

A Computer Program for Converting Between True-of-Date and EME2000 Coordinates

This document is the user's manual for a Fortran computer program called `eme_tod` that can be used to transform between Earth-centered inertial (ECI) true-of-date Cartesian coordinates and the corresponding coordinates in the Earth mean equator and equinox of J2000 (EME2000) coordinate system. The input to the program can be in the form of an ECI state vector (position and velocity vectors) or classical orbital elements.

The software implemented in this application is based on several Fortran subroutines from version 3.0 of the Naval Observatory Vector Astrometry Software (NOVAS) software library located at http://aa.usno.navy.mil/software/novas/novas_info.php. The `eme_tod` computer program was created using version 11.1 of the Intel Visual Fortran software suite.

Please note that this computer program does not include the effects of polar motion in the calculations.

The following is a brief description of each coordinate system. Each reference system is a right-handed Cartesian set of three orthogonal axes.

ECI True-of-date Coordinate System

The origin of the true-of-date ECI inertial coordinate system is the geocenter and the fundamental plane is the Earth's true-of-date equator. The x-axis of this system is aligned with the true-of-date vernal equinox, the y-axis is advanced 90 degrees along the Earth's equator, and the z-axis is along the true-of-date spin axis of the Earth.

EME2000 Coordinate System

The origin of the ECI inertial coordinate system is the geocenter and the fundamental plane is the Earth's mean equator. The z-axis of this system is normal to the Earth's mean equator at epoch J2000, the x-axis is parallel to the vernal equinox of the Earth's mean orbit at epoch J2000 and the y-axis completes the right-handed coordinate system. The epoch J2000 is the Julian Ephemeris Date (JED) 2451545.0 (January 1, 2000, 12 hours Terrestrial Time).

Using the Software

The `eme_tod` software is data-driven by a simple ASCII input file created by the user. To run the program, simply type `eme_tod *.*` at a DOS command line, where `*.*` is the name of a compatible input data file. If you do not include an input file on the command line, the software will interactively ask you for the name of a data file with the following prompt

```
program eme_tod

convert between true-of-date and eme2000 coordinates

please input the name of the data file
```

Typical Data File

The following is a typical state vector input data file for this program. This data file is based on the example given on pages 17-18 of AAS 06-134, "Implementation Issues Surrounding the New IAU Reference Systems for Astrodynamics". This program also provides the classical orbital elements and Keplerian orbital period for each set of state vectors. The user can input a value for the gravitational constant of the Earth which is used in the calculation or conversion of orbital elements. Please note that all input and output is *metric*. Please be sure to provide all four digits of the calendar year.

Each data item within an input file is preceded by one or more lines of annotation text. Do not delete any of these annotation lines or increase or decrease the number of lines reserved for each comment. However, you may change them to reflect your own explanation. The annotation line also includes the correct units and when appropriate, the valid range of the input. ASCII text input is not case sensitive but must be spelled correctly. User-provided data items are in bold font.

```
*****
data file for eme_tod.exe computer program which
converts between true-of-date and eme2000 coordinates
*****

type of coordinate conversion
(1 = eme2000-to-true-of-date, 2 = true-of-date-to-eme2000)
-----
1

UTC calendar date (month, day, year)
-----
4, 6, 2004

UTC time (hours, minutes, seconds)
-----
7, 51, 28.386009

TAI-UTC (seconds)
-----
32.0

x-component of position vector (kilometers)
-----
5.1025096000e+003

y-component of position vector (kilometers)
-----
+6.1230115200e+003

z-component of position vector (kilometers)
-----
+6.3781363000e+003

x-component of velocity vector (kilometers/second)
-----
-4.7432195996e+000

y-component of velocity vector (kilometers/second)
-----
```

+7.9053660026e-001

z-component of velocity vector (kilometers/second)

+5.5337561903e+000

gravitational constant (km**3/sec**2)

398600.4415

The following is a typical classical orbital element version of an input file.

data file for eme_tod.exe computer program which
converts between true-of-date and eme2000 coordinates

type of coordinate conversion

(1 = eme2000-to-true-of-date, 2 = true-of-date-to-eme2000)

1

UTC calendar date (month, day, year)

4, 6, 2004

UTC time (hours, minutes, seconds)

7, 51, 28.386009

TAI-UTC (seconds)

32.0

semimajor axis (kilometers)

16370.58685

orbital eccentricity (non-dimensional)

0.4249757137

orbital inclination (degrees)

63.10562739

argument of perigee (degrees)

2.11617006

right ascension of the ascending node (degrees)

26.24806701

true anomaly (degrees)

42.35721450

gravitational constant (km**3/sec**2)

398600.4415

The following is the program output for this example.

eme2000-to-true-of-date conversion
=====

UTC calendar date 04/06/2004
UTC time 07:51:28.386
UTC Julian date 2453101.82741188

TDB time 07:52:32.572
TDB Julian date 2453101.82815476
TAI-UTC 32 seconds

true-of-date state vector and orbital elements

| | | | |
|------------------|--------------------|-------------------|------------------|
| rx (km) | ry (km) | rz (km) | rmag (km) |
| 0.5094029526D+04 | 0.6127870677D+04 | 0.6380247731D+04 | 0.1020820733D+05 |
| vx (kps) | vy (kps) | vz (kps) | vmag (kps) |
| -.4746262313D+01 | 0.7860144499D+00 | 0.5531791139D+01 | 0.7331134828D+01 |
| sma (km) | eccentricity | inclination (deg) | argper (deg) |
| 0.1637058685D+05 | 0.4249757137D+00 | 0.6309512455D+02 | 0.2140029976D+01 |
| raan (deg) | true anomaly (deg) | arglat (deg) | period (min) |
| 0.2629188029D+02 | 0.4235721450D+02 | 0.4449724448D+02 | 0.3474210292D+03 |

