ASTRONOMICAL TIME STANDARDS AND TIME CONVERSION UTILITIES

RC Chakraborty (Retd), Former Director, DRDO, Delhi & Visiting Professor, JUET, Guna,

www.myreaders.info, rcchak@gmail.com,

www.myreaders.info/html/orbital_mechanics.html, Revised Dec. 16, 2015

(This is Sec. 1, pp 6 - 32, of Orbital Mechanics - Model & Simulation Software (OM-MSS), Sec 1 to 10, pp 1 - 402.)

ASTRONOMICAL TIME STANDARDS AND TIME CONVERSION UTILITIES

First look into few preliminaries and then move to time conversion utilities.

Time Abbreviations :

GMT - Greenwich Mean Time, **LMT** - Local Mean Time, **LST** - Local Sidereal Time, **Sidereal Time**, **Solar Time**,

LMST - Local Mean Sidereal Time, **GMST** - Greenwich Mean Sidereal Time, **GAST** - Greenwich Apparent Sidereal Time, **TAI** - International Atomic Time,

TT - Terrestrial Time, **TDT** - Terrestrial Dynamical Time, **TCB** - Barycentric Coordinate Time, **TCG** - Geocentric Coordinate Time,

UT - Universal Time, **UTC** - Coordinated Universal Time, **JD** - Julian Day, **ET** - Ephemeris Time,

BCE - Before the Common/Current/Christian Era, **CE** - Common Era/Current Era/Christian Era, **Gregorian calendar**.

Time Standards and designations :

Time is a dimension in which the events can be ordered from the past through the present into the future.

Our clocks are set to run (approximately) on solar time (sun time). For astronomical observations, we need to use sidereal time (star time).

Earth rotation is considered relative to the stars. One earth rotation is the time between two successive meridian passages of the same star.

One rotation of Earth is one sidereal day, which is a little shorter than a solar day; ie, one mean sidereal day is about 0.99726958 mean solar day.

Day is a unit of time. A day is measured from local noon to the following local noon. In common usage, a day consists 24 hours, noon is 12.00 hours.

Solar Time is based on the rotation of the Earth with respect to the Sun. There are two types of solar time,

- Apparent or True Solar Time is, that measured by direct observation of the Sun. It is not uniform throughout the year;
- Mean Solar Time is, that would be measured if the Sun traveled at a uniform apparent speed throughout the year. Our clocks use Mean Solar Time.

Solar day is the time for Earth to make a complete rotation on its axis relative to the Sun;

- Apparent or True Solar Day varies through the year, that can be 20 seconds shorter in September and 30 seconds longer in December.

  This variaion is because of inclination (23.4392794383 deg) of Earth's axis of rotation and the elliptical orbit of Earth around the Sun.
- Mean Solar Day, is average of true solar day during entire year, contains 86,400 mean solar seconds.

  The mean solar day is measured from midnight to midnight where midnight is hour 00. The mean solar day is divided into 24 solar hours,

  while each solar hour is divided into 60 solar minutes, and each solar minute divided into 60 solar seconds.

Equation of time describes the discrepancy between the Apparent Solar time and the Mean Solar time.

In a year, compared to Mean Solar time the Apparent Solar time can be ahead (fast) or behind (slow) or near zeros (same).

The typical values are : ahead (fast) as much as 16 min 33 sec around 3 Nov., or behind (slow) as much as 14 min 6 sec around 12 Feb., or near zeros (same) around 15 April, 13 June, 1 Sept and 25 Dec.

Solar year is average of 400 consecutive civil years having 97 leap years, ie ((400 x 365) + 97) = 146097 / 400 = 365.242500 solar days.

Our clocks are set to run on solar time. But for astronomical observations, we need to use sidereal time (star time).

Sidereal Time is based on the rotation of the Earth with respect to fixed stars. ST is a measure of the hour angle of the Vernal equinox.

- Apparent Sidereal Time is measured, if the hour angle is with respect to the true equinox,
- Mean Sidereal Time is measured, if the hour angle is with respect to the mean equinox,

Sidereal Day is equal to the interval of time between two successive transits of the vernal equinox. At Vernal equinox transit point hour angle is zero;

- Apparent or True sidereal Day is affected by the motion of true equinox due to 'Precession' and 'Nutation';
- Mean Sidereal Day is affected by the motion of mean equinox due to Precession only;

Precession is a change in orientation of rotational axis, slowly westward relative to the fixed stars completing one revolution in about 26,000 years.

It is caused by the gravity of the Moon and Sun acting on the Earth.

Nutation is a small cyclical motion superimposed upon the steady 26,000 year Precession of the Earth's axis of rotation.

It is caused by the gravitational effect of the 18.6-year rotation period of the Moon's orbit.

Mean sidereal day is 23.9344699 hours or 23 hours, 56 minutes, 4.0916 seconds, (ie, one mean sidereal day is about 0.99726958 mean solar day).

A clock regulated to Apparent Sidereal time compared with one regulated to Mean Sidereal time, the diff is 2 to 3 sec in 19 years is no inconvenience.

Sidereal year is the time taken by Earth to complete one revolution of its orbit, measured against a fixed frame of reference (as the fixed stars).

A Sidereal year is approximately 365.256363 days, is slightly longer than the solar year (365.2425 days).

The actual durations differ from year to year because the motion of Earth is influenced by the gravity of Moon and other planets.

Sidereal year average duration is precisely 365.256363004 mean solar days (or 365day, 6hr, 9min, 9.76sec in units of mean solar time) at epoch J2000.0, ie YY 2000, MM 1, Hr 12. Thus, the earth mean motion rev per day around sun = 1.0 / 365.256363004.

Sidereal time (ST) of a location is defined by its geographical longitude, thus called Local Sidereal time (LST) of the location.

For observers over Greenwich, whose longitude is set at 0 degrees, the local sidereal time (LST) = Greenwich Sidereal Time (GST) .

For Observers over other longitude location, the LST is calculated using formula LST = GST + observer's log in hr : min : sec .

Earth rotates through 360 deg longitude. The angle between two longitudes is measured in degree or in time, with 24 hr = 360 deg, ie 1 hr = 15 deg.

This means Sun moves through 15 deg of longitude in 1 hour, or 15 minutes of arc in 1 minute of time.

Hour Angle HA of an object is its Geographic Position (GP), measured around the celestial equator, westward from the observer's meridian.

Greenwich hour angle GHA is angular distance of Geographic Position (GP) of a celestial body, measured (in 0-360 deg) westward from Greenwich (0 deg).

Sidereal hour angle SHA is angular distance of of Geographic Position (GP) of a body (X), measured (in 0-360 deg) westward from the point of Aries.

Relation GHA of a body = SHA of the body + GHA of Aries.

Local hour angle LHA is angular distance of between the meridian of the celestial body and the meridian of the observer,

Relation LHA of a body) = GHA of the body - Longitude of observer.

Note : Longitude is an angular distance in degree, East(+ve) or West(-ve) of the prime meridian. This notation is popular for public use.

This means, longitude increases east or west of the prime meridian (from 0 at prime meridian to 180 on other side of Earth).

However, representing longitude 0 to +360 deg east only from Greenwich is preferred since the satellites go around and that makes sense

for the longitude to keep increasing if the satellite moves forward, else calculations need to track switching of east or west of longitude.

Therefore remember, all through the longitude is represented as 0 to +360 deg east only from Greenwich.

For more about Sidereal Time, read at http://en.wikipedia.org/wiki/Sidereal_time , http://star-www.st-and.ac.uk/~fv/webnotes .

GMT - Greenwich Mean Time, was originally referred to Mean Solar Time at Greenwich, later adopted as a global time standard.

GMST - Greenwich Mean Sidereal Time, is mean sidereal time at zero longitude; GMST is in degree.

LMST - Local Mean Sidereal Time, is mean sidereal time at your longitude; LMST is in degree.

LMT - Local Mean Solar Time; LMT at zero meridian is Universal time (UT1) also called Greenwich mean time (GMT)

UT - Universal Time, is International time standard for astronomy & navigation, introduced in 1928 by the International Astronomical Union (IAU).

