SATELLITES MOTION AROUND EARTH : ORBITAL & POSITIONAL PARAMETERS AT EPOCH

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

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

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The Satellites Orbit around Earth, Counterclockwise, in the same way as Earth orbits around Sun.

In the previous section, the Preliminaries about 'Satellite Orbit' followed by NASA/NORAD 'Two-Line Elements'(TLE) were presented.

Here Presented Satellites Motion around Earth : Computing Orbital & Positional parameters, the OM-MSS Software Utility.

This utility is applied one-by-one to six Satellites, LANDSAT 8, SPOT 6, CARTOSAT-2B, ISS (ZARYA), GSAT-14, and Moon .

The Input is NASA/NORAD 'Two-Line Elements'(TLE) Bulletin of the respective Satellite.

The Output is the corresponding Satellite's Motion around Earth the Orbital & Positional parameters.

Satellite Motion around Earth is represented by computing around 120 orbital parameters, put into 28 groups.

The number is large, because some parameters are computed using more than one model equation, that require different inputs.

This confirms accuracy & validation of results and understanding the different input considerations.

Satellite Orbital & Positional parameters for computation purpose are put into following groups :

01. UT Year and Days decimal of year : Convert into UT YY MM DD hh min sec & Julian day.

02. Satellite orbit Semi major axis in km, Ignoring and also Considering earth oblatenes.

03. Satellite Mean motion in rev per day, Ignoring and also Considering earth oblatenes.

04. Satellite Orbit Time Period in minute at time_t Considering earth oblatenes.

05. Satellite Rate of change of Right Ascension and Argument of Perigee in deg per_day at time_t.

06. Satellite Mean anomaly, Eccentric anomaly, True anomaly in deg at time_t considering earth oblateness.

07. Satellite position vector[rp, rq] from Earth center(EC) to Sat in PQW frame, perifocal coordinate system.

08. Satellite Position Range Vector from Earth Ceter(EC) to Satellite(SAT) - finding Range Vector[rI rJ rK r] Components in km in frame IJK

09. GST Greenwich sidereal time and GHA Greenwich hour angle in 0 to 360 deg, at input at time_t.

10. Satellite(SAT) Orbit point direction : Finding Right Ascension(Alpha) deg and Declination(Delta) deg using angles

11. Satellite Longitude & Latitude in deg at time_t; (ie Sub-Sat point log & lat on earth surface).

12. Satellite height in km from EC to Sat and from Earth surface to Sat at time_t.

13. Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface at time_t.
14. Local sidereal time(LST) and Local mean time(LMT) over Sub-Sat point Longitude on earth.
15. Local sidereal time(LST) and Local mean time(LMT) Over Earth stn (ES) or Earth point(EP) Longitude.
16. Earth Stn Position Vector from Earth Center(EC) to Earth Stn(ES) : Finding Range Vector[RI, RJ, RK, R] Components in IJK frame.
17. Satellite Position Range Vector from Earth Stn(ES) to SAT : finding Range Vector[rvI, rvJ, rvK, rv] Components in km in IJK frame
18. Satellite Position Range Vector from Earth Stn(ES) to SAT : finding Range Vector[rvS, rvE, rvZ, rv] Components in km in SEZ frame
19. Elevation(EL) and Azimuth(AZ) angle of Satellite at Earth Observation point ES or EP.
20. Satellite Velocity meter per sec in orbit.
21. Satellite Velocity Vector [vX, vY, vZ] in meter per sec in orbit in frame XYZ.
22. Satellite Pitch and Roll angles.
23. Satellite State Vectors - Position [X, Y, Z] in km and velocity [Vx, Vy, Vz] in meter per sec at time_t.
24. Satellite Direction ie right ascension alpha deg and declination delta deg from sat position vector.
25. Satellite Angular momentum km sqr per sec : finding Hx Hy Hz H from state vector pos and vel.
26. Satellite Orbit normal Vector : finding Wx Wy Wz W Delta Alpha from r_sat_pos frame IJK, i, RA.
27. Satellite Position Keplerian elements computed using State Vector, at time input UT.
28. Satellite position State Vectors, computed using Keplerian elements at time input UT

Computing Orbital & Positional parameters, for following Satellites respectively :

(a) LANDSAT 8 : American satellite launched on February 11, 2013, the NASA/NORAD TLE down load on May 28, 2014, 18:13 hrs IST

(a) SPOT 6 : French satellite launched on September 9, 2012, the NASA/NORAD TLE down load on May 28, 2014, 18:13 hrs IST

(a) CARTOSAT 2B : Indian satellite launched on July 12, 2010, the NASA/NORAD TLE down load on May 28, 2014, 18:13 hrs IST

(a) ISS (ZARYA) : International Space Stn launched on Nov. 20, 1998, the NASA/NORAD TLE down load on May 28, 2014, 18:13 hrs IST

(a) GSAT-14 : Indian Geo Comm. Sat launched on Jan. 05, 2014, the NASA/NORAD TLE down load on May 28, 2014, 18:13 hrs IST

(a) Moon : Natural satellite, moves around Earth , the Keplerian elements set down load on Jun 14, 2014, 16:14 hrs IST

Input NASA/NORAD 'TWO-LINE ELEMENTS' of respective Satellite, and Earth stn Latitude & Longitude in deg and Height in meter.

Move on to all six respective Satellites, one-by-one for computing Orbital & Positional parameters in Section (6.1 to 6.7).

Next Section - 6.1 Computing Orbital & Positional parameters for Satellite LANDSAT 8 .

Satellite LANDSAT 8 : Computing Orbital & Positional parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins.

(a) LANDSAT 8 'Two-Line Elements'(TLE) downloaded on May 28, 2014, 18:13 hrs IST, Satellite launched on February 11, 2013

1 39084U 13008A 14148.14086282 .00000288 00000-0 73976-4 0 4961

2 39084 98.2215 218.5692 0001087 96.5686 263.5699 14.57098925 68534

From this TLE, the data relevant for the purpose are manually interpreted & extracted :

Satellite number 39084, LANDSAT 8 ,

EPOCH_year = 2014 EPOCH_days_decimal_of_year = 147.1408628200

EPOCH_inclination_deg = 98.2215000000 EPOCH_right_asc_acnd_node_deg = 218.5692000000

EPOCH_eccentricity = 0.0001087000 EPOCH_argument_of_perigee_deg = 96.5686000000

EPOCH_mean_anomaly_deg = 263.5699000000 EPOCH_mean_motion_rev_per_day = 14.5709892500

EPOCH_revolution = 6853 EPOCH_node_condition = 1

Earth_stn_latitude_deg = 23.25993 Earth stn longitude_deg = 77.41261 Earth surface height_meter = 494.70000

Earth stn tower_height_meter = 15.00000 Earth stn_height_meter = 509.70000 Earth stn min EL look_angle_deg = -5.00000

Note : EPOCH Corresponds to UT year = 2014, month = 5, day = 28, hr = 3, min = 22, sec = 50.54765 which is Greenwich meam time ie GMT

Converted to Local Meam Time at Earth Stn Longitude, as regular Calender date : year = 2014, month = 5, day = 28, hr = 8, min = 32, sec = 29.58

At this instant Sun Position as seen from Earth Stn Longitude : Sun angles EL deg = 42.87, AZ deg = 81.74,

Sun Surface distance km = 5246.15, Radial km = 151596372.18, Sun Rise D:28, H:05, M:17, S:03 Sun Set D:28, H:18, M:40, S:20

Move to Compute Satellie Orbital parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins, and Earth Stn location.

01. Input EPOCH_year and EPOCH_days_decimal_of_year, Converted into UT YY MM DD hh min sec & Julian day.

S01 011. Input UT year = 2014, month = 5, day = 28, hr = 3, min = 22, sec = 50.54765, and julian_day = 2456805.6408628202

02. Finding Satellite orbit Semi major axis in km, Ignoring and also Considering earth oblatenes .

(a) Semi major axis (SMA) km at time t Ignoring earth oblatenes .

Inputs : SAT mean_motion rev per day at time t, GM_EARTH .

Outputs : SAT Orbit semi major axis km in km and constant_A, constant_k1 .

S02A 011. Satellite orbit Semi major axis in km at time t, Ignoring earth oblatenes = 7080.69383,

(b) Semi major axis (SMA) in km at time_t Considering earth oblatenes

Inputs : SAT mean_motion rev per day at time_t, GM_EARTH , inclination deg at time_t, eccentricity at time_t, constant_k2

Outputs : SAT Orbit semi major axis km in km at time_t and constant_A, constant_k1, constant_k3 .

S02B 011. Satellite orbit Semi major axis km at time t, Considering earth oblatenes = 7077.77844,

03. Finding Satellite Mean motion in rev per day, Ignoring and also Considering earth oblatenes .

(a) Nominal mean motion rev per day at time_t Ignoring earth oblateness .

Inputs : SAT Orbit semi major axis in km ignoring oblateness at time_t, constant_k1 .

Outputs : SAT nominal mean motion in rev_per_day at time_t, ignoring earth oblateness

S03A 011. Satellite Nominal Mean motion in rev_per_day at time_t using SMA Ignoring earth oblateness = 14.57099,

(b) Mean motion rev per day at time_t Considering earth oblatenes

Inputs : SAT nominal mean motion rad per day at time_t Ignoring_oblateness, constant_k2, constant_k3,

SAT orbit semi major axis in km considering oblateness at time_t.

Outputs : SAT mean motion rev per day at time_t, considering earth oblatenes .

S03B 011. Satellite Mean motion in rev_per_day at time t using SMA Considering earth oblatenes = 14.56199,

Note - This calculted value is slightly less than the mean motion rev_per_day as EPH input from NORAD TLE

04. Finding Satellite Orbit Time Period in minute at time_t Considering earth oblatenes .

Inputs : SAT orbit semi major axis in km considering oblateness at time_t, GM_EARTH .

Outputs : SAT orbit time period in minute at time_t considering earth oblatenes .

S04 011. Satellite orbit Time Period in minute at time_t using SMA Considering earth oblatenes = 98.76548,

05. Finding Satellite Rate of change of Right Ascension and Argument of Perigee in deg per_day at time_t.

(a) Rate of change of Right Ascension in deg per day at time_t .

Inputs : SAT mean motion rev per day at time_t considering earth oblatenes, constant_k2, SAT orbit eccentricity at time_t,

SAT semi major axis km considering oblateness at time_t, SAT orbit inclination deg at time_t .

Outputs : SAT rate of change of right ascension in deg per day at time_t and constant_k_deg_per_day

S05A 011. Satellite Rate of change of Right Ascension in deg per day at time_t = 0.98640,

(b) Rate of change of Argument of Perigee in deg per_day at time_t .

Inputs : SAT orbit constant_k_deg_per_day, SAT orbit inclination deg at time_t

SAT orbit semi major axis km considering oblateness at time_t

Outputs : SAT rate of change of argument of perigee in deg per day at time_t

S05B 011. Satellite Rate of change of Argument of Perigee in deg per day at time_t = -3.09630,

06. Finding Satellite Mean anomaly, Eccentric anomaly, True anomaly in deg at time_t considering earth oblateness.

Inputs : SAT mean anomaly rad at time_t, mean_motion_rad_per_day_at_time_t considering_oblateness, SAT orbit eccentricity_at_time_t

Outputs : SAT mean anomaly, eccentric anomaly, and true anomaly in deg at time_t onsidering earth oblateness.

S06A 011. Satellite Mean anomaly in deg at time_t = 263.56990, same as EPH mean anomaly

S06A 011. Satellite Eccentric anomaly in deg at time_t = 263.56371,

S06A 011. Satellite True anomaly in deg at time_t = 263.55752,

Note - 1. Here after, the Earth Oblateness is always considered for the computation of satellite orbit parameters, and not repeatedly mentioned.

Satellite to Earth, the Position Vectors coordinate and the Vector Coordinate Transforms are in PQW, IJK, SEZ frames .

- Perifocal Coordinate System (PQW) is Earth Centered Inertial coordinate frame defined in terms of Kepler Orbital Elements.
- Geocentric Coordinate System(IJK) is Earth Centered Inertial (ECI) frame, a Conventional Inertial System (CIS).
- Topocentric Horizon Coordinate System(SEZ), is Non-Inertial coordinate frame, known as Earth-Centered Earth-Fixed Coordinates (ECEF).

Each of these coordinate system were explained in detail before and therefore not repeated any more.

07. Finding Satellite position vector[rp, rq] from Earth center(EC) to Sat in PQW frame, perifocal coordinate system.

Inputs : SAT orbit semi-major axis (SMA), SAT orbit eccentricity, SAT eccentric anomaly, SATtrue anomaly at time_t

Outputs : Vector(r, rp rq) in PQW frame

S07A 011. r Satellite pos vector magnitude EC to Sat km in PQW frame perifocal cord at time_t = 7077.86469

S07B 011. rp Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = -794.1764390079

S07C 011. rq Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = -7033.1680137615

08. Satellite Position Vector Earth Ceter(EC) to Satellite(SAT) - finding Range Vector(rI rJ rK r) Components in km in frame IJK

Note - Transform_1 : EC to SAT Vector(rp, rq) in frame PQW To EC to SAT Vector(rI rJ rK r) in frame IJK.

Inputs : Vector(rp, rq) EC to Sat in km in frame PQW, SAT right ascension of ascending node at time_t,

SAT argument of perigee rad at time_t, SAT orbit inclination rad at time_t .

