MRD 196- Satellite Ephemerides

Data Product Overview
The "satellite ephemerides" data product is a contingency data product needed only in the event that a satellite of Bennu is identified. It will consist of SPK and NIO files containing Bennu-relative trajectory information for Bennu's satellites, which can be used for analyzing stability and safety concerns of the spacecraft. Uncertainty information will also be provided in a PDF report that will accompany the files.

Overview
In the satellite contingency, this data product is used for safety, science value, and long-term science.

This product will be delivered as binary SPK and NIO files.

Inputs:

(x, y) location of satellite in image, provided by Satellite Search effort
Associated raw images of satellites

Spacecraft CK kernel (attitude)

Spacecraft SPK kernel (trajectory)
Time of images in SCET

In general, ephemeris file delivery will require 2-3 days to complete the analysis and the associated report after receipt of all inputs. The first delivery for a new satellite could take longer, as much as one week for a robust solution.

Data Product Structure and Organization
This data product is delivered as binary SPK and NIO files along with a pdf report.

The PDF report will contain satellite orbit reconstruction information, such as accuracy of the satellite orbit(s), residual, etc. A report will be delivered for each satellite ephemeris delivery.

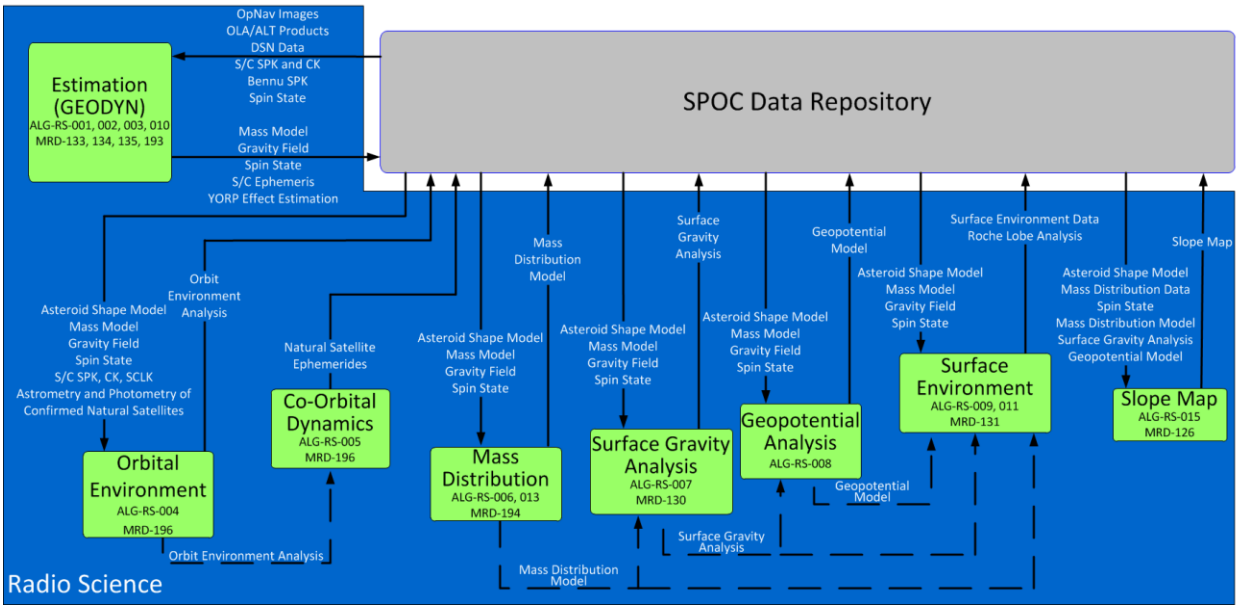
Data Format Descriptions
The satellite ephemeris file will be delivered in SPK AND NIO file format, which contains Chebyshev polynomial coefficients of the satellite trajectories.
The documentation for NIO format is available from ftp://ssd.jpl.nasa.gov/pub/eph/small_bodies/orex/doc/. A copy retrieved 2016-03-10 is here:

Data Product Generation
The satellite ephemerides will be generated at JPL through a least-squares orbit determination process using the onboard optical imagery of the satellite(s). The cadence of ephemeris updates will be as appropriate for the mission phase and satellite orbital stability. In the first few weeks after discovery updates will be appropriate 2-3 times per week. After about one month of regular observation, weekly updates will be appropriate, and after several months of observation monthly reports are expected to be sufficient. This process is also discussed here.

Data Product Validation
The delivered ephemeris files will be verified using internal tools that compare the assumed trajectory with the one in the ephemeris file.

Data Flow
The data inputs listed above will be used to generate optical navigation observation files (Picture Sequence Files). These will be used in a least squares data fitting process to estimate the satellite trajectory, from which the delivered ephemeris files will be derived.

In the current RSWG data flow diagram, shown below, the generation of this data product can be found in the box on the second from the left.



Standards used to generate data product
The ephemeris files will be in the reference frame and time scale of the planetary ephemeris in use by the project at the time.

JET PROPULSION LABORATORY **INTEROFFICE MEMORANDUM**

IOM 312.F-98-022

February 11, 1998

TO: Distribution

FROM: P.W. Chodas

SUBJECT: Small-Body Ephemeris Partials File

Reference: Chamberlin, A.B., "Small-Body Ephemeris NAVIO File Format - Version 2", JPL IOM 312.F-98-004, January 7, 1998.