UT is modern continuation of Greenwich Mean Time (GMT), based on sidereal time at Greenwich, with the day starting at midnight.

UT is a time that Earth's rotation determines, no one controls it. The length of a UT second is defined by the period of Earth's revolution around Sun.

UT has many versions. UT is also known as UT0. UT becomes UT1 when it is corrected for the irregular movements of the terrestrial poles.

UT1 - In conformance with IAU, the Greenwich Mean Sidereal Time GMST is linked directly to Universal Time UT1 through the equation :

GMST = 24110.54841 + 8640184.812866 * T + 0.093104 * T^2 - 0.0000062 * T^3 ; where 24110.4581 in seconds is 6h 41m 50.54841 ,

T is in Julian centuries from epoch JD2000 = 2451545.0, T = d / 36525, d = JD - 2451545.0, JD is input UT in Julian days

LMST = GMST + (observer's east longitude); LMST is usually referred as LST in observatory.

UTC - Coordinated Universal Time, a variant of UT, replaced Greenwich Mean Time (GMT) on 1 January 1972 as international time reference.

UTC is based on atomic measurements rather than the earth's rotation. UTC is a human invention of highly precise clocks that keep time.

UTC is primary time standard by which the world regulates clocks and time for :

1. Internet & World Wide Web standards, the network time protocol over internet for the clocks of computers & servers,
   the online services in aviation, the weather forecasts and others rely on UTC which is universally accepted time.
2. UTC divides time into conventional days, hours, minutes and seconds. Days are identifiable using Gregorian calendar and Julian day numbers.
   A day contains 24 hours, hour contains 60 minutes. A minute usually contains 60 seconds but rarely adjusted to have a leap second.
   All smaller time units are of constant duration for sub-microsecond precision.

Note (UTC, UT, & leap second) : The length of a UTC second is defined by count of radiation cycles of atomic transition of element cesium, and not related to any astronomical phenomena. Contrary to this, the length of a UT second is defined in terms of period of Earth's revolution around Sun. Thus, the two time scale are indepedent but controlled by international agreement that UTC cannot differ from UT or UT1 by more than 0.9 second. When the difference crosses this limit of 0.9 second, then one-second change called a 'leap second' is added into UTC. This occurs about once a year.

TAI - International Atomic Time, is an extreme precise means of time-keeping, deviates only 1 second in about 20 million years.

It is based on a continuous counting of the SI second, does not take into account the Earth's slowing rotation which determines the length of a day. TAI is compared to UT1 and before the difference reaches 0.9 seconds, a leap second is added to UTC.

ET - Ephemeris Time, refers to time in any astronomical ephemeris, was introduced in 1950. ET is calculated from the positions of the sun and moon relative to the earth, assuming that Newton's laws are perfectly obeyed. ET, is reckoned from the beginning of the calendar year A.D. 1900, when the geometric mean longitude of the sun was 279 deg, 41 min, 48.04 sec, at this instant Ephemeris Time was 1900 January 0d 12h precisely.

Gregorian calendar is an internationally accepted civil calendar, also called Western or Christian calendar, (Year, Months and Days).

A year is divided into twelve months. A normal year consists of 365 days and in a leap year a leap day is added as 29 February making the year 366 days. A leap year occurs every 4 years, but the Gregorian calendar omits 3 leap days every 400 years.

The start of day is Midnight as 00 hr: 00 mm: 00 sec UT/GMT.

Julian Day (JD) : Refers to a continuous count of days since the beginning of the Julian Period.

Julian day number is a count of days elapsed since Greenwich mean noon on 1 January 4713 B.C.

BCE - Before the Common/Current/Christian Era, CE - Common Era/Current Era/Christian Era.

BCE 4713 January 1 00:00:00.0 UT is JD -0.500000

BCE 4713 January 1 12:00:00.0 UT is JD 0.000000

CE 1858 November 16 12:00:00.0 UT is JD 2400000.0

CE 1858 November 17 00:00:00.0 UT is JD 2400000.5

MJD is Modified Julian day begins at midnight civil date, defined as MJD = JD - 2400000.5

An Epoch specifies a precise moment in time.

Fundamental epoch is J1900 means Y 1899, M 12, D 31, H 12.0 = 2415020.00 JD is based on Newcomb planatory theory, used till 1984.

New standard epoch is J2000 means Y 2000, M 01, D 01, H 12.0 = 2451545.0000000000 JD

One Julian century (JC) is 36525 days. The start of New standard epoch is one Julian century (JC) after the Newcomb epoch.

Julian epoch for beginning of year 2000 is Y 2000, M 1, D 1, H 12.0 = 2451545.000000000

Calculating Julian Day Number to Gregorian Calendar date or Gregorian Calendar date to Julian Day Number, is easy.

The Julian Day Number so calculated is at 00 hours UT/GMT, on that date.

For more about Time Scales : read at **http://stars.astro.illinois.edu/celsph.html,** **http://www.ucolick.org/~sla/leapsecs/timescales.html**

Concluding : A brief preamble of Time standards and designations were presented. However, unless otherwise specified, in OM-MSS Software :

1. Julian dates are widely used as time variables in the software. A julian day starts at midday 4713 B.C.
2. Standard epoch is Julian Day J2000 which means Y 2000, M 01, D 01, H 12.00 = 2451545.0000000000
3. Year, Month and Days are of Gregorian calendar. The BCE 4713 January 01 12:00:00.0 UT Monday, is JD 0.000000 .
4. A day is Mean Solar Day is average of true solar day during entire year. Our Clock follows Mean Solar Day.
5. A Mean solar day = 24h 00m 00s = 86400 sec is the time for a little more than one earth rotation ie 360.9856473356 deg .
6. Hours, Minutes, Seconds are in universal time UT over Greenwich; Midnight as 00 hr: 00 mm: 00 sec GMT .

   Year, Month, Day, Hours, Minutes, Seconds are unsiged +ve values. The time addition & subtraction are in Julian days, or

   in UT days, hours, minute, seconds, where day = 24 x 3600 seconds.
7. A Sidereal day is Mean sidereal day = 23h 56m 4.090538155680s = 86164.090538155680s is time for exact one earth rotation ie 360 deg .

   All you need to do is, convert universal time to your local time that corresponds to the longitude of your place.
8. Longitude is represented in 0 to +360 deg east only from Greenwich, since satellites go around & longitude keep increasing 0 to +360 deg,

End of a brief on Time Designations, Time Standards.

Move on to Time Conversion Utilities of OM-MSS Software,

Next Precise time conversion utilities are presented in Sections (1.1 to 1.10) respectively :

(a) Conversion of Universal Time (year, month, day, hour decimal) To Julian Day;

(b) Conversion of Julian Day To Universal Time (year, month, day, hour decimal;

(c) Conversion of Fundamental Epoch To Julian day and Julian century;

(d) Add or Subtract time (days, hour, minute seconds) to or from input time;

(e) Julian day for start of any Year;

(f) Solar Time : Local Mean Solar Time (LMT) over observer's Longitude, and Greenwich Mean Time (GMT);

(g) Sidereal Time : Greenwich universal time at hour 0.0 (ST0) and Greenwich Mean Sidereal Time (GMST) ;

(h) Sidereal Time : Greenwich Sidereal Time (GST), Greenwich Hour Angle (GHA), and Mean Sidereal Time (MST) ;

(i) Sidereal Time : Local Mean Sidereal Time (LMST) over observer's Longitude ;

(j) Time Conversions : LMT to LST, LST to LMT, LMT to LMST, LMST to LMT ;

Next Section - 1.1 Conversion of UT To JD

OM-MSS Section - 1.1 --2

Conversion of Universal Time (year, month, day, hour decimal) To Julian Day, while Year 100 to 3500

1. Input UT year = 1899, month = 12, day = 31, hr = 12, min = 0, sec = 0.0000000000 Output julian_day = 2415020.0000000000

2. Input UT year = 2000, month = 1, day = 1, hr = 12, min = 0, sec = 0.0000000000 Output julian_day = 2451545.0000000000

3. Input UT year = 2000, month = 12, day = 31, hr = 11, min = 59, sec = 59.0000000000 Output julian_day = 2451909.9999884260

