO.FT50F001 DD UNIT=AFF=FT09F001, LABEL=(4, NL, , IN), VOL=SER=36493,
// DCB=(RECFM=VBS, LRECL=6664, BLKSIZE=6668), DISP=(OLD, KEEP)
//GO.MASSTORE DD UNIT=DISK, DSN=%%U60, DISP=(NEW, DELETE),
// SPACE=(CYL, (5, 2))
//GO.FT70F001 DD UNIT=DISK, DSN=%%ORB1, SPACE=(TRK, (10, 2)),
// DCB=(RECFM=VBS, LRECL=X, BLKSIZE=7294, BUFNO=1), DISP=(NEW, PASS)
//GO.FT71F001 DD UNIT=DISK, DSN=%%TPL1, SPACE=(CYL, (2, 2)),
// DCB=(RECFM=VBS, LRECL=X, BLKSIZE=7294), DISP=(NEW, DELETE)
//GO.DATAS DD *
```

Figure 7.1 Example of PREFER JCL for Processing Ground Tracking

Notice that Fortran units 9 and 50 use the same tape and tape drive. Unit 9 refers to file 1 (the observation file) and unit 50 refers to file 2 (the ORBIT file). PREFER internally copies unit 9 to unit 10 (disk) so that the input files from the GTDS run may be placed on the same tape.

Fortran unit MASSTORE is the scratch disk used by the filter and smoother to store the intermediate covariance matrices and other arrays. The DCB information is internal to PREFER. The space allocation of (5,2) cylinders should be adequate for most jobs. Unfortunately, it is very difficult to compute the storage required in a given run. It depends upon the number of states adjusted at each point in time. Since the number of states varies greatly during the run (as ground stations and GPS satellites change visibility to the satellite), the storage requirements can also vary greatly. In general, it should not be necessary to change the space allocation unless many GPS satellites are included.

Fortran unit 30 is also scratch storage. However, the storage requirements are modest since only the filtered and smoothed state vectors are stored here.

Units 70 and 71 are used for temporary storage of plotting variables and thus they cannot be ignored (e.g., "DUMMY") if plots are requested. Again the storage requirements are modest. Unit 71 is also used to output the smoothed covariance when this option is requested. The storage requirements for the smoothed covariance can be as large as 50 megabytes although 5 megabytes is a more typical number.

7.0 REFERENCES

- (1) Gibbs, B. P., "Precision Recursive Estimator for Ephemeris Refinement (PREFER/GALAXY) Mathematical Description", Business and Technological Systems, Inc., FR-81-141, February 1981.
- (2) Goddard Trajectory Determination System (GTDS) Users' Guide, NASA/Goddard Space Flight Center, July 1975.
- (3) Edwards, A. W. F., "Likelihood: An Account of the Statistical Concept of Likelihood and its Application to Scientific Inference". Cambridge University Press, London 1972.
- (4) Goddard Trajectory Determination System (GTDS) Data Sets Layout, NASA/Goddard Space Flight Center, January 1980.

APPENDIX A  
PREFER Debug Printout

FILTER (IBUG(1))

ND - number of dynamic parameters  
TL - time of last entry to FILTER (sec)  
T - current time (epoch of mini-batch) (sec)  
X - state vector at epoch time of mini-batch  
PHI - state transition matrix (TL to T)  
X - state vector (at time T) is printed after each measurement

MEAS (IBUG(2))

TI - time of measurement (referenced to epoch of Host Trajectory)  
ISTA - station/satellite number  
MTYPE - measurement type  
Y - measurement  
YD - measurement residual  
SIGM - input  $\sigma$  of measurement  
PY - partial derivatives of measurement WRT state

SNOISE (IBUG(3))

T - current time (sec)  
OLDT - time of last entry to SNOISE (sec)  
ND - number of dynamic parameters  
X - state vector at time T (only dynamic states are printed)  
PHI - state transition matrix (OLDT to T)  
F - 6 x NP6 partial array (current cartesian elements WRT state vector) multiplied by DT  
A = F · QA where QA is spectral density matrix (state noise)  
Q = ND x ND state noise matrix in ECI coordinates



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After transformation to epoch osculating elements, Q is printed again along with PHI4 (the transition matrix from epoch osculating elements to current cartesian elements)

DYNAM (IBUG(4))

TSTART - reference time (start of integration)