Outputs : Vector(rI, rJ, rK, r) EC to SAT in km in frame IJK

S08A 011. rI Satellite pos vector component EC to Sat km frame IJK at at time_t = -5535.2447229896

S08B 011. rJ Satellite pos vector component EC to Sat km frame IJK at at time_t = -4411.0085700927

S08C 011. rK Satellite pos vector component EC to Sat km frame IJK at at time_t = 15.4200278230

S08D 011. r Satellite pos vector magnitude EC to Sat km frame IJK at at time_t = 7077.8646869006

Note - r Satellite pos vector magnitude EC to Sat km in PQW frame is same as that computed above in PQW frame.

09. Finding GST Greenwich sidereal time and GHA Greenwich hour angle in 0 to 360 deg, at input at time_t .

Note - for GST, the year 1900 JAN day_1 hr 1200 is ref for time difference in terms of julian_century,

for GHA, the year 2000_JAN_day_1 hr_1200 is ref for time difference in terms of julian days.

Inputs : Time t UT year = 2014, month = 5, day = 28, hour = 3, minute = 22, seconds = 50.54765

Outputs : GST & GHA in 0-360 deg over Greenwich.

S09A 011. GST Greenwich sidereal time in 0-360 deg, over Greenwich = 296.30768, hr = 19, min = 45, sec = 13.84416

S09B 011. GHA Greenwich hour angle in 0 to 360 deg, over Greenwich = 296.30959, deg = 296, min = 18, sec = 34.52861

10. Satellite(SAT) Orbit point direction : Finding Right Ascension(Alpha) deg and Declination(Delta) deg using angles

Inputs : SAT orbit inclination deg at_time_t, EPH right ascension ascending node deg,

SAT argument of perigee deg at time_t, SAT true anomaly deg calculated at time_t

Outputs : SAT Right Ascension(Alpha) and Declination(Delta) in deg at time_t

S10A 011. SAT Right Ascension(Alpha) in deg = 218.5872355801

S10B 011. SAT Declination(Delta) in deg = 0.1248262368

11. Finding Satellite Longitude & Latitude in deg at time_t; (ie Sub-Sat point log & lat on earth surface).

Inputs : SAT right ascension ascending node deg at time_t, GST in 0-360 deg over Greenwich at time_t

Outputs : Satellite (Sub-Sat point) longitude 0 to 360 deg at time_t.

S11A 011. Satellite longitude 0 to 360 deg at time_t = 218.59 ie deg = 218, min = 35, sec = 14.05

Inputs : argument of_perigee rad at_time_t, inclination rad at time_t, true anomaly rad calculated at time_t.

Outputs : Satellite (Sub-Sat point) latitude +ve or -ve in 0 to 90 deg at time_t.

S11B 011. Satellite latitude +ve or -ve in 0 to 90 deg at time_t = 0.12 ie deg = 0, min = 7, sec = 29.37

12. Finding Satellite height in km from EC to Sat and from Earth surface to Sat at time_t.

(a) Satellite height in km from EC to Sat; (ie Sat orbit radius EC to Sat in km at time_t).

Note - This is SAME as r sat pos vector magnitude EC to Sat in frame IJK calculated above in TRANSFORN_1 .

Inputs : SAT true anomaly at time_t, semi_major_axis_km, inclination at time_t .

Outputs : Sub-Sat point longitude 0 to 360 deg at time_t.

S12A 011. Satellite orbital radious EC to SAT in km using SAT true anomaly at time_t = 7077.86

(b) Satellite height in km from earth surface.

Inputs : Sub-Sat point latitude +ve or -ve in 0 to 90 deg at time_t, earth_equator_radious_km .

Outputs : Sat height in km from earth surface.

S12B 011. Satellite height in km from earth surface at time_t = 699.72

13. Finding Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface at time_t .

Inputs : Sub-Sat point lat & log, ES lat & log .

Outputs : Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface

S13 011. Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface = 15098.60365

14. Finding Local sidereal time(LST) and Local mean time(LMT) over Sub-Sat point Longitude on earth .

(a) Local sidereal time(LST) in 0 to 360 deg over Sub-Sat point Longitude on earth .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, satellite log in 0 to 360 deg at time_t .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14A 011. Local sidereal time(LST) over Sub-Sat point Longitude at time_t = 154.89

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Sub-Sat point Longitude on earth .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Sat longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14B 011. Local sidereal time(LST) in 0 to 360_deg over Sub-Sat point Longitude at time_t = 154.90

S14C 011. LST over Sub-Sat Log, with date adj to CD expressed in JD = 2456805.93, ie YY = 2014, MM = 5, DD = 28, hr = 10, min = 19, sec = 34.87

S14D 011. LMT over Sub-Sat Log, with date adj to CD expressed in JD = 2456805.25, ie YY = 2014, MM = 5, DD = 27, hr = 17, min = 57, sec = 11.48

15. Finding Local sidereal time(LST) and Local mean time(LMT) Over Earth stn (ES) or Earth point(EP) Longitude .

(a) Local sidereal time(LST) in 0 to 360 deg over Earth stn(ES) Longitude .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn(ES) longitude at time_t.

S15A 011. Local sidereal time(LST) over Earth stn(ES) Longitude at time_t = 13.72

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Earth stn(ES) Longitude .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn (ES) longitude at time_t.

S15B 011. Local sidereal time(LST) in 0 to 360_deg over Earth stn (ES) Longitude at time_t = 13.72

S14C 011. LST over ES Log, with date adj to CD expressed in JD = 2456806.54, ie YY = 2014, MM = 5, DD = 29, hr = 0, min = 54, sec = 52.96

S15D 011. LMT over ES Log, with date adj to CD expressed in JD = 2456805.86, ie YY = 2014, MM = 5, DD = 28, hr = 8, min = 32, sec = 29.58

16. Earth Stn (ES) Position Vector from Earth Center(EC) to Earth Stn(ES) : Finding Range Vector(RI, RJ, RK, R) Components in IJK frame

Note - Transform_2 : ES position cord(lat, log, hgt) To EC to ES position Vector(RI, RJ, RK, R) in frame IJK .

Inputs : ES latitude positive_negative 0 to 90 deg, ES longitude in 0 to 360_deg,

ES height in meter (is earth surface + tower hgt), LST in 0 to 360 deg at ES log at time_t .

Outputs : ES Position Vector(RI, RJ, RK, R) Components EC to ES in km in IJK frame .

S16A 011. RI_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 5690.0261762829

S16B 011. RJ_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 1389.2147306682

S16C 011. RK_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 2517.6372173288

S16D 011. R_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 6375.3284317570

17. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvI, rvJ, rvK, rv) Components in km in IJK frame

Note - Transform_3 SAT Pos Vct(rI rJ rK) and ES Pos Vct(RI RJ RK) To SAT Pos Vct(rvI, rvJ, rvK, rv)

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK ,

ES Position Vector(RI RJ RK) EC to ES in km in IJK frame.

Outputs : SAT Position Range Vector(rvI, rvJ, rvK, rv) Components ES to Sat in km in IJK frame

S17A 011. rv_I range vector component ES to SAT km frame IJK = -11225.2708992725

S17B 011. rv_J range vector component ES to SAT km frame IJK = -5800.2233007609

S17C 011. rv_K range vector component ES to SAT km frame IJK = -2502.2171895058

S17D 011. rv range vector component ES to SAT km frame IJK = 12880.6206358313

18. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvS, rvE, rvZ, rv) Components in km in SEZ frame

Note - Transform_4 SAT Pos Vct(rvI, rvJ, rvK, rv) in IJK frame To SAT Pos Vct(rvS, rvE, rvZ, rv) in SEZ frame

Inputs : ES latitude positive_negative 0 to 90_deg, LST in 0 to 360 deg at ES longitude at time_t

SAT PositionRange Vector(rvI, rvJ, rvK, rv) ES to Sat in km in IJK frame

Outputs : SAT Position Range(rvS, rvE, rvZ, rv) Components ES to Sat in km in SEZ frame

S18A 011. rvS range_vector component ES to SAT km_frame SEZ = -2550.8312634026

S18B 011. rvE range_vector component ES to SAT km_frame SEZ = -2972.2788352154

S18C 011. rvZ range_vector component ES to SAT km_frame SEZ = -12270.6644626761

S18D 011. rv range_vector component ES to SAT km_frame SEZ = 12880.6206358313

19. Finding Elevation(EL) and Azimuth(AZ) angles of Satellite and Sun : Steps 1, 2, 3 AT UT TIME t

Rem: Sub-SAT point lat deg = 0.12, log deg = 218.59 YY = 2014, MM = 5, DD = 27, hr = 17, min = 57, sec = 11.48

ES or EP point lat deg = 23.26, log deg = 77.41 YY = 2014, MM = 5, DD = 28, hr = 8, min = 32, sec = 29.58

Note : Step 1 is for Satellite EL & AZ angles. Steps 2 & 3 are for Sun EL & AZ angles

Results verified from other sources; Ref URLs

Geoscience Australia **http://www.ga.gov.au/geodesy/astro/smpos.jsp#intzone** , NOAA Research **http://www.esrl.noaa.gov/gmd/grad/solcalc/** ,

Xavier Jubier, Member IAU **http://xjubier.free.fr/en/site_pages/astronomy/ephemerides.html**

Elevation(EL) & Azimuth(AZ) angle of SAT at Earth Observation point EP : Step 1.

Inputs : Range vector component ES to SAT rv_S, rv_E, rv_Z, in frame_SEZ,

EP and Sub_sat point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SAT at EP

S19A 011. Elevation angle deg of Satellte at Earth point EP at time_t = -72.29698 ie deg = -72, min = -17, sec = -49.12

S19B 011. Azimuth angle deg of Satellte at Earth point EP at time_t = 310.63643 ie deg = 310, min = 38, sec = 11.16

Elevation(EL) & Azimuth(AZ) angle of SUN at Sub_Satellite point on earth surface : Step 2.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of Sun at Sub_Sat

S19C 011. Elevation angle deg of SUN at Sub_Sat point at time_t = 0.0508847018

S19D 011. Azimuth angle deg of SUN at Sub_Sat point at time_t = 291.4359560384

Elevation(EL) & Azimuth(AZ) angle of SUN at Satellite height : Step 3.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SUN at SAT

S19E 011. Elevation angle deg of Sun at Satellite height at time_t = 0.05062

S19F 011. Azimuth angle deg of Sun at Satellite height at time_t = 291.43596

20. Finding Satellite Velocity meter per sec in orbit .

Note : Results computed using 2 different formulations, each require different inputs.

(a) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK.

Outputs : SAT Velocity magnitude and component Xw Yw in frame PQW in meter per sec

S20A 011. Satellite Velocity magnitude meter per sec at UT time = 7504.3851274216

(b) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, SAT orbit eccentricity_at_time_t,

SAT eccentric anomaly deg calculated at time_t.

Outputs : Satellite Velocity components Xw Yw in frame PQW in meter per sec

S20B 011. Satellite Velocity components Xw in frame PQW in meter per sec = 7457.0858889990

S20C 011. Satellite Velocity components Yw in frame PQW in meter per sec = -841.2289728478

21. Finding Satellite(SAT) Velocity Vector (vX, vY, vZ) in meter per sec in orbit in frame XYZ.

Note - Transform_5 SAT Vel Vct(Xw, Yw) in frame PQW To SAT Vel Vct(vX, vY, vZ) in frame XYZ

Inputs : SAT velocity vectors(Xw, Yw), SAT Right Ascension Alpha, SAT Argument of perigee,

SAT orbit inclination at_time_t, SAT eccentric_anomaly_deg_calculated_at_time_t.

Outputs : earth velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ

S21A 011. vX Sat Velocity vector component in meter per sec = -655.5016695670

S21B 011. vY Sat Velocity vector component in meter per sec = 849.8345806371

S21C 011. vZ Sat Velocity vector component in meter per sec = 7427.2400585557

S21D 011. vR Sat Velocity magnitude meter in meter per sec = 7504.3851274216

22. Finding Satellite(SAT) Pitch and Roll angles

Inputs : Earth equator radious km, ES lat, ES log, Sub_Sat point lat, Sub_Sat point log,

Sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK,

Outputs : SAT Pitch and Roll angles

S22A 011. pitch_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = 18.0730937568

S22B 011. roll_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = 11.5734570323

23. Finding Satellite State Vectors - Position [X, Y, Z] in km and velocity [Vx, Vy, Vz] in meter per sec at time_t .

Note - same as values of rI rJ rK r for pos and vX vY vZ vR for vel

(a) Satellite State Position Vector [X, Y, Z] in km at time_t

Inputs : position vector(rI, rJ, rK, r) in frame IJK values assiged to state position vector

Outputs : State Position Vector(X, Y, Z, R) in km, frame XYZ

S23A 011. State vector position X km at time_t = -5535.2447229896

S23B 011. State vector position Y km at time_t = -4411.0085700927

S23C 011. State vector position Z km at time_t = 15.4200278230

S23D 011. State vector position R km at time_t = 7077.8646869006

(b) Satellite State Velocity Vector [Vx, Vy, Vz] in meter per sec at time input UT.