4. Input UT year = 2001, month = 1, day = 1, hr = 0, min = 0, sec = 0.0000000000 Output julian_day = 2451910.5000000000

5. Input UT year = 2050, month = 1, day = 1, hr = 12, min = 0, sec = 0.0000000000 Output julian_day = 2469808.0000000000

Note : The results verified & validated with those reported **(Ref : http://aa.usno.navy.mil/data/docs/JulianDate.php).**

Next Section - 1.2 Conversion of JD To UT

Conversion of Julian Day To Universal Time (year, month, day, hour decimal), while Year 100 to 3500

1. Input julian_day = 2415020.0000000000 Output UT year = 1899, month = 12, day = 31, hr = 12, min = 0, sec = 0.0000000000

2. Input julian_day = 2451545.0000000000 Output UT year = 2000, month = 1, day = 1, hr = 12, min = 0, sec = 0.0000000000

3. Input julian_day = 2451909.9999884260 Output UT year = 2000, month = 12, day = 31, hr = 11, min = 59, sec = 59.0000054240

4. Input julian_day = 2451910.5000000000 Output UT year = 2001, month = 1, day = 1, hr = 0, min = 0, sec = 0.0000000000

5. Input Julian day = 2469808.0000000000 Output UT year = 2050, month = 1, day = 1, hr = 12, min = 0, sec = 0.0000000000

6. Input julian_day = 2451909.9999884260 Output UT Year = 2000, Year days decimal = 365.49999, Month = 12, Day = 31
   Hours decimal = 11.99972, Hour = 11, Min = 59, Sec = 59.000

Note : The results verified & validated with those reported **(Ref : http://aa.usno.navy.mil/data/docs/JulianDate.php).**

Next Section - 1.3 Conversion of Epoch To JD

Conversion of Fundamental Epoch To Julian day and Julian century.

The Fundamental Newcomb Epoch J1900, was used till 1984, is replaced by New Standard Epoch J2000.

The Newcomb Epoch J1900, is beginning of Y 1899, M 12, D 31, H 12.0.

The New standard epoch J2000, is beginning of Y 2000, M 1, D 1, H 12.0.

A Julian century = 36525 days. The New Epoch J2000, is one Julian century after Epoch J1900.

1. Input Fundamental Epoch J1900, corresponds to year = 1900, month = 1, day of month = 1, hours = 12.0.

   Output Julian day = 2415020.00000

2. Input New Standard Epoch J2000, corresponds to year = 2000, month = 1, day of month = 1, hours = 12.0.

   Output Julian day = 2451545.00000

3. A Julian century, 100 years = 36525 days from New Standard Epoch J2000. Prior to year 2000 will have negative Julian century value.

   Input Julian day = 2415021.0000000000, corresponds to year = 1900, month = 1, day_no_of_month = 1, hour decimal = 12.0000000000

   Output Julian day, from Standard Epoch J2000, Converted to Julian century value is = -0.9999726215

   Input Julian day = 2451545.0000000000, corresponds to year = 2000, month = 1, day_no_of_month = 1, hour decimal = 12.0000000000

   Output Julian day, from Standard Epoch J2000, Converted to Julian century value is = 0.0000000000

   Input Julian day = 2488070.0000000000, corresponds to year = 2100, month = 1, day_no_of_month = 1, hour decimal = 12.0000000000

   Output Julian day, from Standard Epoch J2000, Converted to Julian century value is = 1.0000000000

Next Section - 1.4 Add or Subtract time To i/p time

OM-MSS Section - 1.4 --5

Add or Subtract time (days, hour, minute seconds) to or from input time.

```
1. Add       Days,   hour,   minute,   seconds   To   any  Input  UT  Year,  month,  day,  hour,  minute,  seconds

   Input     UT  year  = 2000,  month =  1,   day =  1,  hr =  0,  min =  0,  sec =    0.0000000000

   Add       UT  days  =  365,  hour  =  6,   minute =  0,   seconds =    0.0000000000    Corresponds to days in decimal =  365.2500000000

   Output    UT  year  = 2000,  month = 12,   day = 31,  hr =  6,  min =  0,  sec =    0.0000000000

2. Subtract  Days,   hour,   minute,   seconds   To   any  Input  UT  Year,  month,  day,  hour,  minute,  seconds

   Input     UT  year  = 2000,  month =  1,   day =  1,  hr =  6,  min =  0,  sec =    0.0000000000

   Subtract  UT  days  =    1,  hour  =  6,   minute =  0,   seconds =    0.0000000000    Corresponds to days in decimal =    1.2500000000

   Output    UT  year  = 1999,  month = 12,   day = 31,  hr =  0,  min =  0,  sec =    0.0000000000
```

Next Section - 1.5 JD for start of year

OM-MSS Section - 1.5 ---6

Julian day for start of any Year.

1. Find Julian day for start of Epoch J2000, means the year 2000, M 1, D 1, H 12.0

   Input Start of year = 2000, Output the correspnding Julian day is = 2451545.0000000000

2. Find Julian day for start of any other Year, M 1, D 1, H 12.0

   Input Start of year = 2001, Output the correspnding Julian day is = 2451911.0000000000

Next Section - 1.6 LMT over Longitude and GMT

Solar Time : Local Mean Solar Time (LMT) over Observer's Longitude, and Greenwich Mean Time (GMT) over 0 deg Longitude.

Our Clocks are set on Solar time (Sun time), based on the rotation of the Earth with respect to the Sun.

Solar day is the time for Earth to make a complete rotation on its axis relative to Sun; it varies through +30 to -20 seconds in a year.

A Mean Solar Day (midnight as 0 hour), is average of true solar day during entire year, contains 86,400 mean solar seconds;

A Day is measured midnight to midnight, is divided into 24 solar hours, each hour is 60 solar minutes, and each minute is 60 solar seconds.

Longitude is angular distance in degree, East(+ve) or West(-ve) of the prime meridian. This notation is popular for public use.

But for reasons explained before, the longitude is represented as 0 to +360 deg, east only from Greenwich.

example, log 48 deg west is (360 - 48) = 320 deg east only from Greenwich; and Log 22.5 deg east is 22.5 deg east only from Greenwich

Local Mean solar time (LMT) at 0 deg longitude, is Universal time (UT1), is Greenwich mean time (GMT).

Presented below Conversion between UT(GMT) and LMT over Observer's Geographic Longitude. During conversion, a day change may occur.

Chosen instances of Time/Longitudes that involve log 0 & 180 deg cross over : 82 deg W, 22.5 deg E, 15 deg W, 15 deg E, 195 deg W, 165 deg E.

1. Observer's Longitude West of Greenwich : 48 deg W meaning 312 deg East of Greenwich.

A. Conversion GMT to LMT : Greenwch mean time (UT/GMT) over Greenwich To Local mean time (LMT) over observer's longitude.

```
   Input  Longitude in deg = 312.00, convert to arc_deg =  312, arc_min =  0, arc_sec =  0.00, corresponds to angle hr = 20, min = 48, sec =  0.00

          GMT    year = 2011,   month =  7,   day = 14,   hr = 23,   min = 31,   sec =   25.00000,      over  0 deg   longitude

   Output LMT    year = 2011,   month =  7,   day = 14,   hr = 20,   min = 19,   sec =   25.00001,      over observer longitude
```

B. Conversion LMT to GMT : Local mean time (LMT) over observer longitude To Greenwch mean time (UT/GMT) over Greenwich.

```
   Input  Longitude in deg = 312.00, convert to arc_deg =  312, arc_min =  0, arc_sec =  0.00, corresponds to angle hr = 20, min = 48, sec =  0.00

          LMT    year = 2011,   month =  7,   day = 14,   hr = 20,   min = 19,   sec =   25.00001,      over observer longitude

   Output GMT    year = 2011,   month =  7,   day = 14,   hr = 23,   min = 31,   sec =   25.00001,      over  0 deg   longitude
```