TEND - end time of integration

DT = TEND-TSTART

STMAX - maximum allowed step size (with sign) for Taylor series integration

HSTEP - current step size of iterated integration

HLFSTP = HSTEP/2

TK - current time of iterated integration

OLDTK - last TK

PHI1 - 6x6 transition matrix - cartesian (OLDTK) to cartesian (TK)

PHI4 - 6x6 transition matrix - epoch osculating to cartesian (TEND)

PHI - NDxND output state transition matrix

XI - nominal cartesian elements at TEND

XOUT - filter estimate of dynamic states at TEND

CARD (IBUG(3))

NUMCDS - number of adjusted parameters initialized

LAB - parameter labels as read in

SIG - *a priori*  $\sigma$ 's as read in

QN - state spectral density as read in

STAVAR - station measurement variances as read in

NDRAG - number of drag parameters

NGRAV - number of gravitational parameters

NTHRST - number of thrust parameters

NCLOCK - number of clock parameters

NALT - number of altimeter parameters

NPARM = NDRAG+3\*(NTHRST+NGRAV)

NP6 = 6 + NPARM

ND = number of dynamic parameters (NP6+NCLOCK+NALT)

NBIAS - 0 or 1 (1 indicates that biases are adjusted)

NREFR - 0 or 1 (1 indicates that refraction parameters are adjusted)

INTERG (IBUG(6))

NSAT - satellite number (1-24)

TK1 - current time in seconds from epoch of host tape

TK - current time in seconds from epoch of GPS tape

E - interpolated position and velocity at TK

GETVEC (IBUG(6))

REQTIM - interpolation time

XTO - interpolated satellite position and velocity at REQTIM

EARTH (IBUG(7))

T - time from epoch

STAPOS - station positions (Earth Centered Fixed)

XSTA - station positions and velocities (Earth Centered Inertial)

EVAL (IBUG(7))

CETOL - time tolerance for ephemeris computation

NWSLP - Fortran unit number for SLP file

REFDA2 modified Julian date corresponding to January 1950.0

REFDA4 modified Julian date corresponding to initial conditions

NCFDAY - number of days per curve fit

TSEC - time in seconds from start of year to midpoint of this record time interval

PDELH - polynomial coefficients for delta H

IDAY - beginning day of current record

IND13 - polar motion switch (1 - compute polar motion)

USUN(3) - sun vector

A - transformation matrix: selenocentric to selenographic

ADOT -  $\dot{A}$

B - transformation matrix: earth inertial (TOD) to earth fixed

C - transformation matrix: mean of 1950.0 to true of date

GHA - Greenwich hour angle

XP - X polar motion angle

YP - Y polar motion angle

TZERO - number of A.1 seconds from 1950 to epoch

TZERO1 - time in seconds from beginning of ephemeris year to epoch

DEPOCH - Julian date of epoch

AZERO - difference between A.1 and UTC time at epoch

APPENDIX B  
Guidelines for Setting Up GTDS Runs

Since PREFER must use files created by GTDS, it is important that the GTDS run be set up correctly. The following guidelines are given.

- 1) The GTDS run must create an Observation Save File (Unit 46) and an ORBIT file with partial derivatives (Unit 21) on magnetic tape. The input cards required to do this are:

<u>1 - 8</u>	<u>9 - 11</u>	<u>12 - 14</u>	<u>15 - 17</u>	<u>18 - 38</u>	<u>39 - 59</u>	<u>60 - 80</u>
SAVE	1					time
OUTOPT	0	1	0	start time	end time	interval

It is suggested that a time interval of 30 seconds be used.

- 2) It is strongly recommended that the Observation Save File and the Orbit File be placed on the same tape (with the Observation file first) and tape drive (use UNIT=AFF). This will minimize the number of tapes and drives required for both the GTDS and PREFER runs.
- 3) Time regularized integration must not be used.
- 4) Partial derivatives for the ORBIT file should be cartesian orbital elements with respect to epoch orbital elements. The epoch elements may be cartesian, Keplerian or spherical, but cartesian are preferred.
- 5) Since PREFER is intended to produce accurate ephemerides, it is important that the best models available be used in GTDS. In particular, the refraction corrections should be made in GTDS even though this increases the computer costs of a differential correction run. This is done using an OBSCORR card.

