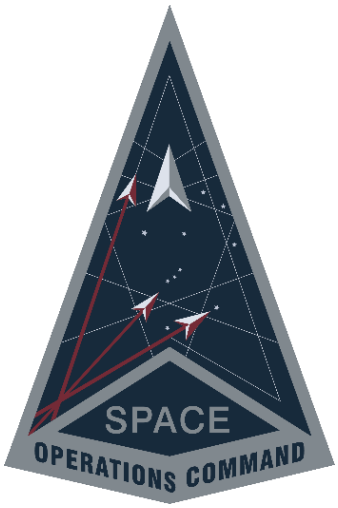
Astrodynamics Standards
Shared Library



External Ephemerides (ExtEphem)

Version 9.4

May 2024

Contents

1. Introduction

ExtEphem provides the users with many library functions to load and manage satellite ephemeris data from an external source. The external ephemeris data can be loaded from the predefined external ephemeris file formats (using file I/O) or it can be loaded using direct method calls (without using file I/O).

The external ephemerides option provides the capability of reading an independently provided satellite ephemeris from an external source, and processing it internally within the Astrodynamic Standard programs.

If you are on Windows, the shared library files will end in ".dll". For example, "ExtEphem.dll". If you are on Linux, the shared library will begin with "lib" and end in ".so", and will be all lowercase. For example, libextephem.so.

2. Prerequisites

The following shared libraries MUST be loaded and initialized before using ExtEphem:

- AstroFunc
- DllMain
- EnvConst
- TimeFunc

3. Getting Started

To get started, please read the README.txt file that came in the root directory of your distribution. In addition to an overall description contained in the distribution, it has a description of a "**wrapper**".

To get started with **ExtEphem**, there is a "wrapper" specific to ExtEphem, under the **SampleCode** directory. Under your language of choice, you will see a "**DriverExample/wrapper**" subdirectory. The files under this directory will have all the Application Programming Interfaces (APIs) available. For ExtEphem specific APIs, you should see a source file labelled with "ExtEphem" in the file name. This will be where you will find all the APIs for that specific library. The "DriverExample" directory will also contain several examples of applications that should run by simply running the runExample.bat or runExample.sh script. You can use these examples as a starting point for building your application.

If you do not see your programming language under "SampleCode", look in the HTML documentation for the APIs. Open a browser to the "Documentation/APIDocs/index.html" file. This document will show all the APIs regardless of programming language.

The Astrodynamics Standards libraries should work with any language capable of using Dynamic Link Library (on Windows) or Shared object (on Linux) files.

4. Terminology

External ephemeris: A dataset that contains historical (captured) or predicted state information for a satellite. As a minimum, this data contains a time, position, and velocity information for numerous points. Proper interpolation of this data can be used to provide precise state information for the satellite at any time T within the time span of the dataset. The accuracy of this resulting interpolated state is entirely dependent on the algorithms/means originally used to create the dataset - a dataset may be based on any orbit determination/propagation method. Typically, the dataset consists of regularly spaced data points on a set time interval, with the time between points small enough that interpolation provides a result consistent with the accuracy of the underlying data.

In the Standardized Astrodynamic Algorithms documentation, the term EXTEPHEM refers to those satellites whose satellite states (ephemeris points) are loaded from external ephemeris source (input external ephemeris file or method calls).

5. Understanding ExtEphem

Internally, this library stores the loaded EXTEPHEMs in its own binary tree. Each EXTEPHEM, when added successfully to the binary tree, will receive a unique key. This unique key is commonly called 'satKey' in the Astrodynamics Standard documentation.

The SatState library has access to the root of the ExtEphem binary tree. Therefore, the associated EXTEPHEM data, external ephemerides, can be retrieved via its satKey. The SatState library uses the retrieved data to compute the satellite's position and velocity vectors.

One error condition peculiar to any given ephemeris can occur for a SatState call: requested time outside of data range. The input ephemerides will have a finite time span. Only times within that span are valid inputs to the SatState call. Other input times lead to an error condition. For valid times, the outputs are interpolated from the input ephemeris which each ExtEphem stores in its own array. A four point Hermite interpolator, centered (when possible) on the input time, generates the output position and velocity. Interpolation will cause significant numerical errors for large time steps. It is the responsibility of the users to ensure the input ephemeris has appropriate time steps between the ephemeris points.

Some ephemeris files specify an epoch time, which does not necessarily match the time of the first, or any other, ephemeris points. Since not all ephemeris files have a defined epoch, and the epoch time may not have state data provided for it, all epoch quantities are computed at the first ephemeris point.