2. Observer's Longitude East of Greenwich : 22.5 deg E meaning 22.5 deg East of Greenwich.

A. Conversion GMT to LMT : Greenwch mean time (UT/GMT) over Greenwich To Local mean time (LMT) over observer's longitude.

```
   Input  Longitude in deg =  22.50, convert to arc_deg =   22, arc_min = 30, arc_sec =  0.00, corresponds to angle hr =  1, min = 30, sec =  0.00
          GMT   year = 2011,   month =  7,   day = 14,   hr = 23,   min = 31,   sec =   25.00000,      over  0 deg   longitude
   Output LMT   year = 2011,   month =  7,   day = 15,   hr =  1,   min =  1,   sec =   25.00001,      over observer longitude
```

B. Conversion LMT to GMT : Local mean time (LMT) over observer longitude To Greenwch mean time (UT/GMT) over Greenwich.

```
   Input  Longitude in deg =  22.50, convert to arc_deg =   22, arc_min = 30, arc_sec =  0.00, corresponds to angle hr =  1, min = 30, sec =  0.00
          LMT   year = 2011,   month =  7,   day = 15,   hr =  1,   min =  1,   sec =   25.00001,      over observer longitude
   Output GMT   year = 2011,   month =  7,   day = 14,   hr = 23,   min = 31,   sec =   25.00001,      over  0 deg   longitude
```

3. Observer's Longitude West of Greenwich : 15 deg W meaning 345 deg East of Greenwich.

A. Conversion GMT to LMT : Greenwch mean time (UT/GMT) over Greenwich To Local mean time (LMT) over observer's longitude.

```
   Input  Longitude in deg = 345.00, convert to arc_deg =  345, arc_min =  0, arc_sec =  0.00, corresponds to angle hr = 23, min =  0, sec =  0.00
          GMT   year = 2011,   month =  7,   day = 14,   hr =  0,   min =  0,   sec =    1.00000,      over  0 deg   longitude
   Output LMT   year = 2011,   month =  7,   day = 13,   hr = 23,   min =  0,   sec =    1.00001,      over observer longitude
```

B. Conversion LMT to GMT : Local mean time (LMT) over observer longitude To Greenwch mean time (UT/GMT) over Greenwich.

```
   Input  Longitude in deg = 345.00, convert to arc_deg =  345, arc_min =  0, arc_sec =  0.00, corresponds to angle hr = 23, min =  0, sec =  0.00
          LMT   year = 2011,   month =  7,   day = 13,   hr = 23,   min =  0,   sec =    1.00001,      over observer longitude
   Output GMT   year = 2011,   month =  7,   day = 14,   hr =  0,   min =  0,   sec =    0.99999,      over  0 deg   longitude
```

4. Observer's Longitude East of Greenwich : 15 deg E meaning 15 deg East of Greenwich.

A. Conversion GMT to LMT : Greenwch mean time (UT/GMT) over Greenwich To Local mean time (LMT) over observer's longitude.

```
   Input  Longitude in deg =  15.00, convert to arc_deg =   15, arc_min =  0, arc_sec =  0.00, corresponds to angle hr =  1, min =  0, sec =  0.00

          GMT   year = 2011,   month =  7,   day = 14,   hr =  0,   min =  0,   sec =    0.99999,      over  0 deg   longitude

   Output LMT   year = 2011,   month =  7,   day = 14,   hr =  1,   min =  0,   sec =    0.99998,      over observer longitude
```

B. Conversion LMT to GMT : Local mean time (LMT) over observer longitude To Greenwch mean time (UT/GMT) over Greenwich.

```
   Input  Longitude in deg =  15.00, convert to arc_deg =   15, arc_min =  0, arc_sec =  0.00, corresponds to angle hr =  1, min =  0, sec =  0.00

          LMT   year = 2011,   month =  7,   day = 14,   hr =  1,   min =  0,   sec =    0.99998,      over observer longitude

   Output GMT   year = 2011,   month =  7,   day = 14,   hr =  0,   min =  0,   sec =    0.99999,      over  0 deg   longitude
```

5. Observer's Longitude West of Greenwich : 165 deg W meaning 195 deg East of Greenwich.

A. Conversion GMT to LMT : Greenwch mean time (UT/GMT) over Greenwich To Local mean time (LMT) over observer's longitude.

```
   Input  Longitude in deg = 195.00, convert to arc_deg =  195, arc_min =  0, arc_sec =  0.00, corresponds to angle hr = 13, min =  0, sec =  0.00

          GMT   year = 2011,   month =  7,   day = 14,   hr =  3,   min =  0,   sec =    0.00000,      over  0 deg   longitude

   Output LMT   year = 2011,   month =  7,   day = 13,   hr = 15,   min = 59,   sec =   59.99999,      over observer longitude
```

B. Conversion LMT to GMT : Local mean time (LMT) over observer longitude To Greenwch mean time (UT/GMT) over Greenwich.

```
   Input  Longitude in deg = 195.00, convert to arc_deg =  195, arc_min =  0, arc_sec =  0.00, corresponds to angle hr = 13, min =  0, sec =  0.00

          LMT   year = 2011,   month =  7,   day = 13,   hr = 15,   min = 59,   sec =   59.99999,      over observer longitude

   Output GMT   year = 2011,   month =  7,   day = 14,   hr =  3,   min =  0,   sec =    0.00000,      over  0 deg   longitude
```

6. Observer's Longitude East of Greenwich : 165 deg E meaning 165 deg East of Greenwich.

A. Conversion GMT to LMT : Greenwch mean time (UT/GMT) over Greenwich To Local mean time (LMT) over observer's longitude.

```
   Input  Longitude in deg = 165.00, convert to arc_deg =  165, arc_min =  0, arc_sec =  0.00, corresponds to angle hr = 11, min =  0, sec =  0.00

          GMT   year = 2011,   month =  7,   day = 14,   hr =  3,   min =  0,   sec =    0.00000,      over  0 deg   longitude

   Output LMT   year = 2011,   month =  7,   day = 14,   hr = 14,   min =  0,   sec =    0.00001,      over observer longitude
```

B. Conversion LMT to GMT : Local mean time (LMT) over input longitude To Greenwch mean time (UT/GMT) over Greenwich.

```
   Input  Longitude in deg = 165.00, convert to arc_deg =  165, arc_min =  0, arc_sec =  0.00, corresponds to angle hr = 11, min =  0, sec =  0.00

          LMT   year = 2011,   month =  7,   day = 14,   hr = 14,   min =  0,   sec =    0.00001,      over observer longitude

   Output GMT   year = 2011,   month =  7,   day = 14,   hr =  3,   min =  0,   sec =    0.00000,      over  0 deg   longitude
```

Note : The results verified & validated with those reported **(Ref : http://www.navy.gov.au/reserves/e-docs/DATA/NAVYPUBS/NAVYMAN/BRD45(2)/02.pdf).**

Next Section - 1.7 Sidereal Time ST0 and GMST

Sidereal Time : Greenwich universal time at hour 0.0 (ST0) and Greenwich Mean Sidereal Time (GMST) at input Universal Time (UT).

Astronomical observations need Sidereal time (Star time), but Our Clocks are set on Solar time (Sun time).

Sidereal Time keeping system is based on Earth's rotation measured relative to fixed stars. To be specific, ST is hour angle of vernal equinox.

Mean sidereal day is about 23 hours, 56 minutes, 4.0916 seconds (ie, 23.9344699 hours or 0.99726958 mean solar days).

For finding Sidereal Time, there are many analytical equations comprising different constants and reference Julian day.

ST0 is sidereal time of Greenwich at universal time (UT) hour 0.0, on 1st January of each year (e.g. ST0 = 100.807 deg for 2013, Jan.1, hr 0.0).

GMST is Greenwich Mean Sidereal Time defined by Greenwich meridian and vernal equinox.

GMST is hour angle of average position of vernal equinox - neglecting short-term effects of nutation.

Presented below computed, ST0 and GMST of Greenwich at universal time (UT) hour 0.0, on 1st January of years 1900, 1999, 2000, 2013.

ST0 of Greenwich at universal time (UT) hour 0.0, on 1st January of each year 1900, 1999, 2000, 2013 respectively.