Inputs : velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ values assiged to state velocity vector

Outputs : state velocity vector(Vx, Vy, Vz, V) meter per sec, frame XYZ

S23E 011. State vector velocity Vx meter per sec at time_t = -655.5016695670

S23F 011. State vector velocity Vy meter per sec at time_t = 849.8345806371

S23G 011. State vector velocity Vz meter per sec at time_t = 7427.2400585557

S23H 011. State vector velocity V meter per sec at time_t = 7504.3851274216

24. Satellite Direction ie right ascension alpha deg and declination delta deg using sat position vector .

Note - results same as that using angles incl, RA, Aug of peri, true anomaly

Inputs : SAT State Vectors Position(X, Y, Z, R) in km , in frame XYZ

Outputs : SAT right ascension alpha deg and declination delta deg

S24A 011. Satellite direction right_asc alpha deg at time_t = 218.5511644199

S24B 011. Satellite direction_declination_delta_deg_at_time_t = 0.1248262368

25. Satellite Angular momentum km sqr per sec : finding Hx Hy Hz H from state vector pos and vel .

Inputs : SAT State Vectors Position(X, Y, Z, R) in km and Velocity (vX, vY, vZ, vR) meter per sec, in frame XYZ

Outputs : SAT angular momentum (Hx Hy Hz H) componts in km sqr per sec

S25A 011. Satellite angular momentum Hx in km sqr per sec at time_t = -32774.7240233036

S25B 011. Satellite angular momentum Hy in km sqr per sec at time_t = 41101.4834865149

S25C 011. Satellite angular momentum Hz in km sqr per sec at time_t = -7595.4658600556

S25D 011. Satellite angular momentum H in km sqr per sec at time_t = 53115.0221804269

26. Satellite Orbit normal Vector : finding Wx Wy Wz W Delta Alpha from r_sat_pos frame IJK, i, RA

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK , inclination_deg_at_time_t, right_ascension_ascending_node_deg_at_time_t

Outputs : SAT orbit normal vector (Wx, Wy, Wz, W) in km , RA , i

S26A 011. Satellite Orbit normal_W in km = 7077.8646869006

S26B 011. Satellite Orbit normal_Wx in km = -4367.4096755425

S26C 011. Satellite Orbit normal_Wy in km = 5476.9955204054

S26D 011. Satellite Orbit normal_Wz in km = -1012.1370072826

S26E 011. Satellite Orbit normal_Delta_W in deg = -8.2215000000

S26F 011. Satellite Orbit interpreted inclination i = 98.2215000000

S26G 011. Satellite Orbit normal_Alpha_W in deg = -51.4308000000

S26H 011. Satellite Orbit interpreted RA of asc node = 218.5692000000

Transform Satellite State Vectors to Keplerian elements.

27. Finding Satellite position Keplerian elements computed using State Vector, at time input UT.

Inputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

Outputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee, mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

S27A 011. Keplerian elements year = 2014, days_decimal_of_year = 147.14086, revolution no = 6853, node = 1 ie ascending

S27B 011. inclination_deg = 98.2215000000

S27C 011. right ascension ascending node deg = 218.5692000000

S27D 011. eccentricity = 0.0001087000

S27E 011. argument of perigee_deg = 96.5686000000

S27F 011. mean anomaly deg = 263.5699000001

S27G 011. mean_motion rev per day = 14.5709892500

S27H 011. mean angular velocity rev_per_day = 14.5799930299

S27I 011. mean motion rev per day using SMA considering oblateness = 14.5619910304

Transform Satellite Keplerian elements to State Vectors .

28. Finding Satellite position State Vectors, computed using Keplerian elements at time input UT

(computed again to validate model equations, Keplerian elements to State Vectors & back)

Inputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee,

mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

Outputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

S28A 011. State vectors year = 2014, days_decimal_of_year = 147.14086, revolution no = 6853, node = 1 ie decending

S28B 011. state vector position X km = -5535.2447229901, state vector velocity Vx meter per sec = -655.5016695622

S28C 011. state vector position Y km = -4411.0085700921, state vector velocity Vy meter per sec = 849.8345806409

S28D 011. state vector position Z km = 15.4200278287, state vector velocity Vz meter per sec = 7427.2400585557

S28E 011. state vector position R km = 7077.8646869005, state vector velocity V meter per sec = 7504.3851274216

Move on to next Satellite.

Next Section - 6.2 Computing Orbital & Positional parameters for Satellite SPOT 6

Satellite SPOT 6 : Computing Orbital & Positional parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins.

(b) SPOT 6 'Two-Line Elements'(TLE) downloaded on May 28, 2014, 18:13 hrs IST, Satellite launched on September 9, 2012

```
1 38755U 12047A   14148.14295346  .00000295  00000-0  73402-4 0  9574
2 38755  98.1987 215.8134 0001368  80.3963 279.7434 14.58528066 91251
```

From this TLE, the data relevant for the purpose are manually interpreted & extracted :

Satellite number 38755, SPOT 6 ,

```
EPOCH_year  =  2014             EPOCH_days_decimal_of_year   =  147.1429534600
EPOCH_inclination_deg          =   98.1987000000              EPOCH_right_asc_acnd_node_deg   =  215.8134000000
EPOCH_eccentricity             =    0.0001368000              EPOCH_argument_of_perigee_deg   =   80.3963000000
EPOCH_mean_anomaly_deg         =  279.7434000000              EPOCH_mean_motion_rev_per_day   =   14.5852806600
EPOCH_revolution               =    9125                      EPOCH_node_condition            =  1

Earth_stn_latitude_deg         =   23.25993     Earth stn longitude_deg        =   77.41261     Earth surface height_meter      =  494.70000
Earth stn tower_height_meter   =   15.00000     Earth stn_height_meter         =  509.70000     Earth stn min EL look_angle_deg =   -5.00000
```

Note : EPOCH Corresponds to UT year = 2014, month = 5, day = 28, hr = 3, min = 25, sec = 51.17894 which is Greenwich meam time ie GMT

Converted to Local Meam Time at Earth Stn Longitude, as regular Calender date : year = 2014, month = 5, day = 28, hr = 8, min = 35, sec = 30.21

At this instant Sun Position as seen from Earth Stn Longitude : Sun angles EL deg = 43.56, AZ deg = 81.94,

Sun Surface distance km = 5169.96, Radial km = 151596361.23, Sun Rise D:28, H:05, M:17, S:03 Sun Set D:28, H:18, M:40, S:20

Move to Compute Satellie Orbital parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins, and Earth Stn location.

01. Input EPOCH_year and EPOCH_days_decimal_of_year, Converted into UT YY MM DD hh min sec & Julian day.

    S01 011. Input UT year = 2014, month = 5, day = 28, hr = 3, min = 25, sec = 51.17894, and julian_day = 2456805.6429534601

02. Finding Satellite orbit Semi major axis in km, Ignoring and also Considering earth oblatenes .

    (a) Semi major axis (SMA) km at time t Ignoring earth oblatenes .

    Inputs : SAT mean_motion rev per day at time t, GM_EARTH .

    Outputs : SAT Orbit semi major axis km in km and constant_A, constant_k1 .

S02A 011. Satellite orbit Semi major axis in km at time t, Ignoring earth oblatenes = 7076.06773,

(b) Semi major axis (SMA) in km at time_t Considering earth oblatenes

Inputs : SAT mean_motion rev per day at time_t, GM_EARTH , inclination deg at time_t, eccentricity at time_t, constant_k2

Outputs : SAT Orbit semi major axis km in km at time_t and constant_A, constant_k1, constant_k3 .

S02B 011. Satellite orbit Semi major axis km at time t, Considering earth oblatenes = 7073.14938,

03. Finding Satellite Mean motion in rev per day, Ignoring and also Considering earth oblatenes .

(a) Nominal mean motion rev per day at time_t Ignoring earth oblateness .

Inputs : SAT Orbit semi major axis in km ignoring oblateness at time_t, constant_k1 .

Outputs : SAT nominal mean motion in rev_per_day at time_t, ignoring earth oblateness

S03A 011. Satellite Nominal Mean motion in rev_per_day at time_t using SMA Ignoring earth oblateness = 14.58528,

(b) Mean motion rev per day at time_t Considering earth oblatenes

Inputs : SAT nominal mean motion rad per day at time_t Ignoring_oblateness, constant_k2, constant_k3,

SAT orbit semi major axis in km considering oblateness at time_t.

Outputs : SAT mean motion rev per day at time_t, considering earth oblatenes .

S03B 011. Satellite Mean motion in rev_per_day at time t using SMA Considering earth oblatenes = 14.57626,

Note - This calculted value is slightly less than the mean motion rev_per_day as EPH input from NORAD TLE

04. Finding Satellite Orbit Time Period in minute at time_t Considering earth oblatenes .

Inputs : SAT orbit semi major axis in km considering oblateness at time_t, GM_EARTH .

Outputs : SAT orbit time period in minute at time_t considering earth oblatenes .

S04 011. Satellite orbit Time Period in minute at time_t using SMA Considering earth oblatenes = 98.66860,

05. Finding Satellite Rate of change of Right Ascension and Argument of Perigee in deg per_day at time_t.

(a) Rate of change of Right Ascension in deg per day at time_t .

Inputs : SAT mean motion rev per day at time_t considering earth oblatenes, constant_k2, SAT orbit eccentricity at time_t,

SAT semi major axis km considering oblateness at time_t, SAT orbit inclination deg at time_t .

Outputs : SAT rate of change of right ascension in deg per day at time_t and constant_k_deg_per_day

S05A 011. Satellite Rate of change of Right Ascension in deg per day at time_t = 0.98594,

(b) Rate of change of Argument of Perigee in deg per_day at time_t .

Inputs : SAT orbit constant_k_deg_per_day, SAT orbit inclination deg at time_t

SAT orbit semi major axis km considering oblateness at time_t

Outputs : SAT rate of change of argument of perigee in deg per day at time_t

S05B 011. Satellite Rate of change of Argument of Perigee in deg per day at time_t = -3.10534,

06. Finding Satellite Mean anomaly, Eccentric anomaly, True anomaly in deg at time_t considering earth oblateness.

Inputs : SAT mean anomaly rad at time_t, mean_motion_rad_per_day_at_time_t considering_oblateness, SAT orbit eccentricity_at_time_t

Outputs : SAT mean anomaly, eccentric anomaly, and true anomaly in deg at time_t onsidering earth oblateness.

S06A 011. Satellite Mean anomaly in deg at time_t = 279.74340, same as EPH mean anomaly

S06A 011. Satellite Eccentric anomaly in deg at time_t = 279.73567,

S06A 011. Satellite True anomaly in deg at time_t = 279.72795,

Note - 1. Here after, the Earth Oblateness is always considered for the computation of satellite orbit parameters, and not repeatedly mentioned.

Satellite to Earth, the Position Vectors coordinate and the Vector Coordinate Transforms are in PQW, IJK, SEZ frames .

- Perifocal Coordinate System (PQW) is Earth Centered Inertial coordinate frame defined in terms of Kepler Orbital Elements.
- Geocentric Coordinate System(IJK) is Earth Centered Inertial (ECI) frame, a Conventional Inertial System (CIS).
- Topocentric Horizon Coordinate System(SEZ), is Non-Inertial coordinate frame, known as Earth-Centered Earth-Fixed Coordinates (ECEF).

Each of these coordinate system were explained in detail before and therefore not repeated any more.

07. Finding Satellite position vector[rp, rq] from Earth center(EC) to Sat in PQW frame, perifocal coordinate system.

Inputs : SAT orbit semi-major axis (SMA), SAT orbit eccentricity, SAT eccentric anomaly, SATtrue anomaly at time_t

Outputs : Vector(r, rp rq) in PQW frame

S07A 011. r Satellite pos vector magnitude EC to Sat km in PQW frame perifocal cord at time_t = 7072.98575

S07B 011. rp Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = 1195.1237964113

S07C 011. rq Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = -6971.2844253704

08. Satellite Position Vector Earth Ceter(EC) to Satellite(SAT) - finding Range Vector(rI rJ rK r) Components in km in frame IJK

Note - Transform_1 : EC to SAT Vector(rp, rq) in frame PQW To EC to SAT Vector(rI rJ rK r) in frame IJK.

Inputs : Vector(rp, rq) EC to Sat in km in frame PQW, SAT right ascension of ascending node at time_t,

SAT argument of perigee rad at time_t, SAT orbit inclination rad at time_t .

Outputs : Vector(rI, rJ, rK, r) EC to SAT in km in frame IJK

S08A 011. rI Satellite pos vector component EC to Sat km frame IJK at at time_t = -5736.9414700815

S08B 011. rJ Satellite pos vector component EC to Sat km frame IJK at at time_t = -4136.9553443077

S08C 011. rK Satellite pos vector component EC to Sat km frame IJK at at time_t = 15.1814434008

S08D 011. r Satellite pos vector magnitude EC to Sat km frame IJK at at time_t = 7072.9857505978

Note - r Satellite pos vector magnitude EC to Sat km in PQW frame is same as that computed above in PQW frame.

09. Finding GST Greenwich sidereal time and GHA Greenwich hour angle in 0 to 360 deg, at input at time_t .

Note - for GST, the year 1900 JAN day_1 hr 1200 is ref for time difference in terms of julian_century,

for GHA, the year 2000_JAN_day_1 hr_1200 is ref for time difference in terms of julian days.

Inputs : Time t UT year = 2014, month = 5, day = 29, hour = 3, minute = 25, seconds = 51.17894

Outputs : GST & GHA in 0-360 deg over Greenwich.