APPENDIX C

Subroutine GSPACE

The subroutine GSPACE gives the user the capability to dynamically allocate core, that is, to allocate core for an array or a number of arrays during the execution of the program. This frees the user from hard-coding the dimension of arrays which will vary in size from run to run.

GSPACE works by taking the amount of core (in bytes) requested by the user, incrementing it up to the next multiple of 8, and then issues a GETMAIN instruction for that amount of core. GSPACE then calculates the offset, in numbers of 4 byte words, from some specific (hard) dimensioned variable to the first location of the space obtained. The user may then access this space by specifying the offset as an index to the (hard) dimension variable.

General Format

CALL GSPACE (N, NA, NB, &Y, &Z)

where

N = the number of arrays for which core is being requested  
(INPUT TO GSPACE)

NA = an integer array of dimension N: the 1st element of A is set equal to the amount of core (bytes) requested for the 1st array, the 2nd element is set equal to the amount of core requested for the second array, etc. (INPUT TO GSPACE)

NB = an integer array of dimension N: the 1st element is set equal to the offset in 4 byte words from NA(1) to the storage area for the first array, the 2nd element is set equal to the offset in 4 byte words from NA(1) to the storage area for the second array, etc. (OUTPUT FROM GSPACE)

Y = the line to which control is transferred if the amount of core requested by the user is not available. (OUTPUT FROM GSPACE)

Z = the line to which control is transferred if the call format is incorrect or the input variables contain invalid values (negative or real numbers) (OUTPUT FROM GSPACE)

Example:

```
DIMENSION NA(2), NB(2)
NA(1) = NPARMS * 4
NA(2) = NDEV * 8
CALL GSPACE (2, NA, NB, & 100, & 200)
```

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To access the storage area for the 1st array, specify  $NA(NB(1) + I)$ ,  $I = 1, NPARMS$ .  $NPARMS$  4-byte words can be stored in this space. To access the storage area for the 2nd array, specify  $NA(NB(2)+I)$ ,  $I = 1, NDEV*2$ . Either  $NDEV*2$  4-byte words or  $NDEV$  8-byte words can be stored in this area. Note that the offset to the 2nd storage area will be calculated from  $NA(1)$  and not  $NA(2)$ .

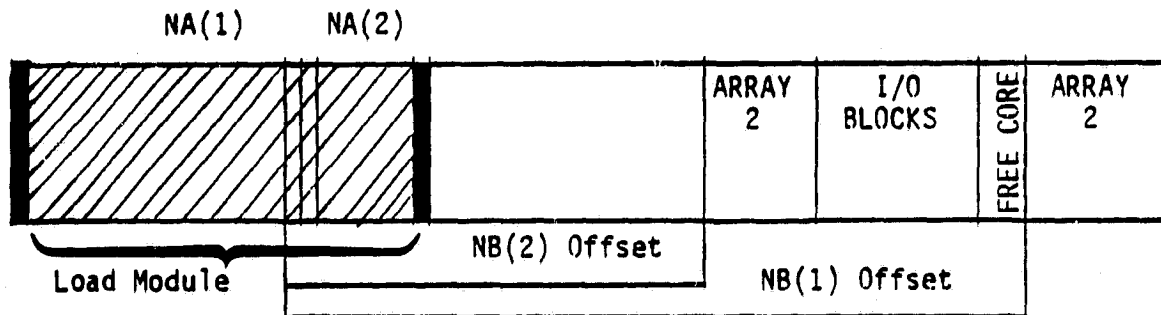
How GSPACE works:

GSPACE first takes the input array NA values and checks to see if they are valid numbers. If they are, it then rounds them up to the next multiple of eight, even if they are already a multiple of eight. GSPACE then calls a routine which issues a separate GETMAIN instruction for each array requested. This will not necessarily result in the different array storage areas (within the same call to GSPACE) being contiguous (if the user has indeed requested multiple array storage areas). If the core is not available for any one of the GETMAIN requests, control is transferred to the line specified for Y. If all the core requested is available, GSPACE then enters a loop to calculate the offsets by the following algorithm:

$$NB(I) = \frac{\left( \begin{array}{l} \text{Storage address of first location} \\ \text{in array I storage area} \end{array} \right) - \left( \begin{array}{l} \text{storage address} \\ \text{of NA(1)} \end{array} \right)}{4} + 1$$

When the loop is complete, control returns to the calling program. Because the GETMAIN always gets core in the highest location (within the region) that is possible, subsequent GETMAIN's will likely get core closer to the load module (stored in the lowest region locations of core), and therefore the increments will decrease, i.e.,  $NB(1) > NB(2) > NB(3) \dots$ . This will not necessarily be true if less core is requested by the subsequent GETMAIN's, i.e.,  $NA(1) > NA(2) > NA(3) \dots$ .