1. Find ST0 Sidereal time in deg, of Greenwich Meridian.

   Input UT/GMT year = 1900, (means start of year on January 1, hr 0.0)

   Output ST0 in deg = 100.1838236674, converted into time unit hr = 6, min = 40, sec = 44.11768, at Greenwich Meridian

2. Find ST0 Sidereal time in deg, of Greenwich Meridian.

   Input UT/GMT year = 1999, (means start of year on January 1, hr 0.0)

   Output ST0 in deg = 100.2061912009, converted into time unit hr = 6, min = 40, sec = 49.48589, at Greenwich Meridian

3. Find ST0 Sidereal time in deg, of Greenwich Meridian.

   Input UT/GMT year = 2000, (means start of year on January 1, hr 0.0)

   Output ST0 in deg = 99.9674763217, converted into time unit hr = 6, min = 39, sec = 52.19432, at Greenwich Meridian

4. Find ST0 Sidereal time in deg, of Greenwich Meridian.

   Input UT/GMT year = 2013, (means start of year on January 1, hr 0.0)

   Output ST0 in deg = 100.8067795999, converted into time unit hr = 6, min = 43, sec = 13.62710, at Greenwich Meridian

GMST of Greenwich at universal time (UT) hour 0.0, on 1st January of each year 1900, 1999, 2000, 2013 respectively.

A day change may occur, therefore GMST with date adjusted to calendar YY MM DD and UT hr mm sec is presented.

1. Find GMST Greenwich mean sidereal time in deg, of Greenwich Meridian, at any input Julian day, since Epoch J2000

   Input UT/GMT year = 1900, month = 1, day = 1, hr = 0, min = 0, sec = 0.000, Corresponds to julian_day = 2415020.50000

   Output GMST in deg = 100.1837763190, converted into time unit hr = 6, min = 40, sec = 44.10632, of day = 1, month = 1, year = 1900,

2. Find GMST Greenwich mean sidereal time in deg, of Greenwich Meridian, at any input Julian day, since Epoch J2000

   Input UT/GMT year = 1999, month = 1, day = 1, hr = 0, min = 0, sec = 0.00000, Corresponds to julian_day = 2451179.50000

   Output GMST in deg = 100.2065060288, converted into time unit hr = 6, min = 40, sec = 49.56145, of day = 1, month = 1, year = 1999,

3. Find GMST Greenwich mean sidereal time in deg, of Greenwich Meridian, at any input Julian day, since Epoch J2000

   Input UT/GMT year = 2000, month = 1, day = 1, hr = 0, min = 0, sec = 0.00000, Corresponds to julian_day = 2451544.50000

   Output GMST in deg = 99.9677946232, converted into time unit hr = 6, min = 39, sec = 52.27071, of day = 1, month = 1, year = 2000,

4. Find GMST Greenwich mean sidereal time in deg, of Greenwich Meridian, at any input Julian day, since Epoch J2000

   Input UT/GMT year = 2013, month = 1, day = 1, hr = 0, min = 0, sec = 0.00000, Corresponds to julian_day = 2456293.50000

   Output GMST in deg = 100.8071438223, converted into time unit hr = 6, min = 43, sec = 13.71452, of day = 1, month = 1, year = 2013,

GMST of Greenwich at universal time (UT) at hour 1.0, 6.0, 12.0, 18.0, 23.0 respectively of year 2013.

A day change may occur, therefore GMST with date adjusted to calendar YY MM DD and UT hr mm sec is presented.

5. Find GMST Greenwich mean sidereal time in deg, of Greenwich Meridian, at any input Julian day, since Epoch J2000

   Input UT/GMT year = 2013, month = 1, day = 1, hr = 1, min = 0, sec = 0.00000, Corresponds to julian_day = 2456293.54167

   Output GMST in deg = 115.8482124098, converted into time unit hr = 7, min = 43, sec = 23.57098, of day = 1, month = 1, year = 2013,

6. Find GMST Greenwich mean sidereal time in deg, of Greenwich Meridian, at any input Julian day, since Epoch J2000

   Input UT/GMT year = 2013, month = 1, day = 1, hr = 6, min = 0, sec = 0.00000, Corresponds to julian_day = 2456293.75000

   Output GMST in deg = 191.0535555147, converted into time unit hr = 12, min = 44, sec = 12.85332, of day = 1, month = 1, year = 2013,

7. Find GMST Greenwich mean sidereal time in deg, of Greenwich Meridian, at any input Julian day, since Epoch J2000

   Input UT/GMT year = 2013, month = 1, day = 1, hr = 12, min = 0, sec = 0.00000, Corresponds to julian_day = 2456294.00000

   Output GMST in deg = 281.2999673747, converted into time unit hr = 18, min = 45, sec = 11.99217, of day = 1, month = 1, year = 2013,

8. Find GMST Greenwich mean sidereal time in deg, of Greenwich Meridian, at any input Julian day, since Epoch J2000

   Input UT/GMT year = 2013, month = 1, day = 1, hr = 18, min = 0, sec = 0.00000, Corresponds to julian_day = 2456294.25000

   Output GMST in deg = 11.5463792346, converted into time unit hr = 0, min = 46, sec = 11.13102, of day = 2, month = 1, year = 2013,

9. Find GMST Greenwich mean sidereal time in deg, of Greenwich Meridian, at any input Julian day, since Epoch J2000

   Input UT/GMT year = 2013, month = 1, day = 1, hr = 23, min = 0, sec = 0.00000, Corresponds to julian_day = 2456294.45833

   Output GMST in deg = 86.7517225072, converted into time unit hr = 5, min = 47, sec = 0.41340, of day = 2, month = 1, year = 2013,

10. Find GMST Greenwich mean sidereal time in deg, of Greenwich Meridian, at any input Julian day, since Epoch J2000

   Input UT/GMT year = 2013, month = 1, day = 3, hr = 9, min = 11, sec = 56.61639, Corresponds to julian_day = 2456295.88329

   Output GMST in deg = 241.1421329901, converted into time unit hr = 16, min = 4, sec = 34.11192, of day = 3, month = 1, year = 2013,

Note : The results verified & validated with those reported **(Ref : http://www.csgnetwork.com/siderealjuliantimecalc.html).**

Next Section - 1.8 Sidereal Time GST, GHA and MST

OM-MSS Section - 1.8 ---9

Sidereal Time : Greenwich Sidereal Time (GST), Greenwich Hour Angle (GHA), and Mean Sidereal Time (MST) at input Universal Time (UT).

Greenwich Sidereal Time (GST) is the Local Sidereal Time (LST) over Greenwich Meridian ie 0 deg longitude.

The Local Sidereal Time (LST) over any longitude location = The Greenwich Sidereal Time (GST) + longitude of the location.

The Greenwich Hour Angle (GHA) hour is the angle is between Greenwich Meridian and the Meridian of a celestial body, here it is first point of Aries .

The Mean Sidereal Time (MST) of a locality is defined by its longitude; the MST over 0 deg longitude is often called Greenwich Mean sidereal Time (GMST).

Finding Sidereal Time (ST) over Greenwich Meridian, corresponding to input Local time LMT over Greenwich ie UT/GMT .

Note : Here GHA is GHA(Aries), and MST at 0 deg longitude is GMST; the Greenwich apparent sidereal time GAST = GMST + equation of the equinoxes;

The angles are measured in deg or time, with 24 hr = 360 deg or 1 hr = 15 deg; thus GST(hour) = GHA(deg)/15.

For finding GST and GHA, there are many analytical equations comprising different constants and reference Julian day.

Here used two different equations for GST and GHA; the ref. Julian day for GST is JD1900 and for GHA is JD2000.