S09A 011. GST Greenwich sidereal time in 0-360 deg, over Greenwich = 297.06238, hr = 19, min = 48, sec = 14.97000

S09B 011. GHA Greenwich hour angle in 0 to 360 deg, over Greenwich = 297.06431, deg = 297, min = 3, sec = 51.52460

10. Satellite(SAT) Orbit point direction : Finding Right Ascension(Alpha) deg and Declination(Delta) deg using angles

Inputs : SAT orbit inclination deg at_time_t, EPH right ascension ascending node deg,

SAT argument of perigee deg at time_t, SAT true anomaly deg calculated at time_t

Outputs : SAT Right Ascension(Alpha) and Declination(Delta) in deg at time_t

S10A 011. SAT Right Ascension(Alpha) in deg = 215.8311188173

S10B 011. SAT Declination(Delta) in deg = 0.1229796485

11. Finding Satellite Longitude & Latitude in deg at time_t; (ie Sub-Sat point log & lat on earth surface).

Inputs : SAT right ascension ascending node deg at time_t, GST in 0-360 deg over Greenwich at time_t

Outputs : Satellite (Sub-Sat point) longitude 0 to 360 deg at time_t.

S11A 011. Satellite longitude 0 to 360 deg at time_t = 215.83 ie deg = 215, min = 49, sec = 52.03

Inputs : argument of_perigee rad at_time_t, inclination rad at time_t, true anomaly rad calculated at time_t.

Outputs : Satellite (Sub-Sat point) latitude +ve or -ve in 0 to 90 deg at time_t.

S11B 011. Satellite latitude +ve or -ve in 0 to 90 deg at time_t = 0.12 ie deg = 0, min = 7, sec = 22.73

12. Finding Satellite height in km from EC to Sat and from Earth surface to Sat at time_t.

(a) Satellite height in km from EC to Sat; (ie Sat orbit radius EC to Sat in km at time_t).

Note - This is SAME as r sat pos vector magnitude EC to Sat in frame IJK calculated above in TRANSFORN_1 .

Inputs : SAT true anomaly at time_t, semi_major_axis_km, inclination at time_t .

Outputs : Sub-Sat point longitude 0 to 360 deg at time_t.

S12A 011. Satellite orbital radious EC to SAT in km using SAT true anomaly at time_t = 7072.99

(b) Satellite height in km from earth surface.

Inputs : Sub-Sat point latitude +ve or -ve in 0 to 90 deg at time_t, earth_equator_radious_km .

Outputs : Sat height in km from earth surface.

S12B 011. Satellite height in km from earth surface at time_t = 694.84

13. Finding Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface at time_t .

Inputs : Sub-Sat point lat & log, ES lat & log .

Outputs : Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface

S13 011. Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface = 14843.67830

14. Finding Local sidereal time(LST) and Local mean time(LMT) over Sub-Sat point Longitude on earth .

(a) Local sidereal time(LST) in 0 to 360 deg over Sub-Sat point Longitude on earth .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, satellite log in 0 to 360 deg at time_t .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14A 011. Local sidereal time(LST) over Sub-Sat point Longitude at time_t = 152.89

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Sub-Sat point Longitude on earth .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Sat longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14B 011. Local sidereal time(LST) in 0 to 360_deg over Sub-Sat point Longitude at time_t = 152.89

S14C 011. LST over Sub-Sat Log, with date adj to CD expressed in JD = 2456805.92, ie YY = 2014, MM = 5, DD = 28, hr = 10, min = 11, sec = 34.53

S14D 011. LMT over Sub-Sat Log, with date adj to CD expressed in JD = 2456805.24, ie YY = 2014, MM = 5, DD = 27, hr = 17, min = 49, sec = 10.658

15. Finding Local sidereal time(LST) and Local mean time(LMT) Over Earth stn (ES) or Earth point(EP) Longitude .

(a) Local sidereal time(LST) in 0 to 360 deg over Earth stn(ES) Longitude .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn(ES) longitude at time_t.

S15A 011. Local sidereal time(LST) over Earth stn(ES) Longitude at time_t = 14.47

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Earth stn(ES) Longitude .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn (ES) longitude at time_t.

S15B 011. Local sidereal time(LST) in 0 to 360_deg over Earth stn (ES) Longitude at time_t = 14.48

S14C 011. LST over ES Log, with date adj to CD expressed in JD = 2456806.54, ie YY = 2014, MM = 5, DD = 29, hr = 0, min = 57, sec = 54.09

S15D 011. LMT over ES Log, with date adj to CD expressed in JD = 2456805.86, ie YY = 2014, MM = 5, DD = 28, hr = 8, min = 35, sec = 30.21

16. Earth Stn (ES) Position Vector from Earth Center(EC) to Earth Stn(ES) : Finding Range Vector(RI, RJ, RK, R) Components in IJK frame

Note - Transform_2 : ES position cord(lat, log, hgt) To EC to ES position Vector(RI, RJ, RK, R) in frame IJK .

Inputs : ES latitude positive_negative 0 to 90 deg, ES longitude in 0 to 360_deg,

ES height in meter (is earth surface + tower hgt), LST in 0 to 360 deg at ES log at time_t .

Outputs : ES Position Vector(RI, RJ, RK, R) Components EC to ES in km in IJK frame .

S16A 011. RI_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 5671.2345911565

S16B 011. RJ_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 1464.0401861835

S16C 011. RK_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 2517.6372173288

S16D 011. R_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 6375.3284317570

17. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvI, rvJ, rvK, rv) Components in km in IJK frame

Note - Transform_3 SAT Pos Vct(rI rJ rK) and ES Pos Vct(RI RJ RK) To SAT Pos Vct(rvI, rvJ, rvK, rv)

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK ,

ES Position Vector(RI RJ RK) EC to ES in km in IJK frame.

Outputs : SAT Position Range Vector(rvI, rvJ, rvK, rv) Components ES to Sat in km in IJK frame

S17A 011. rv_I range vector component ES to SAT km frame IJK = -11408.176061238

S17B 011. rv_J range vector component ES to SAT km frame IJK = -5600.9955304911

S17C 011. rv_K range vector component ES to SAT km frame IJK = -2502.4557739280

S17D 011. rv range vector component ES to SAT km frame IJK = 12952.9887237367

18. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvS, rvE, rvZ, rv) Components in km in SEZ frame

Note - Transform_4 SAT Pos Vct(rvI, rvJ, rvK, rv) in IJK frame To SAT Pos Vct(rvS, rvE, rvZ, rv) in SEZ frame

Inputs : ES latitude positive_negative 0 to 90_deg, LST in 0 to 360 deg at ES longitude at time_t

SAT PositionRange Vector(rvI, rvJ, rvK, rv) ES to Sat in km in IJK frame

Outputs : SAT Position Range(rvS, rvE, rvZ, rv) Components ES to Sat in km in SEZ frame

S18A 011. rvS range_vector component ES to SAT km_frame SEZ = -2615.9229941625

S18B 011. rvE range_vector component ES to SAT km_frame SEZ = -2571.6444671914

S18C 011. rvZ range_vector component ES to SAT km_frame SEZ = -12422.701336675

S18D 011. rv range_vector component ES to SAT km_frame SEZ = 12952.9887237367

19. Finding Elevation(EL) and Azimuth(AZ) angles of Satellite and Sun : Steps 1, 2, 3 AT UT TIME t

Rem: Sub-SAT point lat deg = 0.12, log deg = 215.83 YY = 2014, MM = 5, DD = 27, hr = 17, min = 49, sec = 10.65

ES or EP point lat deg = 23.26, log deg = 77.41 YY = 2014, MM = 5, DD = 28, hr = 8, min = 35, sec = 30.21

Note : Step 1 is for Satellite EL & AZ angles. Steps 2 & 3 are for Sun EL & AZ angles

Results verified from other sources; Ref URLs

Geoscience Australia **http://www.ga.gov.au/geodesy/astro/smpos.jsp#intzone** ,

NOAA Research **http://www.esrl.noaa.gov/gmd/grad/solcalc/** ,

Xavier Jubier, Member IAU **http://xjubier.free.fr/en/site_pages/astronomy/ephemerides.html**

Elevation(EL) & Azimuth(AZ) angle of SAT at Earth Observation point EP : Step 1.

Inputs : Range vector component ES to SAT rv_S, rv_E, rv_Z, in frame_SEZ,

EP and Sub_sat point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SAT at EP

S19A 011. Elevation angle deg of Satellte at Earth point EP at time_t = -73.54866 ie deg = -73, min = -32, sec = -55.19

S19B 011. Azimuth angle deg of Satellte at Earth point EP at time_t = 315.48904 ie deg = 315, min = 29, sec = 20.53

Elevation(EL) & Azimuth(AZ) angle of SUN at Sub_Satellite point on earth surface : Step 2.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of Sun at Sub_Sat

S19C 011. Elevation angle deg of SUN at Sub_Sat point at time_t = 1.9151336743

S19D 011. Azimuth angle deg of SUN at Sub_Sat point at time_t = 291.4445892810

Elevation(EL) & Azimuth(AZ) angle of SUN at Satellite height : Step 3.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SUN at SAT

S19E 011. Elevation angle deg of Sun at Satellite height at time_t = 1.91487

S19F 011. Azimuth angle deg of Sun at Satellite height at time_t = 291.44459

20. Finding Satellite Velocity meter per sec in orbit .

Note : Results computed using 2 different formulations, each require different inputs.

(a) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK.

Outputs : SAT Velocity magnitude and component Xw Yw in frame PQW in meter per sec

S20A 011. Satellite Velocity magnitude meter per sec at UT time = 7507.1055062891

(b) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, SAT orbit eccentricity_at_time_t,

SAT eccentric anomaly deg calculated at time_t.

Outputs : Satellite Velocity components Xw Yw in frame PQW in meter per sec

S20B 011. Satellite Velocity components Xw in frame PQW in meter per sec = 7398.9909470324

S20C 011. Satellite Velocity components Yw in frame PQW in meter per sec = 1269.4747135282

21. Finding Satellite(SAT) Velocity Vector (vX, vY, vZ) in meter per sec in orbit in frame XYZ.

Note - Transform_5 SAT Vel Vct(Xw, Yw) in frame PQW To SAT Vel Vct(vX, vY, vZ) in frame XYZ

Inputs : SAT velocity vectors(Xw, Yw), SAT Right Ascension Alpha, SAT Argument of perigee,

SAT orbit inclination at_time_t, SAT eccentric_anomaly_deg_calculated_at_time_t.

Outputs : earth velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ

S21A 011. vX Sat Velocity vector component in meter per sec = -612.4123815408

S21B 011. vY Sat Velocity vector component in meter per sec = 878.2634599352

S21C 011. vZ Sat Velocity vector component in meter per sec = 7430.3591738511

S21D 011. vR Sat Velocity magnitude meter in meter per sec = 7507.1055062891

22. Finding Satellite(SAT) Pitch and Roll angles

Inputs : Earth equator radious km, ES lat, ES log, Sub_Sat point lat, Sub_Sat point log,

Sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK,

Outputs : SAT Pitch and Roll angles

S22A 011. pitch_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = 19.4439603698

S22B 011. roll_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = 11.6748374344

23. Finding Satellite State Vectors - Position [X, Y, Z] in km and velocity [Vx, Vy, Vz] in meter per sec at time_t .

Note - same as values of rI rJ rK r for pos and vX vY vZ vR for vel

(a) Satellite State Position Vector [X, Y, Z] in km at time_t

Inputs : position vector(rI, rJ, rK, r) in frame IJK values assiged to state position vector

Outputs : State Position Vector(X, Y, Z, R) in km, frame XYZ

S23A 011. State vector position X km at time_t = -5736.9414700815

S23B 011. State vector position Y km at time_t = -4136.9553443077

S23C 011. State vector position Z km at time_t = 15.1814434008

S23D 011. State vector position R km at time_t = 7072.9857505978

(b) Satellite State Velocity Vector [Vx, Vy, Vz] in meter per sec at time input UT.

Inputs : velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ values assiged to state velocity vector

Outputs : state velocity vector(Vx, Vy, Vz, V) meter per sec, frame XYZ

S23E 011. State vector velocity Vx meter per sec at time_t = -612.4123815408

S23F 011. State vector velocity Vy meter per sec at time_t = 878.2634599352

S23G 011. State vector velocity Vz meter per sec at time_t = 7430.3591738511

S23H 011. State vector velocity V meter per sec at time_t = 7507.1055062891

24. Satellite Direction ie right ascension alpha deg and declination delta deg using sat position vector .

Note - results same as that using angles incl, RA, Aug of peri, true anomaly

Inputs : SAT State Vectors Position(X, Y, Z, R) in km , in frame XYZ

Outputs : SAT right ascension alpha deg and declination delta deg

S24A 011. Satellite direction right_asc alpha deg at time_t = 215.7956811827

S24B 011. Satellite direction_declination_delta_deg_at_time_t = 0.1229796485

25. Satellite Angular momentum km sqr per sec : finding Hx Hy Hz H from state vector pos and vel .

Inputs : SAT State Vectors Position(X, Y, Z, R) in km and Velocity (vX, vY, vZ, vR) meter per sec, in frame XYZ

Outputs : SAT angular momentum (Hx Hy Hz H) componts in km sqr per sec

S25A 011. Satellite angular momentum Hx in km sqr per sec at time_t = -30752.3974013968

S25B 011. Satellite angular momentum Hy in km sqr per sec at time_t = 42618.2383781588

S25C 011. Satellite angular momentum Hz in km sqr per sec at time_t = -7572.0687396947

S25D 011. Satellite angular momentum H in km sqr per sec at time_t = 53097.6497915837

26. Satellite Orbit normal Vector : finding Wx Wy Wz W Delta Alpha from r_sat_pos frame IJK, i, RA

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK , inclination_deg_at_time_t, right_ascension_ascending_node_deg_at_time_t

Outputs : SAT orbit normal vector (Wx, Wy, Wz, W) in km , RA , i

S26A 011. Satellite Orbit normal_W in km = 7072.9857505978

S26B 011. Satellite Orbit normal_Wx in km = -4096.4387213100

S26C 011. Satellite Orbit normal_Wy in km = 5677.0533902628

S26D 011. Satellite Orbit normal_Wz in km = -1008.6535752265

S26E 011. Satellite Orbit normal_Delta_W in deg = -8.1987000000

S26F 011. Satellite Orbit interpreted inclination i = 98.1987000000

S26G 011. Satellite Orbit normal_Alpha_W in deg = -54.1866000000

S26H 011. Satellite Orbit interpreted RA of asc node = 215.8134000000

Transform Satellite State Vectors to Keplerian elements.