Overview

A new type of file called the **Small Body Ephemeris Partials (SBP)** file is now available for use in the ODP/DPTRAJ suite of navigation programs. This NAVIO formatted file contains coefficients for Chebyshev polynomials which approximate the partial derivatives of asteroid and/or comet states with respect to their epoch state orbital parameters, as well as other dynamical parameters. The file is designed to be used in conjunction with the Small Body Ephemeris (SBE) file (see Reference), and is analogous to the Planetary Ephemeris Partials file and the Satellite Ephemeris Partials file. Unlike the planetary files, however, the SBE and SBP files can support a virtually unlimited number of bodies. Use of these new small body files has many advantages over the old procedure of creating special versions of the planetary ephemeris/planetary partials files and storing the small body data in the slot for Pluto. It is hoped this old practice will now be quickly phased out.

Contents of the Small Body Ephemeris Partials (SBP) File

The partial derivatives represented in the SBP file are the partials of the small body state (in units of km and km/s) with respect to either the Brouwer and Clemence Set III parameters, as used in the Planetary Partials file, or the set of Keplerian orbital parameters used by the Comet and Asteroid Ephemeris Team (e, q, T_p, Ω, ω, and i). The parameter names stored in the file indicate which set of epoch parameters is used for each body. Partials with respect to other dynamical parameters such as cometary nongravitational parameters A_1 and A_2 may also be included. The nongravitational parameters are essential in the orbital modeling of many comets. (The partial derivatives will then form a 6 by 8 Jacobian matrix rather than the usual 6 by 6 matrix.)

The partials on the SBP file are represented in much the same way as on the Planetary Ephemeris Partials file, viz. via piecewise continuous Chebyshev polynomials. For each small body, the time span of the file is split into small intervals of specified size, typically 8, 16, or 32 days. An approximating polynomial is formed over each interval and the coefficients are stored on the file. The interval size and number of coefficients in the polynomial is fixed for each small body, but may vary from one body to another on the same file. Each body's coefficients are stored in a separate NAVIO item. One restriction of the SBP file is that the partials for all bodies must be represented

over the *same* time interval; the planetary and satellite partials files also require this, but the latest version of the SBE file allows for different time intervals for different bodies.

Unlike the planetary partials file, the epoch of the Set III or Keplerian parameters can be individually set for each body. In particular, it is not restricted to the special Julian date of 2440400.5 (June 28, 1969) used for the planetary partials. Note that for an encounter with a small body, it is often desirable to use an epoch close to the encounter date.

Both the SBP and SBE files include the official IAU name and number for the body, as well as the JPL-assigned SPICE identification number. If the IAU has not assigned a name to the object, its official designation is used, and if the object has not been assigned a number, a zero is used. Thus, if an SBE and/or SBP file is created for an unnumbered or unnamed object, it is possible that these fields could change values in later versions of the files. In contrast, the SPICE object number (typically 7 digits) is intended to be a unique and unchanging identifier for an object.

Ancillary information provided on the SBP file (e.g., orbit solution identifiers, conversion factors, etc.) is very similar to that in the SBE file. A detailed description of the SBP file is attached, and is available on the web at "http://ssd.jpl.nasa.gov/JPL/sbp_file.html". The detailed description for the SBE file was given in the Reference, and is available on the web at "http://ssd.jpl.nasa.gov/JPL/sbe_file.html".

A reader for the SBP file is available in the "ephreaders" library of the ODP/DPTRAJ software suite, under the name SBPRDR.

Small Body Ephemeris Partials File Generation

SBP files are generated by the Comet and Asteroid Ephemeris Team using the program SBPGEN. Inputs to this program are typically placed in a varlist input file (essentially a namelist file). The orbital initial conditions are obtained from an ORB file, which archives all orbital solutions for the small body. The user can request that a particular orbital solution be used, or accept the default of using the latest orbital solution. (The solution identifier is written to the SBP file for traceability.) From the ORB file, SBPGEN extracts the Keplerian orbital elements for the specified solution, along with other dynamical parameters. It then converts the elements to a state, and numerically integrates the state forward or backward to the epoch requested for the partials. It generates an initial Jacobian matrix for the partials with respect to the desired epoch parameters (Set III or Keplerian), and then numerically integrates the variational equations forward and/or backward to cover the time span requested for the SBP file. As it integrates, the program saves the partial derivatives at evenly-spaced times, and when enough saved points are available, it fits a Chebyshev polynomial of specified order to the points and writes the coefficients to the SBP file.

SBPGEN handles only one body at a time, but it will merge its output into an existing SBP file if one is specified, so that a multi-body file can be built up one body at a time.

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Small Body Ephemeris Partials File

VERSION 2.0 - February 1998

General Description

The Small Body Ephemeris Partials File contains coefficients for Chebyshev polynomials which approximate partial derivatives of asteroid or comet states with respect to epoch state orbital parameters for the small bodies. The file may contain partials for many small bodies, although all the partials are represented over a single common time interval. The epoch state parameters may be either the six Brouwer and Clemence Set III parameters denoted DMW, DP, DQ, EDW, DA, and DE, or the classical orbital elements e, q, Tp, Ω, ω, and i. Partials with respect to other dynamic parameters such as cometary nongravitational parameters A1 and A2 may also be included.