Input UT/LMT year = 1986, month = 10, day = 23, hr = 15, min = 0, sec = 0.0000000000, over Greenwich

Output Greenwich sidereal time (GST), Greenwich hour angle (GHA), Mean sidereal time (MST)

1. GST sidereal time in 0 to 360 deg over Greenwich at UT time = 256.7345487561 ie hour = 17, minute = 6, seconds = 56.29170
2. GHA hour angle in 0 to 360 deg over Greenwich at UT time = 256.7435082620 ie deg = 256, arc min = 44, arc sec = 36.62974
3. MST mean sidereal time in deg, over Greenwich at UT time = 256.7348202780 ie hour = 17, minute = 6, seconds = 56.35687

Input UT/LMT year = 2000, month = 1, day = 1, hr = 0, min = 0, sec = 0.0000000000, over Greenwich

Output Greenwich sidereal time (GST), Greenwich hour angle (GHA), Mean sidereal time (MST)

1. GST sidereal time in 0 to 360 deg over Greenwich at UT time = 99.9674763217 ie hour = 6, minute = 39, seconds = 52.19432
2. GHA hour angle in 0 to 360 deg over Greenwich at UT time = 99.9674109260 ie deg = 99, arc min = 58, arc sec = 2.67933
3. MST mean sidereal time in deg, over Greenwich at UT time = 99.9677946919 ie hour = 6, minute = 39, seconds = 52.27073

Input UT/LMT year = 2000, month = 1, day = 1, hr = 12, min = 0, sec = 0.0000000000, over Greenwich

Output Greenwich sidereal time (GST), Greenwich hour angle (GHA), Mean sidereal time (MST)

1. GST sidereal time in 0 to 360 deg over Greenwich at UT time = 280.4603000000 ie hour = 18, minute = 41, seconds = 50.47200

2. GHA hour angle in 0 to 360 deg over Greenwich at UT time = 280.4674269260 ie deg = 280, arc min = 28, arc sec = 2.73693

3. MST mean sidereal time in deg, over Greenwich at UT time = 280.4606183750 ie hour = 18, minute = 41, seconds = 50.54841

Input UT/LMT year = 2013, month = 1, day = 1, hr = 0, min = 0, sec = 0.0000000000, over Greenwich

Output Greenwich sidereal time (GST), Greenwich hour angle (GHA), Mean sidereal time (MST)

1. GST sidereal time in 0 to 360 deg over Greenwich at UT time = 100.8067795999 ie hour = 6, minute = 43, seconds = 13.62710

2. GHA hour angle in 0 to 360 deg over Greenwich at UT time = 100.8066665780 ie deg = 100, arc min = 48, arc sec = 23.99968

3. MST mean sidereal time in deg, over Greenwich at UT time = 100.8071437424 ie hour = 6, minute = 43, seconds = 13.71450

Input UT/LMT year = 2013, month = 1, day = 3, hr = 9, min = 11, sec = 56.6163906455, over Greenwich

Output Greenwich sidereal time (GST), Greenwich hour angle (GHA), Mean sidereal time (MST)

1. GST sidereal time in 0 to 360 deg over Greenwich at UT time = 241.1417688342 ie hour = 16, minute = 4, seconds = 34.02452

2. GHA hour angle in 0 to 360 deg over Greenwich at UT time = 241.1471693383 ie deg = 241, arc min = 8, arc sec = 49.80962

3. MST mean sidereal time in deg, over Greenwich at UT time = 241.1421329996 ie hour = 16, minute = 4, seconds = 34.11192

Note : The results verified & validated with those reported **(Ref : http://www2.arnes.si/~gljsentvid10/longterm.htm).**

Next Section - 1.9 Sidereal Time LMST and GMST

OM-MSS Section - 1.9 --10

Sidereal Time : Local Mean Sidereal Time (LMST) and Greenwich Mean Sidereal Time (GMST) at input Universal Time (UT).

LMST is Local Mean Sidereal time over observer's Longitude and GMST is Greenwich Mean Sidereal Time, while input is UT/GMT time.

Longitude is expressed in 0 to 360 deg only East of Greenwich; not as positive/negative or east/west of Greenwich (0 to 180).

Representing longitude 0 to +360 deg east only from Greenwich, is preferred since satellites go around and angle keep increasing 0 to +360.

example : log 82.5 deg (corresponds 5hr 30min) is 82.5 deg East, and log 285.0 deg (corresponds 19hr 0min) is 75 deg West of Greenwich.

LMST over observer's Log = GMST + Longitude of observer; or simply written as ST over observer's log = GMST + observer's log.

Presented below results of LMST Utilities, for observer Longiudes 0 - 90, 90 - 180, 180 - 270, 270 - 360 deg, East of Greenwich Meridian.

A day change may occur, therefore LMST with date adjusted to calendar YY MM DD and UT hr mm sec is presented.

1. Finding LMST Local Mean Sidereal Time, over observer Longitude (Greenwich Medirian) at time UT/GMT YY MM DD hr min sec

   Input Observer Log arc deg = 0, arc min = 0, arc sec = 0.00, in decimal deg = 0.00000, in time unit hr = 0, min = 0, sec = 0.00

   UT/GMT year = 2000, month = 1, day = 1, hr = 0, min = 0, sec = 0.00000, in julian_day = 2451544.50000 over Greenwich

   Output LMST in deg = 99.9677946232, converted into time unit hr = 6, min = 39, sec = 52.27071, of day = 1, month = 1, year = 2000,

2. Finding LMST Local Mean Sidereal Time, over observer Longitude (0-90 deg East of Greenwich Meridian) at time UT/GMT YY MM DD hr min sec

   Input Observer Log arc deg = 30, arc min = 0, arc sec = 0.00, in decimal deg = 30.00000, in time unit hr = 2, min = 0, sec = 0.00

   UT/GMT year = 2000, month = 1, day = 1, hr = 0, min = 0, sec = 0.00000, in julian_day = 2451544.50000 over Greenwich

   Output LMST in deg = 129.9677946791, converted into time unit hr = 8, min = 39, sec = 52.27072, of day = 1, month = 1, year = 2000,

3. Finding LMST Local Mean Sidereal Time, over observer Longitude (90-180 deg East of Greenwich Meridian) at time UT/GMT YY MM DD hr min sec

   Input Observer Log arc deg = 150, arc min = 0, arc sec = 0.00, in decimal deg = 150.00000, in time unit hr = 10, min = 0, sec = 0.00

   UT/GMT year = 2000, month = 1, day = 1, hr = 0, min = 0, sec = 0.00000, in julian_day = 2451544.50000 over Greenwich

   Output LMST in deg = 249.9677945673, converted into time unit hr = 16, min = 39, sec = 52.27070, of day = 1, month = 1, year = 2000,

4. Finding LMST Local Mean Sidereal Time, over observer Longitude (180-270 deg East of Greenwich Meridian) at time UT/GMT YY MM DD hr min sec

Input Observer Log arc deg = 210, arc min = 0, arc sec = 0.00, in decimal deg = 210.00000, in time unit hr = 14, min = 0, sec = 0.00

UT/GMT year = 2000, month = 1, day = 1, hr = 0, min = 0, sec = 0.00000, in julian_day = 2451544.50000 over Greenwich

Output LMST in deg = 309.9677946791, converted into time unit hr = 20, min = 39, sec = 52.27072, of day = 31, month = 12, year = 1999,

5. Finding LMST Local Mean Sidereal Time, over observer Longitude (270-360 deg East of Greenwich Meridian) at time UT/GMT YY MM DD hr min sec

Input Observer Log arc deg = 330, arc min = 0, arc sec = 0.00, in decimal deg = 330.00000, in time unit hr = 22, min = 0, sec = 0.00

UT/GMT year = 2000, month = 1, day = 1, hr = 0, min = 0, sec = 0.00000, in julian_day = 2451544.50000 over Greenwich

Output LMST in deg = 69.9677945673, converted into time unit hr = 4, min = 39, sec = 52.27070, of day = 1, month = 1, year = 2000,

6. Finding LMST Local Mean Sidereal Time, over observer Longitude (Greenwich Medirian) at time UT/GMT YY MM DD hr min sec

Input Observer Log arc deg = 0, arc min = 0, arc sec = 0.00, in decimal deg = 0.00000, in time unit hr = 0, min = 0, sec = 0.00

UT/GMT year = 2013, month = 1, day = 3, hr = 9, min = 11, sec = 56.61639, in julian_day = 2456295.88329 over Greenwich

Output LMST in deg = 241.1421329901, converted into time unit hr = 16, min = 4, sec = 34.11192, of day = 3, month = 1, year = 2013,

7. Finding LMST Local Mean Sidereal Time, over observer Longitude (Delhi, India) at time UT/GMT YY MM DD hr min sec

Input Observer Log arc deg = 77, arc min = 13, arc sec = 30.11, in decimal deg = 77.22503, in time unit hr = 5, min = 8, sec = 54.01

UT/GMT year = 2013, month = 1, day = 3, hr = 9, min = 11, sec = 56.61639, in julian_day = 2456295.88329 over Greenwich

Output LMST in deg = 318.3671630546, converted into time unit hr = 21, min = 13, sec = 28.11913, of day = 3, month = 1, year = 2013,

Note : The results verified & validated with those reported **(Ref. http://www.csgnetwork.com/siderealjuliantimecalc.html).**

Next Section - 1.10 Time Conversions More on LMT, LST, LMST

Time Conversions : 1. LMT to LST, 2. LST to LMT, 3. LMT to LMST, 4. LMST to LMT

Conversions, from Local Solar time to Local Sidereal time and back from Local Sidereal time to Local Solar time.