27. Finding Satellite position Keplerian elements computed using State Vector, at time input UT.

Inputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

Outputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee,
mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

S27A 011. Keplerian elements year = 2014, days_decimal_of_year = 147.14295, revolution no = 9125, node = 1 ie ascending

S27B 011. inclination_deg = 98.1987000000

S27C 011. right ascension ascending node deg = 215.8134000000

S27D 011. eccentricity = 0.0001368000

S27E 011. argument of perigee_deg = 80.3963000000

S27F 011. mean anomaly deg = 279.7434000000

S27G 011. mean_motion rev per day = 14.5852806600

S27H 011. mean angular velocity rev_per_day = 14.5943083253

S27I 011. mean motion rev per day using SMA considering oblateness = 14.5762585790

Transform Satellite Keplerian elements to State Vectors .

28. Finding Satellite position State Vectors, computed using Keplerian elements at time input UT
(computed again to validate model equations, Keplerian elements to State Vectors & back)

Inputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee,
mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

Outputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

S28A 011. State vectors year = 2014, days_decimal_of_year = 147.14295, revolution no = 9125, node = 1 ie decending

S28B 011. state vector position X km = -5736.9414700815, state vector velocity Vx meter per sec = -612.4123815411

S28C 011. state vector position Y km = -4136.9553443077, state vector velocity Vy meter per sec = 878.2634599350

S28D 011. state vector position Z km = 15.1814434004, state vector velocity Vz meter per sec = 7430.3591738511

S28E 011. state vector position R km = 7072.9857505978, state vector velocity V meter per sec = 7507.1055062891

Move on to next Satellite.

Next Section - 6.3 Computing Orbital & Positional parameters for Satellite CARTOSAT 2B

Satellite CARTOSAT 2B : Computing Orbital & Positional parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins.

(c) CARTOSAT 2B 'Two-Line Elements'(TLE) downloaded on May 28, 2014, 18:13 hrs IST, Satellite launched on July 12, 2010

```
1 36795U 10035A   14148.12955979  .00000641  00000-0  94319-4 0  3461
2 36795  97.9448 207.1202 0016257  44.4835 315.7690 14.78679483209252
```

From this TLE, the data relevant for the purpose are manually interpreted & extracted :

Satellite number 36795, CARTOSAT 2B ,

```
EPOCH_year  =  2014             EPOCH_days_decimal_of_year   =  147.1295597900
EPOCH_inclination_deg          =   97.9448000000              EPOCH_right_asc_acnd_node_deg   =  207.1202000000
EPOCH_eccentricity             =    0.0016257000              EPOCH_argument_of_perigee_deg   =   44.4835000000
EPOCH_mean_anomaly_deg         =  315.7690000000              EPOCH_mean_motion_rev_per_day   =   14.7867948300
EPOCH_revolution               =   20925                      EPOCH_node_condition            =  1

Earth_stn_latitude_deg         =   23.25993     Earth stn longitude_deg         =   77.41261     Earth surface height_meter      =  494.70000
Earth stn tower_height_meter   =   15.00000     Earth stn_height_meter          =  509.70000     Earth stn min EL look_angle_deg =   -5.00000
```

Note : EPOCH Corresponds to UT year = 2014, month = 5, day = 28, hr = 3, min = 6, sec = 33.96586 which is Greenwich meam time ie GMT

Converted to Local Meam Time at Earth Stn Longitude, as regular Calender date : year = 2014, month = 5, day = 28, hr = 8, min = 16, sec = 12.99

At this instant Sun Position as seen from Earth Stn Longitude : Sun angles EL deg = 39.18, AZ deg = 80.63,

Sun Surface distance km = 5657.39, Radial km = 151596423.96, Sun Rise D:28, H:05, M:17, S:03 Sun Set D:28, H:18, M:40, S:20

Move to Compute Satellie Orbital parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins, and Earth Stn location.

01. Input EPOCH_year and EPOCH_days_decimal_of_year, Converted into UT YY MM DD hh min sec & Julian day.

S01 011. Input UT year = 2014, month = 5, day = 28, hr = 3, min = 6, sec = 33.96586, and julian_day = 2456805.6295597898

02. Finding Satellite orbit Semi major axis in km, Ignoring and also Considering earth oblatenes .

(a) Semi major axis (SMA) km at time t Ignoring earth oblatenes .

Inputs : SAT mean_motion rev per day at time t, GM_EARTH .

Outputs : SAT Orbit semi major axis km in km and constant_A, constant_k1 .

S02A 011. Satellite orbit Semi major axis in km at time t, Ignoring earth oblatenes = 7011.63247,

(b) Semi major axis (SMA) in km at time_t Considering earth oblatenes

Inputs : SAT mean_motion rev per day at time_t, GM_EARTH , inclination deg at time_t, eccentricity at time_t, constant_k2

Outputs : SAT Orbit semi major axis km in km at time_t and constant_A, constant_k1, constant_k3 .

S02B 011. Satellite orbit Semi major axis km at time t, Considering earth oblatenes = 7008.67563,

03. Finding Satellite Mean motion in rev per day, Ignoring and also Considering earth oblatenes .

(a) Nominal mean motion rev per day at time_t Ignoring earth oblateness .

Inputs : SAT Orbit semi major axis in km ignoring oblateness at time_t, constant_k1 .

Outputs : SAT nominal mean motion in rev_per_day at time_t, ignoring earth oblateness

S03A 011. Satellite Nominal Mean motion in rev_per_day at time_t using SMA Ignoring earth oblateness = 14.78679,

(b) Mean motion rev per day at time_t Considering earth oblatenes

Inputs : SAT nominal mean motion rad per day at time_t Ignoring_oblateness, constant_k2, constant_k3,
SAT orbit semi major axis in km considering oblateness at time_t.

Outputs : SAT mean motion rev per day at time_t, considering earth oblatenes .

S03B 011. Satellite Mean motion in rev_per_day at time t using SMA Considering earth oblatenes = 14.77744,

Note - This calculted value is slightly less than the mean motion rev_per_day as EPH input from NORAD TLE

04. Finding Satellite Orbit Time Period in minute at time_t Considering earth oblatenes .

Inputs : SAT orbit semi major axis in km considering oblateness at time_t, GM_EARTH .

Outputs : SAT orbit time period in minute at time_t considering earth oblatenes .

S04 011. Satellite orbit Time Period in minute at time_t using SMA Considering earth oblatenes = 97.32259,

05. Finding Satellite Rate of change of Right Ascension and Argument of Perigee in deg per_day at time_t.

(a) Rate of change of Right Ascension in deg per day at time_t .

Inputs : SAT mean motion rev per day at time_t considering earth oblatenes, constant_k2, SAT orbit eccentricity at time_t,
SAT semi major axis km considering oblateness at time_t, SAT orbit inclination deg at time_t .

Outputs : SAT rate of change of right ascension in deg per day at time_t and constant_k_deg_per_day

S05A 011. Satellite Rate of change of Right Ascension in deg per day at time_t = 0.98670,

(b) Rate of change of Argument of Perigee in deg per_day at time_t .

Inputs : SAT orbit constant_k_deg_per_day, SAT orbit inclination deg at time_t

SAT orbit semi major axis km considering oblateness at time_t

Outputs : SAT rate of change of argument of perigee in deg per day at time_t

S05B 011. Satellite Rate of change of Argument of Perigee in deg per day at time_t = -3.22839,

06. Finding Satellite Mean anomaly, Eccentric anomaly, True anomaly in deg at time_t considering earth oblateness.

Inputs : SAT mean anomaly rad at time_t, mean_motion_rad_per_day_at_time_t considering_oblateness, SAT orbit eccentricity_at_time_t

Outputs : SAT mean anomaly, eccentric anomaly, and true anomaly in deg at time_t onsidering earth oblateness.

S06A 011. Satellite Mean anomaly in deg at time_t = 315.76900, same as EPH mean anomaly

S06A 011. Satellite Eccentric anomaly in deg at time_t = 315.70395,

S06A 011. Satellite True anomaly in deg at time_t = 315.63886,

Note - 1. Here after, the Earth Oblateness is always considered for the computation of satellite orbit parameters, and not repeatedly mentioned.

Satellite to Earth, the Position Vectors coordinate and the Vector Coordinate Transforms are in PQW, IJK, SEZ frames .

- Perifocal Coordinate System (PQW) is Earth Centered Inertial coordinate frame defined in terms of Kepler Orbital Elements.
- Geocentric Coordinate System(IJK) is Earth Centered Inertial (ECI) frame, a Conventional Inertial System (CIS).
- Topocentric Horizon Coordinate System(SEZ), is Non-Inertial coordinate frame, known as Earth-Centered Earth-Fixed Coordinates (ECEF).

Each of these coordinate system were explained in detail before and therefore not repeated any more.

07. Finding Satellite position vector[rp, rq] from Earth center(EC) to Sat in PQW frame, perifocal coordinate system.

Inputs : SAT orbit semi-major axis (SMA), SAT orbit eccentricity, SAT eccentric anomaly, SATtrue anomaly at time_t

Outputs : Vector(r, rp rq) in PQW frame

S07A 011. r Satellite pos vector magnitude EC to Sat km in PQW frame perifocal cord at time_t = 7000.52048

S07B 011. rp Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = 5005.0016826023

S07C 011. rq Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = -4894.6138857698

08. Satellite Position Vector Earth Ceter(EC) to Satellite(SAT) - finding Range Vector(rI rJ rK r) Components in km in frame IJK

Note - Transform_1 : EC to SAT Vector(rp, rq) in frame PQW To EC to SAT Vector(rI rJ rK r) in frame IJK.

Inputs : Vector(rp, rq) EC to Sat in km in frame PQW, SAT right ascension of ascending node at time_t,

SAT argument of perigee rad at time_t, SAT orbit inclination rad at time_t .

Outputs : Vector(rI, rJ, rK, r) EC to SAT in km in frame IJK

S08A 011. rI Satellite pos vector component EC to Sat km frame IJK at at time_t = -6231.7560551250

S08B 011. rJ Satellite pos vector component EC to Sat km frame IJK at at time_t = -3189.4018492384

S08C 011. rK Satellite pos vector component EC to Sat km frame IJK at at time_t = 14.8069953230

S08D 011. r Satellite pos vector magnitude EC to Sat km frame IJK at at time_t = 7000.5204759091

Note - r Satellite pos vector magnitude EC to Sat km in PQW frame is same as that computed above in PQW frame.

09. Finding GST Greenwich sidereal time and GHA Greenwich hour angle in 0 to 360 deg, at input at time_t .

Note - for GST, the year 1900 JAN day_1 hr 1200 is ref for time difference in terms of julian_century,

for GHA, the year 2000_JAN_day_1 hr_1200 is ref for time difference in terms of julian days.

Inputs : Time t UT year = 2014, month = 5, day = 28, hour = 3, minute = 6, seconds = 33.96586

Outputs : GST & GHA in 0-360 deg over Greenwich.

S09A 011. GST Greenwich sidereal time in 0-360 deg, over Greenwich = 292.22745, hr = 19, min = 28, sec = 54.58857

S09B 011. GHA Greenwich hour angle in 0 to 360 deg, over Greenwich = 292.22920, deg = 292, min = 13, sec = 45.10952

10. Satellite(SAT) Orbit point direction : Finding Right Ascension(Alpha) deg and Declination(Delta) deg using angles

Inputs : SAT orbit inclination deg at_time_t, EPH right ascension ascending node deg,

SAT argument of perigee deg at time_t, SAT true anomaly deg calculated at time_t

Outputs : SAT Right Ascension(Alpha) and Declination(Delta) in deg at time_t

S10A 011. SAT Right Ascension(Alpha) in deg = 207.1371128409

S10B 011. SAT Declination(Delta) in deg = 0.1211879852

11. Finding Satellite Longitude & Latitude in deg at time_t; (ie Sub-Sat point log & lat on earth surface).

Inputs : SAT right ascension ascending node deg at time_t, GST in 0-360 deg over Greenwich at time_t

Outputs : Satellite (Sub-Sat point) longitude 0 to 360 deg at time_t.

S11A 011. Satellite longitude 0 to 360 deg at time_t = 207.14 ie deg = 207, min = 8, sec = 13.61

Inputs : argument of_perigee rad at_time_t, inclination rad at time_t, true anomaly rad calculated at time_t.

Outputs : Satellite (Sub-Sat point) latitude +ve or -ve in 0 to 90 deg at time_t.

S11B 011. Satellite latitude +ve or -ve in 0 to 90 deg at time_t = 0.12 ie deg = 0, min = 7, sec = 16.28

12. Finding Satellite height in km from EC to Sat and from Earth surface to Sat at time_t.

(a) Satellite height in km from EC to Sat; (ie Sat orbit radius EC to Sat in km at time_t).

Note - This is SAME as r sat pos vector magnitude EC to Sat in frame IJK calculated above in TRANSFORN_1 .