Volume

The size of the file is dependent upon the number of small bodies represented on the file, length of the time interval covered by the file, the number of partials represented for each small body, the number of coefficients used for each partial, and the size of the time interval covered by each set of coefficients. A file covering a period of 6 years for a single small body, with a 32-day interval and 10 coefficients per partial is about 100K bytes in size.

Organization

The Small Body Ephemeris Partials file is written in NAVIO format.

Storage Medium

The file is stored on disk.

Program Usage

The Small Body Ephemeris Partials file is generated by the program **SBPGEN**. The partial derivatives of each small body's heliocentric Cartesian state parameters with respect to the epoch state parameters are first computed at epoch. These partials are then mapped forward and/or backward in time by numerically integrating the variational equations of motion. The resulting Jacobian matrix is sampled over each interval and Chebyshev coefficients are generated for each element of the Jacobian and written to the file. Several programs in the Navigation Software sets DPTRAJ and ODP read the file.

Detailed Description

ID Group

This group contains information used to identify the file, the programs used to create the data in the file, and the time interval covered by the file.

Item	Type	No. of Records	Max. Length	Direct Access
FILE-NAME	C*24	1	1	true
FILE-ID	C*80	1	1	true
PROGRAM-NAME	C*12	1	1	true
NAME-LENGTH	I	1	1	true
EQUINOX	D	1	1	true
START-EPOCH	C*25	1	1	true
START-JED	D	1	1	true
STOP-EPOCH	C*25	1	1	true
STOP-JED	D	1	1	true
FINGERPRINTS	C*80	var	1	true

Item	Description
FILE-NAME	The name of the file format: 'SMALL BODY PARTIALS FILE'.
VERSION	File version number, currently 2. The absence of this item indicates version 1.
FILE-ID	This will be an ID for the small body partials file that may include the small body ephemeris ID as well as an ID for the partials, e.g., 'SBP-A433P-35'.
PROGRAM-NAME	The name of the generating program, e.g., 'SBPGEN'.
NAME-LENGTH	The number of characters reserved for parameter names on the file; typically this is 16.
EQUINOX	The Julian date of the equinox used in the generation of the file. This will be either 2433282.50D0 (for EME1950) or 2451545.0D0 (for J2000).
START-EPOCH	The start time of the interval over which partials are represented on the file, expressed as a calendar date/time in TDB. Equivalent to START-JED in the same group. Example: "15-AUG-1999 01:01:54.1234" Note: All bodies represented on the file have the same START-EPOCH and STOP-EPOCH.
START-JED	The starting epoch of the interval over which partials are represented on the file, expressed as a Julian Ephemeris Date (JED). Equivalent to START-EPOCH.
STOP-EPOCH	The end time of the interval over which partials are represented on the file, expressed in the same calendar date/time format as START-EPOCH. Equivalent to STOP-JED in the same group.
STOP-JED	The ending epoch of the interval over which partials are represented on the file, expressed as a Julian Ephemeris Date (JED). Equivalent to STOP-EPOCH.
FINGERPRINTS	Fingerprints records of the programs which have written or updated the file. Each record contains the name of the program, e.g., 'SBPGEN' , the date/time of the program execution, the link date/time when the generating

program was created, and the name of the body whose partials were written or updated.

SMALL-BODY Group

This group contains information describing the small bodies on the file. The first item, NBODIES, gives the number of bodies on the file, and all the other items in this group contain NBODIES records, one for each of the bodies. The data for each body includes the official IAU number and name, the JPL (NAIF) object number, the an orbital solution identifier, the epoch of the partials for the body, and the epoch state of the body. The 'short name' defined in this group is used in the POLYNOMIAL group as the name of the item containing the Chebyshev coefficients. Note also that the epoch of the partials can vary from one body on the file to another.

Item	Type	No. of Records	Max. Length	Direct Access
NBODIES	I	1	1	true
IAU-NUMBER	I	NBODIES	1	true
OBJ-NUMBER	I	NBODIES	1	true
OBJ-NAME	C*56	NBODIES	1	true
SHORT-NAME	C*12	NBODIES	1	true
OBJ-TYPE	C*8	NBODIES	1	true
SOLUTION-ID	C*20	NBODIES	1	true
CREATE-TIME	C*25	NBODIES	1	true
DE-USED	C*10	NBODIES	1	true
EPOCH	C*25	NBODIES	1	true
EPOCH-JED	D	NBODIES	1	true
EPOCH-STATE	D	NBODIES	6	true
GM	D	NBODIES	1	true
AU	D	NBODIES	1	true