Recall that Our Clocks are set on **Solar time (sun time)** but astronomical observations need **Sidereal time (Star time).**

Local Mean solar time (LMT) at zero meridian is Universal time (UT1) also called Greenwich mean time (GMT).

Greenwich Mean Sidereal Time (GMST) is defined by Greenwich meridian and vernal equinox.

Greenwich apparent sidereal time (GAST) is obtained by adding a correction to Greenwich mean sidereal time (GMST);

the correction term is called the 'Equation of the equinoxes' at mean time interval at UT time;

example : YY 2000, MM 1, DD 1 HH 0 , the Equation of the equinoxes in seconds = -0.8758425604

Longitude is expressed in 0 to 360 deg only East of Greenwich; not as positive/negative or east/west of Greenwich (0 to 180).

Representing longitude 0 to +360 deg east only from Greenwich, is preferred since satellites go around and angle keep increasing 0 to +360.

example : log 82.5 deg (corresponds 5hr 30min) is 82.5 deg East, and log 285.0 deg (corresponds 19hr 0min) is 75 deg West of Greenwich.

Presented below Time Conversion Utilities, for observer Longiudes 0 - 90, 90 - 180, 180 - 270, 270 - 360 deg, East of Greenwich Meridian.

A day change may occur, therefore the input/output are with date adjusted to calendar YY MM DD and UT hr mm sec are presented.

Examples 1 to 10, Time Conversions : LMT to LST, LST to LMT, LMT to LMST, LMST to LMT for observer Longiudes mentioned above.

Conversion Forward LMT to LST ie local mean time to local sidereal time; Backward LST to LMT ie local sidereal time to local mean time;

Conversion Forward LMT to LMST ie local mean time to local mean sidereal time; Backward LMST to LMT ie local mean sidereal time to local mean time.

1. Conversion of Local mean time (LMT) to Local sidereal time (LST) , Observer Longiude 0-90 deg East of Greenwich Meridian.

```
   Input  Observer log arc deg =  77, arc min = 13, arc sec =  0.00,  in decimal deg = 77.21667,  corresponds to angle hr =  5, min =  8, sec = 52.00
          LMT   year = 2000,   month =  1,   day =  1,   hr = 15,   min = 54,   sec = 42.00000,   over Observer longitude
   Output GMT   year = 2000,   month =  1,   day =  1,   hr = 10,   min = 45,   sec = 50.00000,   over  Greenwich
          GMST  year = 2000,   month =  1,   day =  1,   hr = 17,   min = 27,   sec = 28.36472,   over  Greenwich
          LST   year = 2000,   month =  1,   day =  1,   hr = 22,   min = 36,   sec = 20.36470,   over  Observer longitude
```

2. Conversion of Local sidereal time (LST) to Local mean time (LMT) , Observer Longiude 0-90 deg East of Greenwich Meridian.

```
   Input  Observer log arc deg =  77, arc min = 13, arc sec =  0.00,  in decimal deg = 77.21667,  corresponds to angle hr =  5, min =  8, sec = 52.00
          LST   year = 2000,   month =  1,   day =  1,   hr = 22,   min = 36,   sec = 20.36470,    over  Observer longitude
   Output GMST  year = 2000,   month =  1,   day =  1,   hr = 17,   min = 27,   sec = 28.36472,    over  Greenwich
          GMT   year = 2000,   month =  1,   day =  1,   hr = 10,   min = 45,   sec = 50.00221,    over  Greenwich
          LMT   year = 2000,   month =  1,   day =  1,   hr = 15,   min = 54,   sec = 42.00219,    over  Observer longitude
```

3. Conversion of Local mean time (LMT) to Local mean sidereal time (LMST) , Observer Longiude 90-180 deg East of Greenwich Meridian.

```
   Note - The procedure is same as  LMT to LST  neglecting the  Equation of Equinoxes
   Input  Observer log arc deg = 150, arc min =  0, arc sec =  0.00,  in decimal deg = 150.00000,  corresponds to angle hr = 10, min =  0, sec =  0.00
          LMT   year = 2013,   month =  1,   day =  1,   hr =  2,   min =  0,   sec =  0.00000,    over  Observer longitude
   Output GMT   year = 2012,   month = 12,   day = 31,   hr = 16,   min =  0,   sec =  0.00003,    over  Greenwich
          GMST  year = 2012,   month = 12,   day = 31,   hr = 22,   min = 41,   sec = 54.86275,    over  Greenwich
          LST   year = 2013,   month =  1,   day =  1,   hr =  8,   min = 41,   sec = 54.86274,    over  Observer longitude
```

4. Conversion of Local mean sidereal time (LMST) to Local mean time (LMT) , Observer Longiude 90-180 deg East of Greenwich Meridian.

```
   Note - The procedure is same as  LST to LMT  neglecting the  Equation of Equinoxes
   Input  Observer log arc deg = 150, arc min =  0, arc sec =  0.00,  in decimal deg = 150.00000,  corresponds to angle hr = 10, min =  0, sec =  0.00
          LMST  year = 2013,   month =  1,   day =  1,   hr =  8,   min = 41,   sec = 54.86274,    over  Observer longitude
   Output GMST  year = 2012,   month = 12,   day = 31,   hr = 22,   min = 41,   sec = 54.86275,    over  Greenwich
          GMT   year = 2012,   month = 12,   day = 31,   hr = 16,   min =  0,   sec =  0.00123,    over  Greenwich
          LMT   year = 2013,   month =  1,   day =  1,   hr =  2,   min =  0,   sec =  0.00122,    over  Observer longitude
```

Continue Section - 1.10

5. Conversion of Local mean time (LMT) to Local sidereal time (LST) , Observer Longiude 180-270 deg East of Greenwich Meridian.

Input Observer log arc deg = 210, arc min = 0, arc sec = 0.00, in decimal deg = 210.00000, corresponds to angle hr = 14, min = 0, sec = 0.00

LMT year = 2013, month = 1, day = 1, hr = 2, min = 0, sec = 0.00000, over Observer longitude

Output GMT year = 2013, month = 1, day = 1, hr = 12, min = 0, sec = 0.00000, over Greenwich

GMST year = 2013, month = 1, day = 1, hr = 18, min = 45, sec = 11.99217, over Greenwich

LST year = 2013, month = 1, day = 1, hr = 8, min = 45, sec = 11.99218, over Observer longitude

6. Conversion of Local sidereal time (LST) to Local mean time (LMT) , Observer Longiude 180-270 deg East of Greenwich Meridian.

Input Observer log arc deg = 210, arc min = 0, arc sec = 0.00, in decimal deg = 210.00000, corresponds to angle hr = 14, min = 0, sec = 0.00

LST year = 2013, month = 1, day = 1, hr = 8, min = 45, sec = 11.99218, over Observer longitude

Output GMST year = 2013, month = 1, day = 1, hr = 18, min = 45, sec = 11.99217, over Greenwich

GMT year = 2013, month = 1, day = 1, hr = 12, min = 0, sec = 0.00052, over Greenwich

LMT year = 2013, month = 1, day = 1, hr = 2, min = 0, sec = 0.00054, over Observer longitude

7. Conversion of Local mean time (LMT) to Local mean sidereal time (LMST) , Observer Longiude 270-360 deg East of Greenwich Meridian.