Inputs : SAT true anomaly at time_t, semi_major_axis_km, inclination at time_t .

Outputs : Sub-Sat point longitude 0 to 360 deg at time_t.

S12A 011. Satellite orbital radious EC to SAT in km using SAT true anomaly at time_t = 7000.52

(b) Satellite height in km from earth surface.

Inputs : Sub-Sat point latitude +ve or -ve in 0 to 90 deg at time_t, earth_equator_radious_km .

Outputs : Sat height in km from earth surface.

S12B 011. Satellite height in km from earth surface at time_t = 622.38

13. Finding Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface at time_t .

Inputs : Sub-Sat point lat & log, ES lat & log .

Outputs : Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface

S13 011. Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface = 14014.66346

14. Finding Local sidereal time(LST) and Local mean time(LMT) over Sub-Sat point Longitude on earth .

(a) Local sidereal time(LST) in 0 to 360 deg over Sub-Sat point Longitude on earth .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, satellite log in 0 to 360 deg at time_t .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14A 011. Local sidereal time(LST) over Sub-Sat point Longitude at time_t = 139.36

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Sub-Sat point Longitude on earth .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Sat longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14B 011. Local sidereal time(LST) in 0 to 360_deg over Sub-Sat point Longitude at time_t = 139.36

S14C 011. LST over Sub-Sat Log, with date adj to CD expressed in JD = 2456805.89, ie YY = 2014, MM = 5, DD = 28, hr = 9, min = 17, sec = 27.58

S14D 011. LMT over Sub-Sat Log, with date adj to CD expressed in JD = 2456805.20, ie YY = 2014, MM = 5, DD = 27, hr = 16, min = 55, sec = 6.87

15. Finding Local sidereal time(LST) and Local mean time(LMT) Over Earth stn (ES) or Earth point(EP) Longitude .

(a) Local sidereal time(LST) in 0 to 360 deg over Earth stn(ES) Longitude .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn(ES) longitude at time_t.

S15A 011. Local sidereal time(LST) over Earth stn(ES) Longitude at time_t = 9.64

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Earth stn(ES) Longitude .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn (ES) longitude at time_t.

S15B 011. Local sidereal time(LST) in 0 to 360_deg over Earth stn (ES) Longitude at time_t = 9.64

S14C 011. LST over ES Log, with date adj to CD expressed in JD = 2456806.53, ie YY = 2014, MM = 5, DD = 29, hr = 0, min = 38, sec = 33.70

S15D 011. LMT over ES Log, with date adj to CD expressed in JD = 2456805.84, ie YY = 2014, MM = 5, DD = 28, hr = 8, min = 16, sec = 12.99

16. Earth Stn (ES) Position Vector from Earth Center(EC) to Earth Stn(ES) : Finding Range Vector(RI, RJ, RK, R) Components in IJK frame

Note - Transform_2 : ES position cord(lat, log, hgt) To EC to ES position Vector(RI, RJ, RK, R) in frame IJK .

Inputs : ES latitude positive_negative 0 to 90 deg, ES longitude in 0 to 360_deg,

ES height in meter (is earth surface + tower hgt), LST in 0 to 360 deg at ES log at time_t .

Outputs : ES Position Vector(RI, RJ, RK, R) Components EC to ES in km in IJK frame .

S16A 011. RI_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 5774.4514013983

S16B 011. RJ_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 980.8294793588

S16C 011. RK_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 2517.6372173288

S16D 011. R_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 6375.3284317570

17. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvI, rvJ, rvK, rv) Components in km in IJK frame

Note - Transform_3 SAT Pos Vct(rI rJ rK) and ES Pos Vct(RI RJ RK) To SAT Pos Vct(rvI, rvJ, rvK, rv)

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK ,

ES Position Vector(RI RJ RK) EC to ES in km in IJK frame.

Outputs : SAT Position Range Vector(rvI, rvJ, rvK, rv) Components ES to Sat in km in IJK frame

S17A 011. rv_I range vector component ES to SAT km frame IJK = -12006.207456523

S17B 011. rv_J range vector component ES to SAT km frame IJK = -4170.2313285972

S17C 011. rv_K range vector component ES to SAT km frame IJK = -2502.8302220058

S17D 011. rv range vector component ES to SAT km frame IJK = 12953.9185555289

18. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvS, rvE, rvZ, rv) Components in km in SEZ frame

Note - Transform_4 SAT Pos Vct(rvI, rvJ, rvK, rv) in IJK frame To SAT Pos Vct(rvS, rvE, rvZ, rv) in SEZ frame

Inputs : ES latitude positive_negative 0 to 90_deg, LST in 0 to 360 deg at ES longitude at time_t

SAT PositionRange Vector(rvI, rvJ, rvK, rv) ES to Sat in km in IJK frame

Outputs : SAT Position Range(rvS, rvE, rvZ, rv) Components ES to Sat in km in SEZ frame

S18A 011. rvS range_vector component ES to SAT km_frame SEZ = -2650.7074843436

S18B 011. rvE range_vector component ES to SAT km_frame SEZ = -2100.8060786626

S18C 011. rvZ range_vector component ES to SAT km_frame SEZ = -12504.573946983

S18D 011. rv range_vector component ES to SAT km_frame SEZ = 12953.9185555289

19. Finding Elevation(EL) and Azimuth(AZ) angles of Satellite and Sun : Steps 1, 2, 3 AT UT TIME t

Rem: Sub-SAT point lat deg = 0.12, log deg = 207.14 YY = 2014, MM = 5, DD = 27, hr = 16, min = 55, sec = 6.87

ES or EP point lat deg = 23.26, log deg = 77.41 YY = 2014, MM = 5, DD = 28, hr = 8, min = 16, sec = 12.99

Note : Step 1 is for Satellite EL & AZ angles. Steps 2 & 3 are for Sun EL & AZ angles

Results verified from other sources; Ref URLs

Geoscience Australia **http://www.ga.gov.au/geodesy/astro/smpos.jsp#intzone** ,

NOAA Research **http://www.esrl.noaa.gov/gmd/grad/solcalc/** ,

Xavier Jubier, Member IAU **http://xjubier.free.fr/en/site_pages/astronomy/ephemerides.html**

Elevation(EL) & Azimuth(AZ) angle of SAT at Earth Observation point EP : Step 1.

Inputs : Range vector component ES to SAT rv_S, rv_E, rv_Z, in frame_SEZ,

EP and Sub_sat point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SAT at EP

S19A 011. Elevation angle deg of Satellte at Earth point EP at time_t = -74.86473 ie deg = -74, min = -51, sec = -53.02

S19B 011. Azimuth angle deg of Satellte at Earth point EP at time_t = 321.60158 ie deg = 321, min = 36, sec = 5.68

Elevation(EL) & Azimuth(AZ) angle of SUN at Sub_Satellite point on earth surface : Step 2.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of Sun at Sub_Sat

S19C 011. Elevation angle deg of SUN at Sub_Sat point at time_t = 14.4723644816

S19D 011. Azimuth angle deg of SUN at Sub_Sat point at time_t = 292.1397432144

Elevation(EL) & Azimuth(AZ) angle of SUN at Satellite height : Step 3.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SUN at SAT

S19E 011. Elevation angle deg of Sun at Satellite height at time_t = 14.47214

S19F 011. Azimuth angle deg of Sun at Satellite height at time_t = 292.13974

20. Finding Satellite Velocity meter per sec in orbit .

Note : Results computed using 2 different formulations, each require different inputs.

(a) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK.

Outputs : SAT Velocity magnitude and component Xw Yw in frame PQW in meter per sec

S20A 011. Satellite Velocity magnitude meter per sec at UT time = 7550.1615459169

(b) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, SAT orbit eccentricity_at_time_t,

SAT eccentric anomaly deg calculated at time_t.

Outputs : Satellite Velocity components Xw Yw in frame PQW in meter per sec

S20B 011. Satellite Velocity components Xw in frame PQW in meter per sec = 5272.7792443276

S20C 011. Satellite Velocity components Yw in frame PQW in meter per sec = 5403.9558112581

21. Finding Satellite(SAT) Velocity Vector (vX, vY, vZ) in meter per sec in orbit in frame XYZ.

Note - Transform_5 SAT Vel Vct(Xw, Yw) in frame PQW To SAT Vel Vct(vX, vY, vZ) in frame XYZ

Inputs : SAT velocity vectors(Xw, Yw), SAT Right Ascension Alpha, SAT Argument of perigee,

SAT orbit inclination at_time_t, SAT eccentric_anomaly_deg_calculated_at_time_t.

Outputs : earth velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ

S21A 011. vX Sat Velocity vector component in meter per sec = -453.7396013124

S21B 011. vY Sat Velocity vector component in meter per sec = 940.0898291212

S21C 011. vZ Sat Velocity vector component in meter per sec = 7477.6527638575

S21D 011. vR Sat Velocity magnitude meter in meter per sec = 7550.1615459169

22. Finding Satellite(SAT) Pitch and Roll angles

Inputs : Earth equator radious km, ES lat, ES log, Sub_Sat point lat, Sub_Sat point log,

Sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK,

Outputs : SAT Pitch and Roll angles

S22A 011. pitch_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = 24.0229508063

S22B 011. roll_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = 12.1020326731

23. Finding Satellite State Vectors - Position [X, Y, Z] in km and velocity [Vx, Vy, Vz] in meter per sec at time_t .

Note - same as values of rI rJ rK r for pos and vX vY vZ vR for vel

(a) Satellite State Position Vector [X, Y, Z] in km at time_t

Inputs : position vector(rI, rJ, rK, r) in frame IJK values assiged to state position vector

Outputs : State Position Vector(X, Y, Z, R) in km, frame XYZ

S23A 011. State vector position X km at time_t = -6231.7560551250

S23B 011. State vector position Y km at time_t = -3189.4018492384

S23C 011. State vector position Z km at time_t = 14.8069953230

S23D 011. State vector position R km at time_t = 7000.5204759091

(b) Satellite State Velocity Vector [Vx, Vy, Vz] in meter per sec at time input UT.

Inputs : velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ values assiged to state velocity vector

Outputs : state velocity vector(Vx, Vy, Vz, V) meter per sec, frame XYZ

S23E 011. State vector velocity Vx meter per sec at time_t = -453.7396013124

S23F 011. State vector velocity Vy meter per sec at time_t = 940.0898291212

S23G 011. State vector velocity Vz meter per sec at time_t = 7477.6527638575

S23H 011. State vector velocity V meter per sec at time_t = 7550.1615459169

24. Satellite Direction ie right ascension alpha deg and declination delta deg using sat position vector .

Note - results same as that using angles incl, RA, Aug of peri, true anomaly

Inputs : SAT State Vectors Position(X, Y, Z, R) in km , in frame XYZ

Outputs : SAT right ascension alpha deg and declination delta deg

S24A 011. Satellite direction right_asc alpha deg at time_t = 207.1032871591

S24B 011. Satellite direction_declination_delta_deg_at_time_t = 0.1211879852

25. Satellite Angular momentum km sqr per sec : finding Hx Hy Hz H from state vector pos and vel .

Inputs : SAT State Vectors Position(X, Y, Z, R) in km and Velocity (vX, vY, vZ, vR) meter per sec, in frame XYZ

Outputs : SAT angular momentum (Hx Hy Hz H) componts in km sqr per sec

S25A 011. Satellite angular momentum Hx in km sqr per sec at time_t = -23863.1594587127

S25B 011. Satellite angular momentum Hy in km sqr per sec at time_t = 46592.1893691367

S25C 011. Satellite angular momentum Hz in km sqr per sec at time_t = -7305.5684084861

S25D 011. Satellite angular momentum H in km sqr per sec at time_t = 52855.0264339402

26. Satellite Orbit normal Vector : finding Wx Wy Wz W Delta Alpha from r_sat_pos frame IJK, i, RA

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK , inclination_deg_at_time_t, right_ascension_ascending_node_deg_at_time_t

Outputs : SAT orbit normal vector (Wx, Wy, Wz, W) in km , RA , i

S26A 011. Satellite Orbit normal_W in km = 7000.5204759091

S26B 011. Satellite Orbit normal_Wx in km = -3160.6177819132

S26C 011. Satellite Orbit normal_Wy in km = 6171.0228468759

S26D 011. Satellite Orbit normal_Wz in km = -967.6048747356

S26E 011. Satellite Orbit normal_Delta_W in deg = -7.9448000000

S26F 011. Satellite Orbit interpreted inclination i = 97.9448000000

S26G 011. Satellite Orbit normal_Alpha_W in deg = -62.8798000000

S26H 011. Satellite Orbit interpreted RA of asc node = 207.1202000000

Transform Satellite State Vectors to Keplerian elements.

27. Finding Satellite position Keplerian elements computed using State Vector, at time input UT.

Inputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

Outputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee, mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

S27A 011. Keplerian elements year = 2014, days_decimal_of_year = 147.12956, revolution no = 20925, node = 1 ie ascending

S27B 011. inclination_deg = 97.9448000000

S27C 011. right ascension ascending node deg = 207.1202000000

S27D 011. eccentricity = 0.0016257000

S27E 011. argument of perigee_deg = 44.4835000000

S27F 011. mean anomaly deg = 315.7690000000

S27G 011. mean_motion rev per day = 14.7867948300

S27H 011. mean angular velocity rev_per_day = 14.7961532483

S27I 011. mean motion rev per day using SMA considering oblateness = 14.7774423308

Transform Satellite Keplerian elements to State Vectors .