6. External Ephemeris File Formats

6.1. Vector Ephemeris File Description

Sample file:

Copy

```
columns  1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
---------------------------------------------------------------------------------
 0.743668599541789D-01 0.637813630000000D+04 94012155614.999              SP eci
         0.000000      973.486674    -5487.983980     3834.145830 16609 1 SP eci
  94012155614.999     5.196330328     3.833589348     4.151804753 16609 1 SP eci
       360.000000    -1997.347435    -6388.827895     1012.022467 16609 1 SP eci
  94012215614.999     4.866551015    -0.578214424     5.906492156 16609 1 SP eci
       720.000000    -4219.534575    -4825.996769    -2183.642923 16609 1 SP eci
  94013035614.999     2.559299861    -4.715610847     5.482832602 16609 1 SP eci
      1080.000000    -4782.610734    -1429.928997    -4575.840399 16609 1 SP eci
  94013095614.999    -0.825774886    -6.989282406     3.043858323 16609 1 SP eci
      1440.000000    -3432.219056     2471.015279    -5286.553414 16609 1 SP eci
  94013155614.999    -3.944523981    -6.556070622    -0.508605620 16609 1 SP eci
```

Record 1:

- Earth gravitational constant (Earth Radius$^{3/2}$ / minute)
- Mean earth radius (km)
- Epoch time (YYDDDHHMMSS.SSS UTC)
- Propagator used to generate ephemeris (column 75-76): "SP" or "GP"
- File coordinate system (column 78-80):
  - "eci" = ECI position and velocity
  - "j2k" = J2K position and velocity
  - "efg" = EFG position and velocity

- "ecr" = ECR position and velocity

Record 2:

- Time since epoch (minutes)
- pos x (km)
- pos y (km)
- pos z (km)
- Satellite number
- Vector ephemeris file type (ignored)
- Propagation type ("SP" or "GP") (ignored)
- File Coordinate system (ignored)

Record 3:

- Time (YYDDDHHMMSS.SSS UTC)
- vel x (km/sec)
- vel y (km/sec)
- vel z (km/sec)
- Satellite number (ignored)
- Vector ephemeris file type (ignored)
- Propagation type ("SP" or "GP") (ignored)
- File coordinate system (ignored)

Note:

- All records start in column 2.
- Records 2 and 3 are repeated for each time point.

6.2. Simulated Observation File Description

Sample file:

Copy

```
columns  1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
---------------------------------------------------------------------------------
 0.743668599541789D-01 0.637813630000000D+04 94012155614.999                   Z
 16609 94012155614.999  45103                                              eci Z
 0.973486674121399D+03 -.548798398048386D+04 0.383414582999846D+04         eci Z
 0.519633032840763D+01 0.383358934759739D+01 0.415180475253440D+01         eci Z
 16609 94012215614.999  45107                                              eci Z
 -.199734743503652D+04 -.638882789456959D+04 0.101202246680042D+04         eci Z
 0.486655101481692D+01 -.578214423983053D+00 0.590649215622663D+01         eci Z
```

Record 1:

- Earth gravitational constant (Earth Radius$^{3/2}$ / minute)
- Mean earth radius (km)
- Epoch time (YYDDDHHMMSS.SSS UTC)
- File descriptor (Z)

Record 2:

- Satellite number
- Time (YYDDDHHMMSS.SSS UTC)
- Revolution number
- File coordinate system (column 76-78):
  - "eci" = ECI position and velocity
  - "j2k" = J2K position and velocity
  - "efg" = EFG position and velocity
  - "ecr" = ECR position and velocity
- File descriptor (Z)

Record 3:

- pos x (km)
- pos y (km)
- pos z (km)
- File coordinate system (ignored)
- File descriptor (Z)

Record 4:

- vel x (km/sec)
- vel y (km/sec)
- vel z (km/sec)
- File coordinate system (ignored)
- File descriptor (Z)

Note:

- All records start in column 2.

6.3. ASCII Vector Covariance Ephemeris (ITC) File Description

This file format was developed in conjunction with Analytical Graphics Inc. in order to incorporate ASW produced ephemerides and error ellipsoids into STK for visualization and further analysis purposes.