Item	Description
NBODIES	The number of small bodies represented on the file.
IAU-NUMBER	The official IAU number assigned to the small body, e.g. 243 for asteroid 243 Ida, or 1 for comet 1P/Halley. Note that these numbers are unique only within bodies of the same type (asteroid or comet); for example, there is both an asteroid 1 (Ceres) and a comet 1 (Halley). Furthermore, if the IAU has not assigned a number to the object, this field will have a value of zero.
OBJ-NUMBER	A unique integer number assigned to the small body by JPL and used to identify the body within the NAIF software set, e.g. 2000433 for asteroid 433 Eros. For numbered asteroids, OBJ-NUMBER is often set to 2000000 + the IAU number, but this is not always the case, and users should not attempt to derive the IAU number from the object number. For comets, OBJ-NUMBER is set to 1000000 + an arbitrary unique number unrelated to the IAU number.
OBJ-NAME	Official IAU name for the small body, if it has been assigned a name; otherwise the official IAU designation for the body. Official IAU names can be lengthy, can

	contain spaces, and usually contain both uppercase and lowercase letters; official designations often begin with year of discovery, and usually contain spaces.
SHORT-NAME	A short name for the body, no more than 12 characters in length, and unique at least within the file. This name will not contain embedded spaces or lowercase letters. Examples are 'MATHILDE', 'EROS', and 'WILD2'. SHORT-NAMEs are used as the names of the items in the POLYNOMIAL group containing the Chebyshev coefficients representing the partials for the small body.
OBJ-TYPE	A character string indicating the type of the object, either 'ASTEROID' or 'COMET'. Asteroids and comets may be included on the same NAVIO partials file.
SOLUTION-ID	A character identifier for the orbital solution used to generate the small body partials. This is often just a numeric string, but it may contain non-numeric characters.
CREATE-TIME	The time of creation of the partials coefficients for the body, represented as a calendar date/time string, e.g. "10-JUL-1997 04:05:06.1234".
DE-USED	The character representation of the JPL Development Ephemeris (DE) number for the planetary ephemeris used to generate CMOD's solution, e.g. "DE-0403", where 0403 specifies a particular ephemeris.
EPOCH	The epoch of the partials for the small body, represented as a calendar date/time string in TDB, e.g. "15-AUG-1999 01:01:54.1234".
EPOCH-JED	The epoch of the partials for the small body, expressed in Julian Ephemeris Date form.
EPOCH-STATE	Inertial-frame Cartesian heliocentric position and velocity of the small body at its epoch. The frame used is that of the planetary ephemeris identified in DE-USED. The units are AU and AU/d.
GM	The value of the gravitational parameter of the Sun, used to convert between state and classical or Set III elements. Units are AU^3/d^2.
AU	The length of the AU in kilometers, used for converting the partials from units of AU and AU/d to km and km/s, which are the numerator units of the output partials. The value of AU is obtained from the planetary ephemeris.

PARAMETER Group

This group contains the names of all the small body parameters on the file. These include the epoch orbital parameters with respect to which the partials are computed, along with possibly other dynamic parameters. The parameter names include suffixes to identify the small body. The nominal values for these parameters are also included in this group (although, note that the nominal values for Set III parameters are always zeroes).

Item	Type	No. of Records	Max. Length	Direct Access
NUMPAR	I	1	1	true
NAMPAR	C*16	1	NUMPAR	true
VALUES	D	1	NUMPAR	true

STATE-PTR	I	1	NBODIES	true

Item	Description
NUMPAR	The number of small body parameters whose names appear in item NAMPAR and whose nominal values appear in item VALUES.
NAMPAR	The names of small body parameters with respect to which partial derivatives are represented on the file. The maximum number of characters the parameter names may have is stored in item NAME-LENGTH of the ID group, and is nominally 16 characters, to match the large parameter set size limitation in the ODP. For each small body, the parameters are either heliocentric Set III parameters, (DMW, DP, DQ, EDW, DA, DE), or heliocentric Keplerian elements: eccentricity (EC), perihelion distance in AU (QR), time of perihelion passage in TDB Julian date form (TP), R.A. of the ascending node in degrees (OM), argument of perihelion in degrees (W), and inclination to the ecliptic in degrees (IN). Other dynamic parameters may be appended to the 6 orbital parameters: e.g., for a comet, the non-gravitational acceleration parameters A1 and A2 may be appended. (These are defined as the radial and transverse components of the nongravitational acceleration at 1 AU, in units of AU/d^2). To each parameter name is appended an underscore followed by an object identifier string. If the object is a numbered asteroid, the IAU number is appended: e.g., for asteroid 433 Eros, the Set III parameter names would be DMW_433, DP_433, DQ_433, EDW_433, DA_433, and DE_433. For a numbered comet, the character "P" for "Periodic comet" appears before the IAU number: e.g., for comet 81P/Wild 2, the Keplerian and nongrav parameter names would be EC_P81, QR_P81, TP_P81, OM_P81, W_P81, IN_P81, A1_P81, and A2_P81. If the object has no IAU number, the OBJ-NUMBER (typically 7 digits) is used as the suffix after the underscore (with no "P" for comets, since OBJ-NUMBER is unique). NAMPAR will be well-ordered in the sense that at least the 6 state names for a given body will be contiguous.
VALUES	These are the NUMPAR double precision nominal values for the parameters named in NAMPAR. Note that the nominal values for Set III parameters are zeroes.
STATE-PTR	An array of pointers, one for each body on the file, and in the same order as the records in SHORT-NAME. Each pointer is the index in NAMPAR of the 6 state parameters for the corresponding body.