28. Finding Satellite position State Vectors, computed using Keplerian elements at time input UT

(computed again to validate model equations, Keplerian elements to State Vectors & back)

Inputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee, mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

Outputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

S28A 011. State vectors year = 2014, days_decimal_of_year = 147.12956, revolution no = 20925, node = 1 ie decending

S28B 011. state vector position X km = -6231.7560551250, state vector velocity Vx meter per sec = -453.7396013125

S28C 011. state vector position Y km = -3189.4018492384, state vector velocity Vy meter per sec = 940.0898291212

S28D 011. state vector position Z km = 14.8069953229, state vector velocity Vz meter per sec = 7477.6527638575

S28E 011. state vector position R km = 7000.5204759091, state vector velocity V meter per sec = 7550.1615459169

Move on to next Satellite.

Next Section - 6.4 Computing Orbital & Positional parameters for Satellite ISS (ZARYA)

Satellite ISS (ZARYA) : Computing Orbital & Positional parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins.

(d) ISS (ZARYA) 'Two-Line Elements'(TLE) downloaded on May 28, 2014, 18:13 hrs IST, Satellite launched on November 20, 1998

```
1 25544U 98067A   14148.25353351  .00006506  00000-0  11951-3 0  3738
2 25544  51.6471 198.4055 0003968  47.6724  33.3515 15.50569135888233
```

From this TLE, the data relevant for the purpose are manually interpreted & extracted :

Satellite number 25544, ISS (ZARYA) ,

```
EPOCH_year  =  2014             EPOCH_days_decimal_of_year   =  147.2535335100

EPOCH_inclination_deg          =   51.6471000000              EPOCH_right_asc_acnd_node_deg   =  198.4055000000

EPOCH_eccentricity             =    0.0003968000              EPOCH_argument_of_perigee_deg   =   47.6724000000

EPOCH_mean_anomaly_deg         =   33.3515000000              EPOCH_mean_motion_rev_per_day   =   15.5056913500

EPOCH_revolution               =   88823                      EPOCH_node_condition            =  1

Earth_stn_latitude_deg         =   23.25993     Earth stn longitude_deg         =   77.41261     Earth surface height_meter      =  494.70000

Earth stn tower_height_meter   =   15.00000     Earth stn_height_meter          =  509.70000     Earth stn min EL look_angle_deg =   -5.00000
```

Note : EPOCH Corresponds to UT year = 2014, month = 5, day = 28, hr = 6, min = 5, sec = 5.29526 which is Greenwich meam time ie GMT

Converted to Local Meam Time at Earth Stn Longitude, as regular Calender date : year = 2014, month = 5, day = 28, hr = 11, min = 14, sec = 44.32

At this instant Sun Position as seen from Earth Stn Longitude : Sun angles EL deg = 80.01, AZ deg = 98.36,

Sun Surface distance km = 1111.87, Radial km = 151595496.79, Sun Rise D:28, H:05, M:17, S:03 Sun Set D:28, H:18, M:40, S:20

Move to Compute Satellie Orbital parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins, and Earth Stn location.

01. Input EPOCH_year and EPOCH_days_decimal_of_year, Converted into UT YY MM DD hh min sec & Julian day.

    S01 011. Input UT year = 2014, month = 5, day = 28, hr = 6, min = 5, sec = 5.29526, and julian_day = 2456805.7535335100

02. Finding Satellite orbit Semi major axis in km, Ignoring and also Considering earth oblatenes .

    (a) Semi major axis (SMA) km at time t Ignoring earth oblatenes .

    Inputs : SAT mean_motion rev per day at time t, GM_EARTH .

    Outputs : SAT Orbit semi major axis km in km and constant_A, constant_k1 .

S02A 011. Satellite orbit Semi major axis in km at time t, Ignoring earth oblatenes = 6793.20027,

(b) Semi major axis (SMA) in km at time_t Considering earth oblatenes

Inputs : SAT mean_motion rev per day at time_t, GM_EARTH , inclination deg at time_t, eccentricity at time_t, constant_k2

Outputs : SAT Orbit semi major axis km in km at time_t and constant_A, constant_k1, constant_k3 .

S02B 011. Satellite orbit Semi major axis km at time t, Considering earth oblatenes = 6793.70175,

03. Finding Satellite Mean motion in rev per day, Ignoring and also Considering earth oblatenes .

(a) Nominal mean motion rev per day at time_t Ignoring earth oblateness .

Inputs : SAT Orbit semi major axis in km ignoring oblateness at time_t, constant_k1 .

Outputs : SAT nominal mean motion in rev_per_day at time_t, ignoring earth oblateness

S03A 011. Satellite Nominal Mean motion in rev_per_day at time_t using SMA Ignoring earth oblateness = 15.50569,

(b) Mean motion rev per day at time_t Considering earth oblatenes

Inputs : SAT nominal mean motion rad per day at time_t Ignoring_oblateness, constant_k2, constant_k3,

SAT orbit semi major axis in km considering oblateness at time_t.

Outputs : SAT mean motion rev per day at time_t, considering earth oblatenes .

S03B 011. Satellite Mean motion in rev_per_day at time t using SMA Considering earth oblatenes = 15.50741,

Note - This calculted value is slightly less than the mean motion rev_per_day as EPH input from NORAD TLE

04. Finding Satellite Orbit Time Period in minute at time_t Considering earth oblatenes .

Inputs : SAT orbit semi major axis in km considering oblateness at time_t, GM_EARTH .

Outputs : SAT orbit time period in minute at time_t considering earth oblatenes .

S04 011. Satellite orbit Time Period in minute at time_t using SMA Considering earth oblatenes = 92.87941,

05. Finding Satellite Rate of change of Right Ascension and Argument of Perigee in deg per_day at time_t.

(a) Rate of change of Right Ascension in deg per day at time_t .

Inputs : SAT mean motion rev per day at time_t considering earth oblatenes, constant_k2, SAT orbit eccentricity at time_t,

SAT semi major axis km considering oblateness at time_t, SAT orbit inclination deg at time_t .

Outputs : SAT rate of change of right ascension in deg per day at time_t and constant_k_deg_per_day

S05A 011. Satellite Rate of change of Right Ascension in deg per day at time_t = -4.94720,

(b) Rate of change of Argument of Perigee in deg per_day at time_t .

Inputs : SAT orbit constant_k_deg_per_day, SAT orbit inclination deg at time_t

SAT orbit semi major axis km considering oblateness at time_t

Outputs : SAT rate of change of argument of perigee in deg per day at time_t

S05B 011. Satellite Rate of change of Argument of Perigee in deg per day at time_t = 3.68794,

06. Finding Satellite Mean anomaly, Eccentric anomaly, True anomaly in deg at time_t considering earth oblateness.

Inputs : SAT mean anomaly rad at time_t, mean_motion_rad_per_day_at_time_t considering_oblateness, SAT orbit eccentricity_at_time_t

Outputs : SAT mean anomaly, eccentric anomaly, and true anomaly in deg at time_t onsidering earth oblateness.

S06A 011. Satellite Mean anomaly in deg at time_t = 33.35150, same as EPH mean anomaly

S06A 011. Satellite Eccentric anomaly in deg at time_t = 33.36400,

S06A 011. Satellite True anomaly in deg at time_t = 33.37651,

Note - 1. Here after, the Earth Oblateness is always considered for the computation of satellite orbit parameters, and not repeatedly mentioned.

Satellite to Earth, the Position Vectors coordinate and the Vector Coordinate Transforms are in PQW, IJK, SEZ frames .

- Perifocal Coordinate System (PQW) is Earth Centered Inertial coordinate frame defined in terms of Kepler Orbital Elements.
- Geocentric Coordinate System(IJK) is Earth Centered Inertial (ECI) frame, a Conventional Inertial System (CIS).
- Topocentric Horizon Coordinate System(SEZ), is Non-Inertial coordinate frame, known as Earth-Centered Earth-Fixed Coordinates (ECEF).

Each of these coordinate system were explained in detail before and therefore not repeated any more.

07. Finding Satellite position vector[rp, rq] from Earth center(EC) to Sat in PQW frame, perifocal coordinate system.

Inputs : SAT orbit semi-major axis (SMA), SAT orbit eccentricity, SAT eccentric anomaly, SATtrue anomaly at time_t

Outputs : Vector(r, rp rq) in PQW frame

S07A 011. r Satellite pos vector magnitude EC to Sat km in PQW frame perifocal cord at time_t = 6791.45029

S07B 011. rp Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = 5671.3601057139

S07C 011. rq Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = 3736.2376169157

08. Satellite Position Vector Earth Ceter(EC) to Satellite(SAT) - finding Range Vector(rI rJ rK r) Components in km in frame IJK

Note - Transform_1 : EC to SAT Vector(rp, rq) in frame PQW To EC to SAT Vector(rI rJ rK r) in frame IJK.

Inputs : Vector(rp, rq) EC to Sat in km in frame PQW, SAT right ascension of ascending node at time_t,

SAT argument of perigee rad at time_t, SAT orbit inclination rad at time_t .

Outputs : Vector(rI, rJ, rK, r) EC to SAT in km in frame IJK

S08A 011. rI Satellite pos vector component EC to Sat km frame IJK at at time_t = 311.7253734371

S08B 011. rJ Satellite pos vector component EC to Sat km frame IJK at at time_t = -4283.4907194611

S08C 011. rK Satellite pos vector component EC to Sat km frame IJK at at time_t = 5261.0200081909

S08D 011. r Satellite pos vector magnitude EC to Sat km frame IJK at at time_t = 6791.4502853764

Note - r Satellite pos vector magnitude EC to Sat km in PQW frame is same as that computed above in PQW frame.

09. Finding GST Greenwich sidereal time and GHA Greenwich hour angle in 0 to 360 deg, at input at time_t .

Note - for GST, the year 1900 JAN day_1 hr 1200 is ref for time difference in terms of julian_century,

for GHA, the year 2000_JAN_day_1 hr_1200 is ref for time difference in terms of julian days.

Inputs : Time t UT year = 2014, month = 5, day = 28, hour = 6, minute = 5, seconds = 5.29526

Outputs : GST & GHA in 0-360 deg over Greenwich.

S09A 011. GST Greenwich sidereal time in 0-360 deg, over Greenwich = 336.98019, hr = 22, min = 27, sec = 55.24463

S09B 011. GHA Greenwich hour angle in 0 to 360 deg, over Greenwich = 336.98371, deg = 336, min = 59, sec = 1.37032

10. Satellite(SAT) Orbit point direction : Finding Right Ascension(Alpha) deg and Declination(Delta) deg using angles

Inputs : SAT orbit inclination deg at_time_t, EPH right ascension ascending node deg,

SAT argument of perigee deg at time_t, SAT true anomaly deg calculated at time_t

Outputs : SAT Right Ascension(Alpha) and Declination(Delta) in deg at time_t

S10A 011. SAT Right Ascension(Alpha) in deg = 274.1622871100

S10B 011. SAT Declination(Delta) in deg = 50.7736185669

11. Finding Satellite Longitude & Latitude in deg at time_t; (ie Sub-Sat point log & lat on earth surface).

Inputs : SAT right ascension ascending node deg at time_t, GST in 0-360 deg over Greenwich at time_t

Outputs : Satellite (Sub-Sat point) longitude 0 to 360 deg at time_t.

S11A 011. Satellite longitude 0 to 360 deg at time_t = 274.16 ie deg = 274, min = 9, sec = 44.23

Inputs : argument of_perigee rad at_time_t, inclination rad at time_t, true anomaly rad calculated at time_t.

Outputs : Satellite (Sub-Sat point) latitude +ve or -ve in 0 to 90 deg at time_t.

S11B 011. Satellite latitude +ve or -ve in 0 to 90 deg at time_t = 50.77 ie deg = 50, min = 46, sec = 25.03

12. Finding Satellite height in km from EC to Sat and from Earth surface to Sat at time_t.

(a) Satellite height in km from EC to Sat; (ie Sat orbit radius EC to Sat in km at time_t).

Note - This is SAME as r sat pos vector magnitude EC to Sat in frame IJK calculated above in TRANSFORN_1 .

Inputs : SAT true anomaly at time_t, semi_major_axis_km, inclination at time_t .

Outputs : Sub-Sat point longitude 0 to 360 deg at time_t.

S12A 011. Satellite orbital radious EC to SAT in km using SAT true anomaly at time_t = 6791.45

(b) Satellite height in km from earth surface.

Inputs : Sub-Sat point latitude +ve or -ve in 0 to 90 deg at time_t, earth_equator_radious_km .

Outputs : Sat height in km from earth surface.

S12B 011. Satellite height in km from earth surface at time_t = 426.15

13. Finding Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface at time_t .

Inputs : Sub-Sat point lat & log, ES lat & log .

Outputs : Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface

S13 011. Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface = 11633.16757

14. Finding Local sidereal time(LST) and Local mean time(LMT) over Sub-Sat point Longitude on earth .

(a) Local sidereal time(LST) in 0 to 360 deg over Sub-Sat point Longitude on earth .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, satellite log in 0 to 360 deg at time_t .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14A 011. Local sidereal time(LST) over Sub-Sat point Longitude at time_t = 251.14

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Sub-Sat point Longitude on earth .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Sat longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14B 011. Local sidereal time(LST) in 0 to 360_deg over Sub-Sat point Longitude at time_t = 251.14

S14C 011. LST over Sub-Sat Log, with date adj to CD expressed in JD = 2456806.20, ie YY = 2014, MM = 5, DD = 28, hr = 16, min = 44, sec = 34.28

S14D 011. LMT over Sub-Sat Log, with date adj to CD expressed in JD = 2456805.52, ie YY = 2014, MM = 5, DD = 28, hr = 0, min = 21, sec = 44.24

15. Finding Local sidereal time(LST) and Local mean time(LMT) Over Earth stn (ES) or Earth point(EP) Longitude .

(a) Local sidereal time(LST) in 0 to 360 deg over Earth stn(ES) Longitude .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn(ES) longitude at time_t.