REGION AVAILABLE



Other Entry Points

CALL RELESE (N, NA, NB) - releases core allocated in a previous call to GSPACE. N, NA and NB have the same definitions as for GSPACE.

CALL REGION - computes IREG in common block CORE\$\$.

CALL GCORE - computes MCOR and ICORE in common block CORE\$\$.

Note: GCORE will allocate the entire region specified on the EXEC statement. Thus the user should ignore the SIZE listed in the job system messages.

Common Block/CORE\$\$/

IREG - allocated region (in bytes) of current job step (from REGION parameter on EXEC statement).

MCOR - maximum unused region (bytes) in any previous call to GCORE (including the current call).

ICORE - unused region (bytes) at the current call to GCORE.



APPENDIX D

Description of "CDC Type" Disk  
Random Access I/O Package

PREFER uses an assembly language subroutine which simulates "CDC type" random access disk I/O on an IBM 360. This subroutine has several advantages compared to standard IBM random access (or DAIO) in that the length and number of records can be variable. In fact, it is possible to write over existing records with a different length as long as that length is less than or equal to the old length. Although this routine is not suitable for use with permanent data sets, it is very useful for scratch storage within a program. This routine is documented here since it is general purpose and may be useful for a variety of other applications.

The subroutine has six entry points: OPENMS, ENDMS, WRITSS, WRITMS, READMS AND CLOSMS. A description of each of these functions is given below.

- 1) CALL OPENMS(IX) - Opens mass storage (DDNAME=MASSTORE) for write/print/sequential access and saves the address of the record index for use by the routines WRITSS, READMS, and WRITMS. IX is an integer array which must be dimensioned as large as the number of records to be written. Note that the DCB information for MASSTORE is obtained internally in the routine. The user need only specify UNIT, DISP and SPACE.
- 2) CALL WRITSS(IA,IR) - Writes a record to the next available space and stores the relative address in the index. If the entire record will not fit on the current track, then the remainder of the record is segmented and written to subsequent tracks. IA is the data array to be written to disk and IR is the record number. Note: The first 4-byte integer of IA must contain the length of the record in words (4-bytes). The example at the end demonstrates the use of WRITSS and READMS for writing and reading double precision words.

- 3) CALL ENDMS - closes the mass storage data set for sequential access, alters the macro form of the DCB to read/point and reopens the data set for update.
- 4) CALL READMS(IA,IR) - reads a record from mass storage. If the record spans several tracks then it will be brought in segment by segment. The point macro is used to position the disk at the beginning of the records. Each read attempts to read an entire track of data (incorrect length is ignored). The actual length of segments read in is computed from the residual count in the CSW, and segments are read in until the total number of bytes read equals the record length. It is assumed that the record length is stored in the 1st fullword of the record. IA is the array to which data will be retrieved from the disk and IR is the record number.
- 5) CALL WRITMS(IA,IR) - writes an updated record back to mass storage. If the record spans several tracks, then it will be rewritten in segments. The point macro is used to specify the disk address of each segment. On each write, a length of one track is specified, and incorrect length errors are intercepted by the SYNAD routine 'EX'. The actual length of a written segment is determined from the residual count in the CSW. Segments are written until the total number of bytes written equals the record length. The definitions of IA and IR are the same as for WRITSS. Note that the length of the updated record must be less than or equal to the length of the old record.
- 6) CALL CLOSMS - closes the mass storage dataset.

ERROR CODES

The routines can abend with 5 different error codes. Core dumps are produced by these abends.

- 103 - error in WRITSS: too many bytes have been written.
- 104 - error in READMS: too many bytes have been read. Record length was probably incorrect.
- 105 - error in WRITMS: too many bytes have been written.
- 106 - error in WRITMS: I/O error other than incorrect length.
- 999 - error in READMS: ENDMS was not called prior to first call to READMS.