POLYNOMIAL Group

This group contains the coefficients of the Chebyshev polynomials used to represent the partial derivatives of

the small body's heliocentric state at a given time with respect to the parameters given in NAMPAR. Other essential information is also given, such as the interval covered by each approximation, and the number of coefficients used. Items INTERVAL, NCOEFFS, and COEFF-PTR each contain one record per small body, with the records in the same order as the records of SMALL-BODY/SHORT-NAME. The Chebyshev coefficients themselves are stored in a separate item for each body, with the name of the item being that body's SHORT-NAME. Each of these items contains an ordered series of records, one per interval, running from the START-JED to or past the STOP-JED. The first two elements of each coefficients record are the start and stop times for the interval covered by that record.

Item	Type	No. of Records	Max. Length	Direct Access
INTERVAL	D	NBODIES	1	true
NCOEFFS	I	NBODIES	NUMPAR	true
COEFF-PTR	I	NBODIES	NUMPAR	true
Body Name	D	var	var	true

Item	Description
INTERVAL	The length of the time interval for the small body, in days. There is one record of Chebyshev coefficients per interval per body in this group. The interval should be a power of 2. There is a record for each small body on the file.
NCOEFFS	The number of coefficients used to represent the partial derivatives of the small body's heliocentric state with respect to each of the NUMPAR parameters on the file. If the body's state does not depend on parameter i of NAMPAR (i.e. if the partial derivative is identically zero), NCOEFFS(i) is zero. There is a record for each small body on the file.
COEFF-PTR	The starting locations in the coefficients records of the three coefficient sets for the partial derivative of the small body's heliocentric state with respect to each of the NUMPAR parameters on the file. If the body's state does not depend on parameter i of NAMPAR (i.e. if the partial derivative is identically zero), COEFF-PTR(i) is zero. There is a record for each small body on the file.
Body Name	The coefficients of the Chebyshev polynomial representing the partials of the small body heliocentric state in km and km/s, with respect to the parameters in NAMPAR (whose units are defined above). The names in item SMALL-BODY/SHORT-NAME are used as the item names in this group. For each body, there is one record per interval, beginning at START-JED and running through STOP-JED. The first two elements of each record are the beginning and ending times of the interval covered by the record, in JED form. These are followed by the coefficient sets, whose locations are given by COEFF-PTR. The number of double precision words in the coefficient set for the partial derivative of the three

components of heliocentric position with respect to parameter i is 3*NCOEFFS(i). Partial derivatives of the velocity components are computed by differentiating the polynomials for the position partials.

Last revision: 1998 Feb 11 (P.W. Chodas)

JET PROPULSION LABORATORY **INTEROFFICE MEMORANDUM**
IOM 312.F-98-004
January 7, 1998

TO: Distribution

FROM: A. B. Chamberlin

SUBJECT: Small-Body Ephemeris NAVIO File Format - Version 2

Overview

The small-body ephemeris file (SBEF) format has been changed and requires the use of new generating software and new readers. This memo explains the reasons for changing the format, how to use the new format, and who is responsible for maintaining the relevant software.

Why Change the Format?

The previous SBEF format [1-4] was designed to provide ephemerides for a limited number of small-bodies whose states would be computed at a given time. Thus, for maximum efficiency, ephemeris data (i.e. Chebyshev coefficients) for all bodies were stored in a single NAVIO item. This design was adequate for files of small-body perturbers (e.g. Ceres, Pallas, and Vesta) and mission target bodies (e.g. Eros and Mathilde).

With the requirements for the DS-1 mission came the need to provide small-body ephemeris files containing more than 100 bodies. To accommodate this requirement with the old file format would have produced inefficient readers and restricted the maximum number of bodies allowed on a single file. The new file format allows for ephemeris data to be stored in a single NAVIO item for N bodies (called the "combined" form and functionally identical to the old format) or stored in N separate NAVIO items for each body (called the "separate" form). In most cases, files will be in one of these two forms. However, the format allows for hybrid files combining both forms in one file. This design should provide the flexibility needed to handle future requirements. The complete description of the new SBEF format is shown in attachment 1.

New Software Use, Description, and Maintenance

This section describes the general process of creating and using typical SBEFs. A program called SBGEN v2.0 is used to create N SBEFs for N bodies. These N SBEFs are combined in a single file using the program SBCOMB v1.0 which creates either a "combined" or "separate" form SBEF. This SBEF is then read by the appropriate reader. For example, in the ODP, a "combined" form SBEF is read by the reader SBERDR.

SBGEN v2.0 is significantly improved over SBGEN v1.0. The new version integrates the states

directly from precise orbital initial conditions (ORB file), saves a series of test states within the fit interval, fits Chebyshev coefficients to states within the interval, compares the fit with the integrated test states, and reports the maximum error in the fit for each state component. The user can specify the fit tolerance to ensure the SBEF is sufficiently accurate. SBGEN v2.0 further improves on the previous version by eliminating the need to produce an intermediate ASCII file of states and eliminating any "double" integration over the same time span (i.e. integrating backward from initial epoch to the start time and then forward over the same interval).

The Solar System Dynamics group will be responsible for creating SBEF NAVIO files for delivery and maintaining the programs used therein. The Navigation Software group will be responsible for maintaining the subroutines required for reading "combined" form files for use in the ODP. Projects requiring other reading capabilities will be responsible for creating and maintaining such software. These responsibilities reflect the author's understanding and may change in the future.