Note - The procedure is same as LMT to LST neglecting the Equation of Equinoxes

Input Observer log arc deg = 330, arc min = 0, arc sec = 0.00, in decimal deg = 330.00000, corresponds to angle hr = 22, min = 0, sec = 0.00

LMT year = 2013, month = 1, day = 1, hr = 2, min = 0, sec = 0.00000, over Observer longitude

Output GMT year = 2013, month = 1, day = 1, hr = 4, min = 0, sec = 0.00003, over Greenwich

GMST year = 2013, month = 1, day = 1, hr = 10, min = 43, sec = 53.14040, over Greenwich

LST year = 2013, month = 1, day = 1, hr = 8, min = 43, sec = 53.14039, over Observer longitude

Continue Section - 1.10

8. Conversion of Local mean sidereal time (LMST) to Local mean time (LMT) , Observer Longiude 270-360 deg East of Greenwich Meridian.

Note - The procedure is same as LST to LMT neglecting the Equation of Equinoxes

Input Observer log arc deg = 330, arc min = 0, arc sec = 0.00, in decimal deg = 330.00000, corresponds to angle hr = 22, min = 0, sec = 0.00

LMST year = 2013, month = 1, day = 1, hr = 8, min = 43, sec = 53.14039, over Observer longitude

Output GMST year = 2013, month = 1, day = 1, hr = 10, min = 43, sec = 53.14040, over Greenwich

GMT year = 2013, month = 1, day = 1, hr = 4, min = 0, sec = 0.00023, over Greenwich

LMT year = 2013, month = 1, day = 1, hr = 2, min = 0, sec = 0.00021, over Observer longitude

9. Conversion of Local mean time (LMT) to Local mean sidereal time (LMST) , Observer Longiude 270-360 deg East of Greenwich Meridian.

Note - The procedure is same as LMT to LST neglecting the Equation of Equinoxes

Input Observer log arc deg = 0, arc min = 0, arc sec = 0.00, in decimal deg = 0.00000, corresponds to angle hr = 0, min = 0, sec = 0.00

LMT year = 2013, month = 1, day = 3, hr = 9, min = 11, sec = 56.61639, over Observer longitude

Output GMT year = 2013, month = 1, day = 3, hr = 9, min = 11, sec = 56.61639, over Greenwich

GMST year = 2013, month = 1, day = 3, hr = 16, min = 4, sec = 34.11192, over Greenwich

LST year = 2013, month = 1, day = 3, hr = 16, min = 4, sec = 34.11192, over Observer longitude

10. Conversion of Local mean sidereal time (LMST) to Local mean time (LMT) , Observer Longiude 270-360 deg East of Greenwich Meridian.

Note - The procedure is same as LST to LMT neglecting the Equation of Equinoxes

Input Observer log arc deg = 0, arc min = 0, arc sec = 0.00, in decimal deg = 0.00000, corresponds to angle hr = 0, min = 0, sec = 0.00

LMST year = 2013, month = 1, day = 3, hr = 16, min = 4, sec = 34.11192, over Observer longitude

Output GMST year = 2013, month = 1, day = 3, hr = 16, min = 4, sec = 34.11192, over Greenwich

GMT year = 2013, month = 1, day = 3, hr = 9, min = 11, sec = 56.61663, over Greenwich

LMT year = 2013, month = 1, day = 3, hr = 9, min = 11, sec = 56.61663, over Observer longitude

Note : The results verified & validated with those reported. **(Ref. http://koti.mbnet.fi/jukaukor/astronavigation_time.html).**

Next Section - 1.11 Concluding Time Standards and Conversion Utilities

OM-MSS Section - 1.11 ---12

Concluding Time Standards and Time Conversion Utilities presented in Sections (1.0 to 1.10).

The Time Designations, Time Standards and Time Conversion Utilities were illustrated & accomplished.

Our Clocks are set on Solar time (sun time), called local mean time (LMT) at a given location, corrected for its longitude.

Mean solar time (LMT) at zero meridian is Universal time (UT1) also called Greenwich mean time (GMT).

One Sidereal day is One Rotation of Earth on its axis is the time between two successive Meridian pass over a fixed Star.

Longitude is expressed in 0 to 360 deg only East of Greenwich and not as positive/negative or east/west of Greenwich (0 to 180).

Representing longitude 0 to +360 deg east only from Greenwich, is preferred since satellites go around and angle keep increasing 0 to +360.

In Sections (1.1 to 1.10), all that presented were results of following Time Conversions & Computing Utilities :

1. Conversion of Universal Time, Year, Month, Day, Hour decimal to Julian Day, while Year 100 to 3500,
2. Conversion of Julian Day to Universal Time, Year, Month, Day, Hour decimal, while Year 100 to 3500,
3. Conversion of Fundamental Epoch to Julian day and Julian century.
4. Add or Subtract Time in days, hour, minute seconds.
5. Julian days at the Start of Epoch J2000 or any other year.
6. Find Local Mean Solar Time (LMT) over Observer's Longitude, and Greenwich Mean Time (GMT) over Greenwich Meridian, 0 deg),
7. Find Sidereal time STO & GMST of Greenwich Meridian,
8. Find Greenwich Sidereal Time (GST), Greenwich Hour_Angle (GHA), and Mean Sidereal Time (MST) at any input Universal Time (UT) ,
9. Find Local Mean Sidereal Time (LMST) over Observer's Longitude at input UT time over Greenwich Meridian.
10. Conversion of LMT to LST, LST to LMT, LMT to LMST, LMST to LMT.

The Results themselves validate, show accuracy and applicability of the OM-MSS software utilities.

However, readers may compare the results with those reported elsewhere or at respective references mentioned.

End of Time Designations, Time Standards and Time Conversion & Computing Utilities

Next Section - 2 Positional Astronomy and Astronomical Events

REFERENCES : TEXT BOOKS & INTERNET WEB LINKS.

Books

1. Dennis Roddy, 'Satellite Communication', Third Edition, McGraw Hill, chap. 2 - 3, pp 21-86, Jan 2001.
2. Gerard Maral, Michel Bousquet, 'Satellite Communications Systems', Fifth Edition, John Wiley & Sons, chap. 2, pp 19-97, 2002.
3. Hannu Karttunen, Pekka Kroger, et al, 'Fundamental Astronomy', Springer, 5th Edition, pp 1 - 491, 2007.
4. Vladimir A. Chobotov,'Orbital mechanics', American Institute of Aeronautics and Astronautics, pp 1 - 447, 1996.
5. Howard Curtis, 'Orbital Mechanics: For Engineering Students', Aerospace Engineering, Butterworth-Heinemann, , pp 1 - 704, 2004.
6. Howard D. Curtis, 'Orbital Mechanics For Engineering Students, Solutions Manual', Embry-Riddle Aeronautical University, Florida.

Internet Weblinks

Ref. Sec 1 Astronomical Time

1. Ephemeris.com, 'solar system', URL http://www.ephemeris.com/solar-system.html
2. Ephemeris.com, 'Space and Time', URL http://www.ephemeris.com/space-time.html
3. Wikipedia, 'Time standard', URL http://en.wikipedia.org/wiki/Time_standard
4. Digplanet, 'Time standard', URL http://www.digplanet.com/wiki/Time_standard
5. Yost, Daunt, 'Timekeeping', URL http://csep10.phys.utk.edu/astr161/lect/time/timekeeping.html
6. Eric Weisstein's World of Astronomy, 'Time standard',
   URL http://scienceworld.wolfram.com/astronomy/topics/TimeStandards.html
7. J. Richard Fisher, 'Astronomical Times', National Radio Astronomy Observatory,
   URL http://www.cv.nrao.edu/~rfisher/Ephemerides/times.html
8. Kaye and Laby, 'Astronomical and atomic time systems', National Physical Laboratory,
   URL http://www.kayelaby.npl.co.uk/general_physics/2_7/2_7_1.html
9. Kaye and Laby, 'Astronomical units and constants', National Physical Laboratory,
   URL http://www.kayelaby.npl.co.uk/general_physics/2_7/2_7_2.html
10. Kaye and Laby, 'The Solar System', National Physical Laboratory,
    URL http://www.kayelaby.npl.co.uk/general_physics/2_7/2_7_3.html