From: M. Bester
To: Operations & Science Team
Date: 12-Oct-2006
Re: Ephemeris Format Definition

Ephemeris Format Definition

1. Introduction

Ephemeris files containing position, velocity, attitude and other relevant orbit and mission parameters are used to exchange and process orbit and trajectory information within the THEMIS flight dynamics system, in particular with MDT, GTDS, GMAN and SatTrack. Ephemeris files in the format described here or in alternate formats are also used to distribute pre-launch orbit data to the THEMIS team and to the science community. Ephemeris data are also archived along with the mission science data for further scientific analysis.

2. Ephemeris File Format

Ephemeris files are written in plain ASCII format, and contain one header line plus an unlimited number of data lines. The header line identifies the content in each column and consists of names of parameters plus their associated units, enclosed in double quotes and separated by commas. The data are listed sequentially, and columns are separated by any number of white space characters. Each line – header or data – is terminated with a linefeed character (ASCII 10). An additional carriage return character (ASCII 13) is allowed also. File reader functions should be implemented in a case insensitive form. Time steps from one line to the next may be as small as 0.001 s.

Several samples illustrating how headers are formed are shown below. Allowed data columns and associated entries in the header line are summarized in Table 1. Additional parameters may be added in the future. Note that for clarity of this document, the single header line is broken up into several lines.

```
"Date (UTC)","Time (UTC)","ECI TOD X [km]","ECI TOD Y [km]","ECI TOD Z [km]",
"ECI TOD VX [km/s]","ECI TOD VY [km/s]","ECI TOD VZ [km/s]",
"Anomalistic Orbit [rev]"

"ECI TOD AX [---]","ECI TOD AY [---]","ECI TOD AZ [---]"

"SARA TOD [deg]","SADEC TOD [deg]","Spin Rate [rpm]"

"Total Mass [kg]","Fuel Mass [kg]","Total Delta V [m/s]","Maneuver Status [---
]"
```
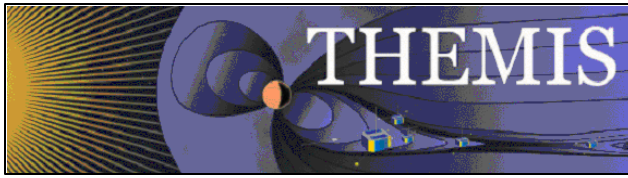
For the Date and Time columns the time zone is enclosed in round brackets, and for all other columns units are enclosed in square brackets. If a parameter is dimensionless, then the unit is shown as three dashes.

Note that all position, velocity and attitude components are to be expressed in the same, Earth Centered Inertial (ECI) true-of-date (TOD) (true equator and true equinox of date) reference frame. Presently, the second valid reference frame is J2000.0 (mean equator and mean equinox of J2000.0). When the latter is specified, then *J2000.0* needs to be inserted into the header entries of all vector components in the following way:

```
"ECI J2000.0 X [km]","ECI J2000.0 Y [km]","ECI J2000.0 Z [km]"
```

Other reference frames may be implemented in the future. Allowed length units are km (kilometers), sm (statute miles), nm (nautical miles) and ft (feet), and allowed angle units are deg (degrees) and rad (radians). Hour angle units may be expressed in h (hours), deg (degrees) or rad (radians).
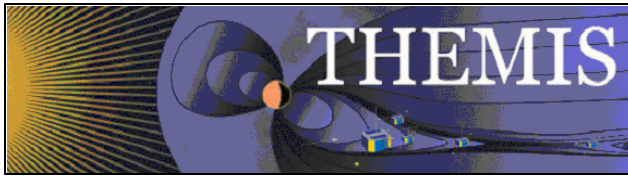
Table 1: Definition of Header Elements and Data Columns			
Parameter	**Allowed Header Entries**	**Data Format**	**Number of Decimal Places**
Date	Date (UTC)	yyyy/ddd yyyy/mm/dd dd-Mmm-yyyy	Fixed Format
Time	Time (UTC)	hh :mm :ss.sss	Fixed Format
Position	ECI TOD X [km] ECI TOD Y [km] ECI TOD Z [km]	Double Precision	16
Velocity	ECI TOD VX [km/s] ECI TOD VY [km/s] ECI TOD VZ [km/s]	Double Precision	16
Attitude (Body Z Axis)	ECI TOD AX [---] ECI TOD AY [---] ECI TOD AZ [---]	Double Precision	12
Spin Axis Right Ascension / Declination	SARA TOD [deg] SADEC TOD [deg]	Double Precision	6
Geographic Coordinates	Latitude [deg N] or [deg S] Longitude [deg W] or [deg E] Altitude [km] or Height [km]	Double Precision	6 6 6
Celestial Coordinates	RA TOD [h] DEC TOD [deg]	Double Precision	12 9
Orbital Elements	SMA [km] ECC [---] INC [deg] RAAN [deg] ARGP [deg] MA [deg] or TA [deg]	Double Precision	12 12 12 12 12 12
Orbit	Anomalistic Orbit [rev] or Nodal Orbit [rev]	Double Precision	9
Mass	Total Mass [kg] Fuel Mass [kg]	Double Precision	3 3
Delta V	Total Delta V [m/s]	Double Precision	3
Spin Rate	Spin Rate [rpm]	Double Precision	3