References

1. Chamberlin, A. B., "Revised Small Body Ephemeris NAVIO File Format", JPL IOM 312.1-96-015, 9 May 1996.
2. Standish, E. M., "Small Body Ephemeris File Programs", JPL IOM 314.10-010, 15 March 1996.
3. Standish, E. M., "Small Body Auxiliary Files", JPL IOM 314.10-007, 29 February 1996.
4. Ekelund, J. E., "Software to Generate and Read a NAVIO Ephemeris File Containing Multiple Asteroids and/or Comets", IOM 312.9-95-044, 24 January 1996.

Attachments

1. Small-Body Ephemeris File Format Description - Version 2.0

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Small-Body Ephemeris File Format Description

Version 2.0 - January 1998

General Description

The Small-Body Ephemeris File is a NAVIO formatted file of comet and asteroid ephemeris data represented as Chebyshev coefficients. The file may contain Chebyshev coefficients for several comets and/or asteroids.

Volume

The maximum size of the file in blocks is a function of the length of time covered, the number of Chebyshev coefficients per body, the time span per set of coefficients per body, and the number of small-bodies represented: typically 3.4 kilobytes/year/body + 0.5 kilobytes/body of header data. As an example, a file spanning 6 years and containing 12 coefficients fit over 32 day intervals for two bodies requires about 41.8 kilobytes.

Organization

The file is in the NAVIO format and organized into one of three possible forms: "combined", "separate", or "hybrid" (contains both "combined" and "separate" forms). Most small-body ephemeris files will not be "hybrid". The "combined" form means that the Chebyshev coefficients for *all* bodies are combined in a single record such that for a given time, the state for all bodies can be determined with a single NAVIO file read. There is a limit on the number of bodies in the "combined" section of a file (typically 32). Note that the previous version of the small-body ephemeris file format was very similar to a "combined" form file. The "separate" form means the Chebyshev coefficients are stored in separate records for each body. There is no limit on the number of "separate" bodies in a file (except the maximum file size must be within specified NAVIO limits). The details of these forms are described below.

Storage Medium

The file is intended to be stored on disk.

Program Usage

The Small-Body Ephemeris File is generated by numerically integrating an initial Cartesian state (at some epoch) over time spans sufficient to cover the requested ephemeris time span (repeated for each body on the file). If the initial state epoch is within the requested ephemeris time span, maximum accuracy is maintained by first integrating from epoch backward to the start time and then from epoch forward to the end time. The computed Cartesian states are fit using *Chebyshev routines* and the resulting interpolated states are then compared with arbitrary test states previously stored during the

integration. The maximum errors for each state component are compared with user specified limits which cannot be exceeded, ensuring the resulting file is within tolerance. The program **SBGEN** generates single-body Small-Body Ephemeris Files. The program **SBCOMB** combines single-body and/or multi-body files into one new multi-body file.

Detailed NAVIO Format Description

Note: all items in all groups are direct access (i.e. Random=True).

ID Group

This group contains information which may be used to identify the file.

Item	Type	RECS	LEN	Description
FILE-NAME	C*25	1	1	The unique identifier name of the file format: "SMALL BODY EPHEMERIS FILE".
VERSION	I	1	1	An integer version number associated with a particular description of this file's format. Currently VERSION=2. The previous version, 1, did not have this item defined. Therefore, version 1 is assumed by the absence of this item.
FILE-ID	C*12	1	1	A unique identifier, selected by the file creator, representing the set of small-bodies and their individual orbit solutions. It is recommended that every identifier begin with "SB-". For example, a file containing recent solutions of Ceres, Pallas, and Vesta may use "SB-CPV005". This item is patterned after the planetary ephemeris NAVIO file item called FILE-NUMBER which is something like "DE-0403LE-0403".
PROGRAM-NAME	C*12	1	1	The name of the generating program: typically "SBGEN" or "SBCOMB".
EQUINOX	D	1	1	The Julian date of the equinox used in the generation of the file. This will be either 2433282.50D0 (for EME1950) or 2451545.0D0 (for J2000).
DE-USED	C*10	1	1	The character representation of the JPL Development Ephemeris (DE) number for the planetary ephemeris used to generate each small-body ephemeris. For example, "DE-0403", where "0403" specifies a particular ephemeris.
FINGERPRINTS	C*80	var	1	Each record contains the execution date/time, name/version, and link date/time of each program (typically SBGEN and SBCOMB) used to create the NAVIO file.

CONSTANTS Group

This group contains constants such as the number of bodies on the file, the Chebyshev fit interval, and the start/stop times for each body.

Item	Type	RECS	LEN	Description
NBODIES (*NB*)	I	1	1	An integer count of the number of small-bodies represented on the file.
NCOMBINED (*NC*)	I	1	1	Number of bodies in the *combined* section of the COEFFICIENTS group. *NC* may be any value between zero and *NB*, inclusive. The difference (*NB* - *NC*) indicates how many bodies are in the *separate* section of the COEFFICIENTS group.
BUFFER-SIZE	I	1	1	Length of each {COEFFICIENTS/DATA-RECORD} item (below). Could be zero if *NC*=0.
RECORD-SPAN	D	*	1	Record 1, if *NC*>0, contains the number of days spanned by each {COEFFICIENTS/DATA-RECORD} item (below). Also referred to as the "master interval" over which the Chebyshev polynomial fit was made. Subsequent records (if any) contain the number of days spanned in each corresponding {COEFFICIENTS/*short-name*} item.
START-JED	D	*	1	The start/first epoch (JED) of each small-body's ephemeris. Record 1, if *NC*>0, contains the start epoch of all *NC* bodies in the "combined" section (i.e. in the {COEFFICIENTS/DATA-RECORD} item). Subsequent records (if any) contain the start epoch of each body in the "separate" section (i.e. in the corresponding {COEFFICIENTS/*short-name*} item).
STOP-JED	D	*	1	The stop/last epoch (JED) of each small-body's ephemeris. (See {CONSTANTS/START-JED}.)
AU	D	1	1	The value of AU used in the planetary ephemeris file DE-USED.