eme2000 state vector and orbital elements

| | | | |
|------------------|--------------------|-------------------|------------------|
| rx (km) | ry (km) | rz (km) | rmag (km) |
| 0.5102509600D+04 | 0.6123011520D+04 | 0.6378136300D+04 | 0.1020820733D+05 |
| vx (kps) | vy (kps) | vz (kps) | vmag (kps) |
| -.4743219600D+01 | 0.7905366003D+00 | 0.5533756190D+01 | 0.7331134828D+01 |
| sma (km) | eccentricity | inclination (deg) | argper (deg) |
| 0.1637058685D+05 | 0.4249757137D+00 | 0.6310562739D+02 | 0.2116170060D+01 |
| raan (deg) | true anomaly (deg) | arglat (deg) | period (min) |
| 0.2624806701D+02 | 0.4235721450D+02 | 0.4447338456D+02 | 0.3474210292D+03 |

The following is an input file which performs the true-of-date to EME2000 transformation using the output from the previous example.

```

*****
data file for eme_tod.exe computer program
converts between true-of-date and eme2000 coordinates
*****

type of coordinate conversion
(1 = eme2000-to-true-of-date, 2 = true-of-date-to-eme2000)
-----
2

UTC calendar date (month, day, year)
-----
4, 6, 2004

UTC time (hours, minutes, seconds)
-----
7, 51, 28.386

TAI-UTC (seconds)
-----
32.0

x-component of position vector (kilometers)
-----
5094.029526

y-component of position vector (kilometers)
-----
6127.870677

z-component of position vector (kilometers)
-----
6380.247731

x-component of velocity vector (kilometers/second)
-----
-4.746262313

y-component of velocity vector (kilometers/second)
-----
0.7860144499

z-component of velocity vector (kilometers/second)
-----
5.531791139

gravitational constant (km**3/sec**2)
-----
398600.4415

```

The following is the program output for this example.

```

true-of-date-to-eme2000 conversion
=====

UTC calendar date      04/06/2004

```

```

UTC time          07:51:28.386
UTC Julian date   2453101.82741188

TDB time          07:52:32.572
TDB Julian date   2453101.82815476

TAI-UTC          32 seconds

```

true-of-date state vector and orbital elements

```

-----
      rx (km)          ry (km)          rz (km)          rmag (km)
0.5094029526D+04    0.6127870677D+04    0.6380247731D+04    0.1020820733D+05

      vx (kps)          vy (kps)          vz (kps)          vmag (kps)
-.4746262313D+01    0.7860144499D+00    0.5531791139D+01    0.7331134828D+01

      sma (km)          eccentricity          inclination (deg)          argper (deg)
0.1637058685D+05    0.4249757138D+00    0.6309512456D+02    0.2140029984D+01

      raan (deg)          true anomaly (deg)          arglat (deg)          period (min)
0.2629188029D+02    0.4235721449D+02    0.4449724448D+02    0.3474210293D+03

```

eme2000 state vector and orbital elements

```

-----
      rx (km)          ry (km)          rz (km)          rmag (km)
0.5102509600D+04    0.6123011520D+04    0.6378136300D+04    0.1020820733D+05

      vx (kps)          vy (kps)          vz (kps)          vmag (kps)
-.4743219600D+01    0.7905366002D+00    0.5533756191D+01    0.7331134828D+01

      sma (km)          eccentricity          inclination (deg)          argper (deg)
0.1637058685D+05    0.4249757138D+00    0.6310562740D+02    0.2116170069D+01

      raan (deg)          true anomaly (deg)          arglat (deg)          period (min)
0.2624806701D+02    0.4235721449D+02    0.4447338456D+02    0.3474210293D+03

```

The following are brief definitions of information output by the software.

EME2000 = Earth mean equator and equinox of J2000

UTC = coordinated universal time

TDB = barycentric dynamical time

rx (km) = x-component of the position vector in kilometers

ry (km) = y-component of the position vector in kilometers

r_z (km) = z-component of the position vector in kilometers
 v_x (kps) = x-component of the velocity vector in kilometers/second
 v_y (kps) = y-component of the velocity vector in kilometers/second
 v_z (kps) = z-component of the velocity vector in kilometers/second

 sma (km) = semimajor axis in kilometers

 $eccentricity$ = orbital eccentricity (non-dimensional)

 $inclination$ (deg) = orbital inclination in degrees

 $argper$ (deg) = argument of perigee in degrees

 $raan$ (deg) = right ascension of the ascending node in degrees

 $true\ anomaly$ (deg) = true anomaly in degrees

 $arglat$ (deg) = argument of latitude in degrees

 $period$ (min) = orbital period in minutes

Algorithm Resources

“The IAU Resolutions on Astronomical Reference Systems, Time Scales, and Earth Rotation Models: Explanation and Implementation”, United States Naval Observatory Circular No. 179, George H. Kaplan, October 20, 2005.

“User’s Guide to NOVAS 3.0”, United States Naval Observatory Circular No. 180, George H. Kaplan, John A. Bangert, Jennifer L. Bartlett, Wendy K. Puatua, and Alice K. B. Monet, December 31, 2009.

“Nutation Series Evaluation in NOVAS 3.0”, United States Naval Observatory Circular No. 181, George H. Kaplan, December 15, 2009.

Explanatory Supplement to the Astronomical Almanac, Edited by P. K. Seidelmann, University Science Books, 1992.

“IERS Conventions (2003)”, IERS Technical Note 32, November 2003.

Astronomical Algorithms, Jean Meeus, Willmann-Bell, Inc., 1991.