Sample file:

Copy

```
Columns:                                                                                                1         1
        1         2         3         4         5         6         7         8         9         0         1
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
 21654 0.743668599541789E-01 0.637813630000000E+04 1999203071500.374                                        SP
 1999203071500.374     5529.024105   -11312.951754     1519.348669     6.508734619    -1.289694229     0.352371442
    0.40680623E+10  0.00000000E+00  0.40680623E+10  0.00000000E+00  0.00000000E+00  0.40680623E+10  0.00000000E+00
    0.00000000E+00  0.00000000E+00  0.62494814E+04  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
    0.62494814E+04  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.62494814E+04
 1999203071700.374     6302.232390   -11452.313872     1559.553619     6.377654948    -1.037197117     0.318199307
    0.40680623E+10  0.00000000E+00  0.40680623E+10  0.00000000E+00  0.00000000E+00  0.40680623E+10  0.00000000E+00
    0.00000000E+00  0.00000000E+00  0.62494814E+04  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
    0.62494814E+04  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.62494814E+04
```

Record 1:

- SSC Satellite Number in columns 2 - 6
- Root Earth Gravitational Constant (Earth Radius$^{3/2}$ / minute) in columns 8 - 28
- Earth Radius in columns 30 - 50
- Epoch Time (UTC YYYYDDDHHMMSS.SSS) in columns 52 - 68
- Propagator used to generate ephemeris in columns 113 - 114 (GP or SP)

Record 2:

- Time of point (UTC YYYYDDDHHMMSS.SSS) in columns 2 - 18
- x-position component (km) in columns 20 - 34
- y-position component (km) in columns 36 - 50
- z-position component (km) in columns 52 - 66
- x-velocity component (km/sec) in columns 68 - 82
- y-velocity component (km/sec) in columns 84 - 98
- z-velocity component (km/sec) in columns 100 - 114

Note:

- Position and velocity coordinate system is mean equinox, true equator of date.

Records 3, 4, and 5 contain the covariance. There are 21 terms in the lower half of the 6x6 matrix. Terms 1 - 7 are in record 3, 8 - 14 are in record 4, and 15 - 21 are in record 5.

The seven terms in each covariance record are located in columns 4 - 18, 20 - 34, 36 - 50, 52 - 66, 68 - 82, 84 - 98, and 100 - 114 respectively.

Term and units:

	U	**V**	**W**	**U-DOT**	**VDOT**	**WDOT**
U	1 (km^2)					
V	2 (km^2)	3 (km^2)				
W	4 (km^2)	5 (km^2)	6 (km^2)			
U-DOT	7 (km^2/s)	8 (km^2/s)	9 (km^2/s)	10 (km^2/s^2)		
V-DOT	11 (km^2/s)	12 (km^2/s)	13 (km^2/s)	14 (km^2/s^2)	15 (km^2/s^2)	
W-DOT	16 (km^2/s)	17 (km^2/s)	18 (km^2/s)	19 (km^2/s^2)	20 (km^2/s^2)	21 (km^2/s^2)

Records 2, 3, 4, and 5 are repeated for each ephemeris point.

6.4. ASCII ITC Compact Format File Description

This file format is similar to the full ITC format but without the covariance data. This format needs to have the keyword “WOCOV” (without covariance) in column 107-111 in Record 1 as described above.

Sample file:

Copy

```
Columns:                                                                                                  1         1
         1         2         3         4         5         6         7         8         9         0         1
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
 21654 0.743668599541789E-01 0.637813630000000E+04 1999203071500.374                                      WOCOV SP
 1999203071500.374      5529.024105    -11312.951754     1519.348669     6.508734619    -1.289694229     0.352371442
 1999203071700.374      6302.232390    -11452.313872     1559.553619     6.377654948    -1.037197117     0.318199307
```

6.5. External Ephemeris V31 File Description

Sample file:

Copy

```
EPHEMERIS FILE FOR SATELLITE  7646 on file 07646.EPH
1  7646U 75010A    98 60.29280547  .00215868  00000-0  45026-2 6  14322
2  7646  49.8328 213.7848 0216294 123.5870  19.4980 13.81505971164992
  6347.53939   959.82557  3232.26467  1550.114844  5728.822559 -4622.011437 UB1P
 7646 75010A  1998 60070138.393  16499  1430.002158680.004502700.00000000TMDAT2P
011211  0  0   01.0  241400   100              05    4 0    00 100.0000001 1.4P
Time span: 1998/060 0701 00.000 to 1998/063 0701 00.000 (UTC),  interval:    1.000 min
Coordinate frame: TRUE EQUATOR & MEAN EQUINOX OF DATE  ,  Using the FK5 mean of J2000 time and reference frame
Propagation by SP    , using the EGM-96    earth model;   Format: ECI Position & velocity    (units: Km, m/sec     )
YYDDDHHMMSS.SSS (UTC)    X (km)            Y (km)            Z (km)            X-dot (m/s )        Y-dot (m/s)         Z-dot (m/s)
==============================================================================================================================
98060070100.000       6283.01904978      739.17752884     3407.10653207     1810.51930508     5763.84631607    -4484.77528762
98060070200.000       6379.43963740     1083.35746392     3131.59335170     1402.54184241     5705.13397587    -4695.99192002
98060070300.000       6451.22597957     1423.35472379     2843.95617446      989.66035395     5624.48053750    -4888.77782947
98060070400.000       6498.13481652     1757.86403181     2545.32348055      573.57594883     5522.27518402    -5062.39334857
98060070500.000       6520.02517235     2085.60635016     2236.86541705      155.99544508     5399.00284319    -5216.18976861
98060070600.000       6516.85842013     2405.33452428     1919.78825384     -261.37788456     5255.24072740    -5349.61209833

...

98063065600.000      -5185.79816654     2340.56229914    -4863.70696313    -4805.42510364    -4556.62313100     2879.46170675
98063065700.000      -5465.10311383     2063.32324883    -4682.71186506    -4502.11504882    -4682.03663405     3151.96311080
98063065800.000      -5725.74698247     1779.03862878    -4485.68934124    -4183.55684406    -4791.41506076     3413.56808623
98063065900.000      -5966.84547060     1488.68096610    -4273.31826822    -3850.77670574    -4884.41848117     3663.44558047
98063070000.000      -6187.57702633     1193.24182967    -4046.32641473    -3504.83976174    -4960.75220470     3900.79716406
98063070100.000      -6387.18512421      893.72909714    -3805.48843807    -3146.84810850    -5020.16739470     4124.85856872
EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
ZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZ
```

The file is identified by the start of the first header record: "EPHEMERIS FILE FOR SATELLITE". The satellite number is in the next field. The ephemerides can be input in two coordinate systems, Earth Centered Inertial (ECI) or Earth Fixed Greenwich (EFG). The coordinate system is on the record starting "Propagation by SP". The remainder of the header contains images of the input, and other summary data. All of it is ignored through the line starting "=============================".

The time for the ephemeris points is UTC. The ephemeris point is converted to units of km and km/sec and simply stored. The coordinate frame of the ephemeris is recorded from the header record. All required conversion to the output coordinate frame is performed in the SatState library if needed.

Revolution number is not input by this format, so is set to zero.

6.6. Owner/Operator Ephemeris File Description

Sample file:

Copy

```
03330000000.000 -106.9076002 -7080.537295 161.5209929 -1.067394501 0.1945613928 7.424724251
03330000100.000 -170.6921229 -7054.561199 606.3761402 -1.058039492 0.6710317336 7.398769362
03330000200.000 -233.7867483 -7000.06616 1048.773292 -1.044405529 1.144868779 7.342817447
03330000300.000 -295.9362857 -6917.268372 1486.918634 -1.026547116 1.61413518 7.257089711
03330000400.000 -356.8893423 -6806.499724 1919.035372 -1.004536282 2.076913225 7.141931768
03330000500.000 -416.3993639 -6668.206382 2343.371112 -0.9784622302 2.531312528 6.997811103
03330000600.000 -474.2256574 -6502.946944 2758.205126 -0.9484311035 2.975477066 6.82531551
03330000700.000 -530.1343977 -6311.390127 3161.85553 -0.9145655719 3.407593691 6.625151636
```

The file is always in J2000 coordinate system with units in km and km/sec. The position and velocity are free format (fields separated by at least one blank character).

This file format doesn't contain a satellite number field. ExtEphem will try to parse the input file name's first 5 character as the satellite number. If the parsing fails, the satellite number is set to 99999.

6.7. ECR Position/Velocity File Format

Sample file:

Copy

```
CLASSIFICATION: UNCLASSIFIED
 2150 CALIBRATION REFERENCE EPHEMERIS
TIME OF LAST MODIFICATION TO FILE: 01 347 21 10 25.000
EPHEMERIS FILE START TIME:         98 025 00 00 00.000
EPHEMERIS FILE STOP TIME:          98 026 00 00 00.000
EARTH MODEL: USER
COORDINATE SYSTEM: EARTH CENTERED ROTATING (ECR)

                      X(KM)          Y(KM)          Z(KM)
YYDDDHHMMSS.SSS   XDOT(KM/SEC)   YDOT(KM/SEC)   ZDOT(KM/SEC)
--------------  -------------  -------------  ------------
98025000000.000    2107.182735   -2278.376810   -9707.272978
                     -1.734771       5.136867      -1.035837
98025000100.000    2003.064512   -1968.254395   -9762.815843
                     -1.735432       5.199470      -0.815030
```

6.8. ECR Position Only File Format

Sample file:

Copy

```
CLASSIFICATION: UNCLASSIFIED
16907 CALIBRATION REFERENCE EPHEMERIS
TIME OF LAST MODIFICATION TO FILE: 01 007 00 00 00.000
EPHEMERIS FILE START TIME:         01 007 00 00 00.000
EPHEMERIS FILE STOP TIME:          01 007 23 59 45.000
EARTH MODEL: EGM-96
COORDINATE SYSTEM: EARTH CENTERED ROTATING (ECR)

YYDDDHHMMSS.SSS      X(KM)          Y(KM)          Z(KM)
--------------  -------------  -------------  -------------
23107000000.000    4572.304970    4510.617966    4517.765766
23107000100.000    4459.286832    4830.803688    4294.993557
23107000200.000    4335.895494    5137.813003    4059.477769
23107000300.000    4202.375213    5430.832806    3811.917399
23107000400.000    4058.993297    5709.089138    3553.047325
23107000500.000    3906.039661    5971.849336    3283.636109
23107000600.000    3743.826324    6218.424059    3004.483684
23107000700.000    3572.686856    6448.169184    2716.418938
23107000800.000    3392.975765    6660.487557    2420.297211
23107000900.000    3205.067845    6854.830612    2116.997696
23107001000.000    3009.357459    7030.699827    1807.420775
```

6.9. J2K File Format

Sample file:

Copy

```
SPEPH PREDICTION EPHEMERIS # 0001 (*****   CIRCULAR/ELLIPTICAL   *****)
  18006    98 025 00 00  0.000          705.7853     3022.9816    -9706.9984      -3.4992809    -4.2665523    -1.0367166
  18006    98 025 00 01  0.000          495.3972     2764.9958    -9762.5942      -3.5128827    -4.3321035    -0.8159150
  18006    98 025 00 02  0.000          284.3331     2503.2349    -9804.8415      -3.5217992    -4.3923653    -0.5917782
  18006    98 025 00 03  0.000           72.8771     2238.0207    -9833.5424      -3.5259262    -4.4471881    -0.3643795
```

6.10. OASYS File Formats

Copy

```
Sample 1:
            Version: OASYS v5.4.2a (November 24, 2008), Integral Systems, Inc.
        Description: F930117.eph
               Date: 2012/01/16 16:54:40
               Path: M:\oasys\common\CMOC\6393_F930117.rpt
         Spacecraft: [6393] AEHF Flt 1
          Ephemeris: /M=/oasys/6393/ephem/F930117.eph
            Equinox: MEME of Epoch [JD2000] FK5
           Attitude: OrbitPlaneRadial
Report Span Initial: 2012/01/16 23:59:45.000
  Report Span Delta: 17.000 days
  Report Span Final: 2012/02/02 23:59:45.000


Ephemeris Parameter Report
==========================

     Title:  CMOC Ephemeris
  Subtitle:  F930117.eph

                  Time         ECI Pos.x         ECI Pos.y         ECI Pos.z ECI Vel.x(km/sec) ECI Vel.y(km/sec) ECI Vel.z(km/sec)
```

```
            UTC.YmdHMs3                km                 km                 km            km/sec            km/sec            km/sec

2012/01/16 23:59:45.000        28884.90643        30628.96473        2381.263136       -2.228655789        2.113446136       -0.1375783064

 Sample 2:
*
*
*


*
*
*
*
*
*
*
*
```

UTC	ECI Pos.x km	ECI Pos.y km	ECI Pos.z km	ECI Vel.x km/sec	ECI Vel.y km/sec	ECI Vel.z km/sec
2011/10/10 00:00:00.000	-24926.27236599	34013.46304948	60.74570489891	-2.479275135874	-1.817880758229	0.006145418627

```
 Sample 3:
2011/10/10 00:00:00.000   -24926.27236599    34013.46304948    60.74570489891   -2.479275135874   -1.817880758229    0.006145418627
```

6.11. Various STK's Dot E ".e" Files

ExtEphem can read various STK's ephemeris ".e" file formats.

6.12. DC Ephemeris Binary File

ExtEphem can read DC Ephemeris (DCE) binary file.

6.13. External Ephemeris Record Name

The record name allows the users to add their own descriptive information about the EXTEPHEM they are about to load.

Example:

Copy

```
#EXTEPHEM=Sgp4 Propagated Ephemeris
EPHFIL = extephem1.inp

#EXTEPHEM=SP Propagated Ephemeris
EPHFIL = extephem1.inp

#EXTEPHEM=Owner Operator Ephemeris
EPHFIL = 12345OwnerOperExtEphem.inp
```