| Table 1 (Continued): Definition of Header Elements and Data Columns			
Parameter	**Allowed Header Entries**	**Data Format**	**Number of Decimal Places**
Ground Network Access Status Code	GN Status [---]	Coded Integer 0-65535 Ground Station 1 1 … Ground Station 16 32768	0
Space Network Access Status Code	SN Status [---]	Coded Integer 0-65535 TDRS 1 1 … TDRS 16 32768	0
Space Environment Region Crossing Status Code	SE Region Status [---]	Coded Integer 0-262143 Earth Shadow 1 Lunar Shadow 2 Atmospheric Absorption Zone 4 South Atlantic Anomaly 8 Northern Auroral Zone 16 Southern Auroral Zone 32 Perigee Passage 64 Inner & Outer Radiation Belts 128 Deep Plasma Sphere 256 Foreshock Solar Wind 512 Solar Wind Beam 1024 High Magnetic Field 2048 Average Plasma Sheet 4096 Bowshock Crossing 8192 Magnetopause Crossing 16384 Ground Based Observatories 32768 2-Day Conjunctions 65536 4-Day Conjunctions 131072	0

Table 1 (Continued): Definition of Header Elements and Data Columns			
Parameter	**Allowed Header Entries**	**Data Format**	**Number of Decimal Places**
Maneuver Status Code	Maneuver Status [---]	Coded Integer XYYZZZ Unpowered Flight (Coast) 0 X=0, YY=00, ZZZ=000 Maneuver Sequence Number 001-999 ZZZ Maneuver Type Code YY Launch Vehicle Maneuver 0 Axial-thrust Maneuver 1 Side-thrust Maneuver 2 Beta-thrust Maneuver 3 Attitude Precession 4 Spin Rate Change 5 Maneuver Sequencing Code X No Segmentation 0 Segmented Maneuver 1	0
Data Processing Status Code	Data Status [---]	Coded Integer 0-65535 No Change 0 Orbit Determination 1 Maneuver Reconstruction 2 Attitude Determination 4 Mass Properties Update 8 RCS Parameter Update 16 Spare 32-32768	0

3. Regions of Interest

Definitions of the Regions of Interest (ROIs) are summarized in Table 2 below. Note that not all of these regions are used with THEMIS but are listed for compatibility with other missions.

Table 2: Regions of Interest		
Region Name	**Acronym**	**Region Definition**
Earth Shadow	ESH	Solar disk obscured by Earth by more than 1% (99% visible) (including umbra and penumbra)
Lunar Shadow	LSH	Solar disk obscured by Moon by more than 1% (99% visible) (including umbra and penumbra)
Atmospheric Absorption Zone	AAZ	Spacecraft sees Sun through Earth atmosphere
South Atlantic Anomaly	SAA	Region defined by mission specific latitude/longitude contour
Northern Auroral Zone	NAZ	Region defined by mission specific latitude/longitude contour
Southern Auroral Zone	SAZ	Region defined by mission specific latitude/longitude contour
Perigee Passage	PGP	Spacecraft passes within ± 1 hour of perigee
Inner & Outer Radiation Belts	RBT	Spacecraft within L-shell at $L = 4 R_E$ (IGRF model)
Deep Plasma Sphere	PSP	Spacecraft within L-shell at $L = 4 R_E$ (IGRF model)
Foreshock Solar Wind	SHK	Outside of nominal bowshock distance D minus a tolerance t $t = \min(3 R_E, \frac{1}{2}$ sheath thickness)
Solar Wind Beam	SWB	$X_{GSE} >$ threshold radius (20 R_E)
High Magnetic Field	HMF	Spacecraft within radial distance of 5 R_E (approximation of B field magnitude > 300 nT)
Average Plasma Sheet	APS	Spacecraft within $X_{GSE} < -5 R_E$, thickness of plasma sheet = 5 R_E, hinge point at -10 R_E (Hammond model)
Bowshock Crossing	BSC	Bowshock crossing ± 1.5 hours
Magnetopause Crossing	MPC	Magnetopause crossing ± 1.5 hours
Ground Based Observatories	GBO	UTC range of Ground Based Observatories: 06:30 UTC ± 6 h on tail season wedding day ± 60 days 18:30 UTC ± 6 h on dayside season wedding day ± 60 days
2-Day Conjunctions	C2D	THEMIS P2 / P3 / P4 Probe alignment
4-Day Conjunctions	C4D	THEMIS P1 / P2 / P3 / P4 Probe alignment
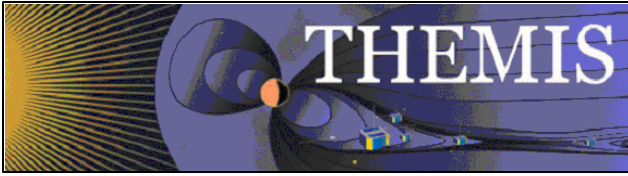
4. Sample Ephemeris File

The following data set is an abbreviated sample ephemeris file illustrating date, time and Cartesian spacecraft position columns:

```
"Date (UTC)","Time (UTC)","ECI TOD X [km]","ECI TOD Y [km]","ECI TOD Z [km]"
2005/277  00:00:00.000     6124.037249   -1710.773860   -2770.373467
2005/277  00:01:00.000     6126.919825   -1305.861124   -2978.072602
2005/277  00:02:00.000     6103.464919    -895.334874   -3172.935022
2005/277  00:03:00.000     6053.784434    -480.961425   -3354.126556
2005/277  00:04:00.000     5978.102991     -64.522149   -3520.872702
2005/277  00:05:00.000     5876.756717     352.194241   -3672.461856
```