* **RECS** is equal to (*NB* - *NC* + *k*), where *k*=1 if *NC* is greater than 0 and *k*=0 otherwise.

SMALL_BODY Group

This group contains information about each small-body on the file.

Item	Type	RECS	LEN	Description
IAU-NUMBER	I	*NB*	1	The official IAU number assigned to the small-body, e.g. 243 for asteroid 243 Ida, or 1 for comet 1P/Halley. Note that these numbers are unique only within bodies of the same type (asteroid or comet); for example, there is both an asteroid 1 (Ceres) and a comet 1 (Halley). Furthermore, if the IAU has not assigned a number to the object, this field will have a value of zero.

OBJ-NUMBER	I	*NB*	1	A unique integer number assigned to the small-body by JPL, e.g. 2000433 for asteroid 433 Eros. OBJ-NUMBER is set to 2000000 + IAU number for an asteroid with an IAU number, 1500000 + IAU number for a comet with an IAU number, 3000000 + an arbitrary unique number for an asteroid without an IAU number, or 1000000 + an arbitrary unique number for a comet without an IAU number.
OBJ-NAME	C*56	*NB*	1	Official IAU name for the small-body, if it has been assigned a name; otherwise the official IAU designation for the body. Official IAU names can be lengthy, can contain spaces, and usually contain both uppercase and lowercase letters; official designations often begin with a numeric string, which is the year of discovery, and usually contain spaces.
SHORT-NAME	C*12	*NB*	1	A short name for the body, no more than 12 characters in length, and unique at least within the file. This name must not contain embedded spaces or lowercase letters. Examples are "MATHILDE" and "EROS". SHORT-NAMEs are used as the names of the items (if any) in the *separate* section of the COEFFICIENTS group and in the SIGMAS group.
OBJ-TYPE	C*8	*NB*	1	A character string indicating the type of the object, either "ASTEROID" or "COMET". Asteroids and comets may be included on the same ephemeris file.
GM	D	*NB*	1	The double precision values of GM (km**3/s**2).
RADIUS	D	*NB*	1	The double precision values of radius (in km).
MAG-PARS	R	*NB*	5	Magnitude parameters: For asteroids, the parameters are H and G. For comets, the parameters are M1, M2, K1, K2, and phase-coefficient.
ALBEDO	R	*NB*	1	The object's geometric albedo.
B-V	R	*NB*	1	The object's color index: B-V.
SPEC-CLASS	C*6	*NB*	1	The object's Tholen spectral class. Blank if unknown.
ROT-PERIOD	R	*NB*	1	The object's rotation period in hours. Zero if unknown.
NON-GRAVS	D	*NB*	2	Non-gravitational parameters A1 and A2 (e-8 AU/d^2) in the transverse and radial directions (respectively). The radial direction is from the sun to the small-body and the transverse direction is normal to the radial direction, in the orbit plane, and in the general direction of the the object's velocity.
CENTER	I	*NB*	1	The body NAIF ID used as the center of integration.
SOLUTION-ID	C*20	*NB*	1	The character identifier of the orbit solution used to generate the ephemeris.
CREATE-TIME	C*25	*NB*	1	A character representation of the creation date/time of each body's ephemeris.
STEP-USED	D	*NB*	1	The step size, in days, used to generate the ephemeris for each small-body.

PRODUCER-ID	C*56	*NB*	1	The name of the analyst who generated the small-body ephemeris.
SBE-USED	C*20	*NB*	1	The character representation of the JPL small-body perturber ephemeris (SBE) number (as defined in FILE-ID) for the perturbing ephemeris used to generate the small-body ephemeris (blank if none used). For example, "SB-CPV001", where "CPV" indicates Ceres, Pallas, Vesta (all used), and "SB-CPV001/3" indicates the 3rd perturber (Vesta) was excluded.
COMMENTS	C*80	*NB*	1	This item may contain any character data that the producer provided when creating the ephemeris.
EPOCH-JED	D	*NB*	1	The epoch of the reference/initial state, expressed in Julian Ephemeris Date form.
EPOCH-STATE	D	*NB*	6	Inertial-frame Cartesian heliocentric position and velocity of the small-body at its epoch. The frame used is that of the planetary ephemeris identified in DE-USED. The units are AU and AU/d.
SIGMA-SCALE	D	*NB*	1	The scale factor applied to the formal covariance used to generate the ephemeris uncertainties (if any) which are stored in item {SIGMAS/*short-name*}. If SIGMA-SCALE is zero, no uncertainty data exist for that body.

POINTER Group

This group contains info necessary to locate Chebyshev coefficients for any given small-body. The first two items (COEFF-PTR and NCOEFF-SETS) are required only for the *combined* section (if any) of the COEFFICIENTS group.

Item	**Type**	**RECS**	**LEN**	**Description**
COEFF-PTR	I	1	*NC*	Location of the first coefficient for body *i* within a {COEFFICIENTS/DATA-RECORD} item. Defined only for the first *NC* small-bodies on the file.
NCOEFF-SETS	I	1	*NC*	The number of subintervals within the "master interval" {CONSTANTS/RECORD-SPAN} for the first *NC* small-bodies.
NCOEFFS	I	*NB*	1	The number of the Chebyshev coefficients per Cartesian coordinate for each small-body on the file.

COEFFICIENTS Group

This group contains records of double precision data consisting of Chebyshev coefficients for each small-body. This group is divided into two sections: the *combined* section and the *separate* section. Either or both sections may be present. The *combined* section contains *NC* bodies and corresponds to the {COEFFICIENTS/DATA-RECORD} item and the *separate* section contains *NB-NC* bodies and corresponds to the {COEFFICIENTS/*short-name*} item(s).

The data are such that a subroutine to read and interpolate this file for a given body *i* within a given time span may provide the position, velocity and acceleration of the requested body relative to the central body {SMALL_BODY/CENTER}(*i*). Interpolation of the coefficients using the reader SBPV provides positions, velocities and accelerations of the small-bodies in kilometers, kilometers/sec, and kilometers/sec**2.

Item	Type	RECS	LEN	Description
DATA-RECORD	D	*	*	The combined set of Chebyshev coefficients for the first *NC* small-bodies. The coefficients are separated into time spans specified by {CONSTANTS/RECORD-SPAN}(1) days from the start and stop dates (JED) specified in words 1 and 2 of the record (respectively). The remaining words of each record contain Chebyshev coefficients for each Cartesian component (*x*,*y*,*z*) for each small-body in the file. The number of (*x*,*y*,*z*) sets of coefficients for body *i* is specified by {POINTER/NCOEFF-SETS}(*i*).
short-name	D	*	*	The set of Chebyshev coefficients for the single small-body *i* (*i*>*NC*) with the specified *short-name*. These items are given only for the *separate* section small-bodies (i.e. bodies *NC*+1 through *NB*). The time span for the first of these items is defined in {CONSTANTS/RECORD-SPAN}(*j*) where *j*=1+(*i*-*NC*). Implicitly, {POINTER/NCOEFF-SETS}=1 and {POINTER/COEFF-PTR}=3 for these items.

* **RECS** is [{SMALL_BODY/STOP-JED}(*i*) - {SMALL_BODY/START-JED}(*i*)] / {CONSTANTS/RECORD-SPAN}(*j*) where *j*=1+(*i*-*NC*) for *i*>*NC*, and *j*=1 otherwise.

* **LEN** is equal to the sum of each body (*i*) of 2+3*{POINTER/NCOEFFS}(*i*)*{POINTER/NCOEFF-SETS}(*i*). This value is stored in item {CONSTANTS/BUFFER-SIZE}.

The format of each record in DATA-RECORD is the sequential ordering of the following parts:

- Start and stop JEDs of the master interval {CONSTANTS/RECORD-SPAN}(1).
- Coefficients for body 1.
- Coefficients for body 2.
- ...
- Coefficients for body N (N = *NB*).

where the "Coefficients for body N" are structured as follows:

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-  Coefficients for the x-component of subinterval 1 for body N.
       "        "   "  y-component of subinterval 1 for body N.
       "        "   "  z-component of subinterval 1 for body N.
-  Coefficients for the x-component of subinterval 2 for body N.
       "        "   "  y-component of subinterval 2 for body N.
       "        "   "  z-component of subinterval 2 for body N.
                                .
                                .
                                .
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-  Coefficients for the x-component of subinterval M for body N.
        "         "    "  y-component of subinterval M for body N.
        "         "    "  z-component of subinterval M for body N.
                                                  (M=NCOEFF-SETS(N)).
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SIGMAS Group

This *optional* group contains the 1-sigma position uncertainty for selected small-bodies on the file, expressed in the RTN reference frame. Records are stored at the body's coefficients interval *N* (*). Uncertainty data are available for body *short-name* only if item *short-name* exists. If this group isn't present, then no uncertainty data exist for any body.

Item	Type	RECS	LEN	Description
short-name	D	*	7	Contains records of ephemeris uncertainties (1-sigma values, km) for the small-body identified by *short-name*. The first element is the time (JED) of the position uncertainty. The next 3 elements are the 1-sigma values in the RTN coordinate system, and the last 3 elements contain square-root covariances (R-T,R-N,T-N). Each record starts with a specified time JED with *N* days between records. The first record is at the ephemeris start time {SMALL_BODY/START-JED}, and the last record is at the end time {SMALL_BODY/STOP-JED}.

* *N* = {CONSTANTS/RECORD-SPAN(*j*)} / *NSS* where *NSS* = 1 for *i*>*NC*, and *NSS* = {POINTER/NCOEFF-SETS(*i*)} otherwise.

* **RECS** = [{SMALL_BODY/STOP-JED}(*i*) - {SMALL_BODY/START-JED}(*i*)] / *N*.

* *j* = 1+(*i*-*NC*) for *i*>*NC*, and *j* = 1 otherwise.

Last revision: 1998 January 07 (Alan B. Chamberlin)