S15A 011. Local sidereal time(LST) over Earth stn(ES) Longitude at time_t = 54.39

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Earth stn(ES) Longitude .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn (ES) longitude at time_t.

S15B 011. Local sidereal time(LST) in 0 to 360_deg over Earth stn (ES) Longitude at time_t = 54.39

S14C 011. LST over ES Log, with date adj to CD expressed in JD = 2456806.65, ie YY = 2014, MM = 5, DD = 29, hr = 3, min = 37, sec = 34.36

S15D 011. LMT over ES Log, with date adj to CD expressed in JD = 2456805.97, ie YY = 2014, MM = 5, DD = 28, hr = 11, min = 14, sec = 44.32

16. Earth Stn (ES) Position Vector from Earth Center(EC) to Earth Stn(ES) : Finding Range Vector(RI, RJ, RK, R) Components in IJK frame

Note - Transform_2 : ES position cord(lat, log, hgt) To EC to ES position Vector(RI, RJ, RK, R) in frame IJK .

Inputs : ES latitude positive_negative 0 to 90 deg, ES longitude in 0 to 360_deg,

ES height in meter (is earth surface + tower hgt), LST in 0 to 360 deg at ES log at time_t .

Outputs : ES Position Vector(RI, RJ, RK, R) Components EC to ES in km in IJK frame .

S16A 011. RI_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 3410.1853501576

S16B 011. RJ_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 4762.0322691327

S16C 011. RK_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 2517.6372173288

S16D 011. R_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 6375.3284317570

17. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvI, rvJ, rvK, rv) Components in km in IJK frame

Note - Transform_3 SAT Pos Vct(rI rJ rK) and ES Pos Vct(RI RJ RK) To SAT Pos Vct(rvI, rvJ, rvK, rv)

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK ,

ES Position Vector(RI RJ RK) EC to ES in km in IJK frame.

Outputs : SAT Position Range Vector(rvI, rvJ, rvK, rv) Components ES to Sat in km in IJK frame

S17A 011. rv_I range vector component ES to SAT km frame IJK = -3098.4599767204

S17B 011. rv_J range vector component ES to SAT km frame IJK = -9045.5229885937

S17C 011. rv_K range vector component ES to SAT km frame IJK = 2743.3827908621

S17D 011. rv range vector component ES to SAT km frame IJK = 9947.2654283333

18. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvS, rvE, rvZ, rv) Components in km in SEZ frame

Note - Transform_4 SAT Pos Vct(rvI, rvJ, rvK, rv) in IJK frame To SAT Pos Vct(rvS, rvE, rvZ, rv) in SEZ frame

Inputs : ES latitude positive_negative 0 to 90_deg, LST in 0 to 360 deg at ES longitude at time_t

SAT PositionRange Vector(rvI, rvJ, rvK, rv) ES to Sat in km in IJK frame

Outputs : SAT Position Range(rvS, rvE, rvZ, rv) Components ES to Sat in km in SEZ frame

S18A 011. rvS range_vector component ES to SAT km_frame SEZ = -6137.0343240468

S18B 011. rvE range_vector component ES to SAT km_frame SEZ = -2747.3972741696

S18C 011. rvZ range_vector component ES to SAT km_frame SEZ = -7330.5325471668

S18D 011. rv range_vector component ES to SAT km_frame SEZ = 9947.2654283333

19. Finding Elevation(EL) and Azimuth(AZ) angles of Satellite and Sun : Steps 1, 2, 3 AT UT TIME t

Rem: Sub-SAT point lat deg = 50.77, log deg = 274.16 YY = 2014, MM = 5, DD = 28, hr = 0, min = 21, sec = 44.24

ES or EP point lat deg = 23.26, log deg = 77.41 YY = 2014, MM = 5, DD = 28, hr = 11, min = 14, sec = 44.32

Note : Step 1 is for Satellite EL & AZ angles. Steps 2 & 3 are for Sun EL & AZ angles

Results verified from other sources; Ref URLs

Geoscience Australia **http://www.ga.gov.au/geodesy/astro/smpos.jsp#intzone** ,

NOAA Research **http://www.esrl.noaa.gov/gmd/grad/solcalc/** ,

Xavier Jubier, Member IAU **http://xjubier.free.fr/en/site_pages/astronomy/ephemerides.html**

Elevation(EL) & Azimuth(AZ) angle of SAT at Earth Observation point EP : Step 1.

Inputs : Range vector component ES to SAT rv_S, rv_E, rv_Z, in frame_SEZ,

EP and Sub_sat point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SAT at EP

S19A 011. Elevation angle deg of Satellte at Earth point EP at time_t = -47.47135 ie deg = -47, min = -28, sec = -16.87

S19B 011. Azimuth angle deg of Satellte at Earth point EP at time_t = 335.88313 ie deg = 335, min = 52, sec = 59.26

Elevation(EL) & Azimuth(AZ) angle of SUN at Sub_Satellite point on earth surface : Step 2.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of Sun at Sub_Sat

S19C 011. Elevation angle deg of SUN at Sub_Sat point at time_t = -17.5724321856

S19D 011. Azimuth angle deg of SUN at Sub_Sat point at time_t = 5.9788181882

Elevation(EL) & Azimuth(AZ) angle of SUN at Satellite height : Step 3.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SUN at SAT

S19E 011. Elevation angle deg of Sun at Satellite height at time_t = -17.57259

S19F 011. Azimuth angle deg of Sun at Satellite height at time_t = 5.97882

20. Finding Satellite Velocity meter per sec in orbit .

Note : Results computed using 2 different formulations, each require different inputs.

(a) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK.

Outputs : SAT Velocity magnitude and component Xw Yw in frame PQW in meter per sec

S20A 011. Satellite Velocity magnitude meter per sec at UT time = 7662.3074951298

(b) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, SAT orbit eccentricity_at_time_t,

SAT eccentric anomaly deg calculated at time_t.

Outputs : Satellite Velocity components Xw Yw in frame PQW in meter per sec

S20B 011. Satellite Velocity components Xw in frame PQW in meter per sec = -4213.9331945858

S20C 011. Satellite Velocity components Yw in frame PQW in meter per sec = 6399.5096047658

21. Finding Satellite(SAT) Velocity Vector (vX, vY, vZ) in meter per sec in orbit in frame XYZ.

Note - Transform_5 SAT Vel Vct(Xw, Yw) in frame PQW To SAT Vel Vct(vX, vY, vZ) in frame XYZ

Inputs : SAT velocity vectors(Xw, Yw), SAT Right Ascension Alpha, SAT Argument of perigee,

SAT orbit inclination at_time_t, SAT eccentric_anomaly_deg_calculated_at_time_t.

Outputs : earth velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ

S21A 011. vX Sat Velocity vector component in meter per sec = 7415.4532574405

S21B 011. vY Sat Velocity vector component in meter per sec = 1686.8647169809

S21C 011. vZ Sat Velocity vector component in meter per sec = 936.2139516379

S21D 011. vR Sat Velocity magnitude meter in meter per sec = 7662.3074951298

22. Finding Satellite(SAT) Pitch and Roll angles

Inputs : Earth equator radious km, ES lat, ES log, Sub_Sat point lat, Sub_Sat point log,

Sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK,

Outputs : SAT Pitch and Roll angles

S22A 011. pitch_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = -7.7991142227

S22B 011. roll_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = 11.2997817577

23. Finding Satellite State Vectors - Position [X, Y, Z] in km and velocity [Vx, Vy, Vz] in meter per sec at time_t .

Note - same as values of rI rJ rK r for pos and vX vY vZ vR for vel

(a) Satellite State Position Vector [X, Y, Z] in km at time_t

Inputs : position vector(rI, rJ, rK, r) in frame IJK values assiged to state position vector

Outputs : State Position Vector(X, Y, Z, R) in km, frame XYZ

S23A 011. State vector position X km at time_t = 311.7253734371

S23B 011. State vector position Y km at time_t = -4283.4907194611

S23C 011. State vector position Z km at time_t = 5261.0200081909

S23D 011. State vector position R km at time_t = 6791.4502853764

(b) Satellite State Velocity Vector [Vx, Vy, Vz] in meter per sec at time input UT.

Inputs : velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ values assiged to state velocity vector

Outputs : state velocity vector(Vx, Vy, Vz, V) meter per sec, frame XYZ

S23E 011. State vector velocity Vx meter per sec at time_t = 7415.4532574405

S23F 011. State vector velocity Vy meter per sec at time_t = 1686.8647169809

S23G 011. State vector velocity Vz meter per sec at time_t = 936.2139516379

S23H 011. State vector velocity V meter per sec at time_t = 7662.3074951298

24. Satellite Direction ie right ascension alpha deg and declination delta deg using sat position vector .

Note - results same as that using angles incl, RA, Aug of peri, true anomaly

Inputs : SAT State Vectors Position(X, Y, Z, R) in km , in frame XYZ

Outputs : SAT right ascension alpha deg and declination delta deg

S24A 011. Satellite direction right_asc alpha deg at time_t = 274.1622871100

S24B 011. Satellite direction_declination_delta_deg_at_time_t = 50.7736185669

25. Satellite Angular momentum km sqr per sec : finding Hx Hy Hz H from state vector pos and vel .

Inputs : SAT State Vectors Position(X, Y, Z, R) in km and Velocity (vX, vY, vZ, vR) meter per sec, in frame XYZ

Outputs : SAT angular momentum (Hx Hy Hz H) componts in km sqr per sec

S25A 011. Satellite angular momentum Hx in km sqr per sec at time_t = -12884.8928004185

S25B 011. Satellite angular momentum Hy in km sqr per sec at time_t = 38721.0063135077

S25C 011. Satellite angular momentum Hz in km sqr per sec at time_t = 32289.8637426827

S25D 011. Satellite angular momentum H in km sqr per sec at time_t = 52038.1791853826

26. Satellite Orbit normal Vector : finding Wx Wy Wz W Delta Alpha from r_sat_pos frame IJK, i, RA

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK , inclination_deg_at_time_t, right_ascension_ascending_node_deg_at_time_t

Outputs : SAT orbit normal vector (Wx, Wy, Wz, W) in km , RA , i

S26A 011. Satellite Orbit normal_W in km = 6791.4502853764

S26B 011. Satellite Orbit normal_Wx in km = -1681.5943650662

S26C 011. Satellite Orbit normal_Wy in km = 5053.4394841355

S26D 011. Satellite Orbit normal_Wz in km = 4214.1175529755

S26E 011. Satellite Orbit normal_Delta_W in deg = 38.3529000000

S26F 011. Satellite Orbit interpreted inclination i = 51.6471000000

S26G 011. Satellite Orbit normal_Alpha_W in deg = -71.5945000000

S26H 011. Satellite Orbit interpreted RA of asc node = 198.4055000000

Transform Satellite State Vectors to Keplerian elements.

27. Finding Satellite position Keplerian elements computed using State Vector, at time input UT.

Inputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

Outputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee,
mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

S27A 011. Keplerian elements year = 2014, days_decimal_of_year = 147.25353, revolution no = 88823, node = 1 ie ascending

S27B 011. inclination_deg = 51.6471000000

S27C 011. right ascension ascending node deg = 198.4055000000

S27D 011. eccentricity = 0.0003968000

S27E 011. argument of perigee_deg = 47.6723999999

S27F 011. mean anomaly deg = 33.3515000001

S27G 011. mean_motion rev per day = 15.5056913500

S27H 011. mean angular velocity rev_per_day = 15.5039745355

S27I 011. mean motion rev per day using SMA considering oblateness = 15.5074083546

Transform Satellite Keplerian elements to State Vectors .

28. Finding Satellite position State Vectors, computed using Keplerian elements at time input UT
(computed again to validate model equations, Keplerian elements to State Vectors & back)

Inputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee,
mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

Outputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

S28A 011. State vectors year = 2014, days_decimal_of_year = 147.25353, revolution no = 88823, node = 1 ie decending

S28B 011. state vector position X km = 311.7253734381, state vector velocity Vx meter per sec = 7415.4532574405

S28C 011. state vector position Y km = -4283.4907194609, state vector velocity Vy meter per sec = 1686.8647169816

S28D 011. state vector position Z km = 5261.0200081910, state vector velocity Vz meter per sec = 936.2139516370

S28E 011. state vector position R km = 6791.4502853764, state vector velocity V meter per sec = 7662.3074951298

Move on to next Satellite.

Next Section - 6.5 Computing Computing Orbital & Positional parameters for Satellite GSAT-14

Satellite GSAT-14 : Computing Orbital & Positional parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins.

(e) GSAT-14 'Two-Line Elements'(TLE) downloaded on May 28, 2014, 18:14 hrs IST, Satellite launched on January 05, 2014

```
1 39498U 14001A   14146.03167358 -.00000092  00000-0  00000+0 0  1238
2 39498   0.0049 223.9821 0002051 110.2671 354.6468  1.00272265  1407
```

From this TLE, the data relevant for the purpose are manually interpreted & extracted :

Satellite number 39498, GSAT-14 ,

EPOCH_year = 2014 EPOCH_days_decimal_of_year = 145.0316735800

EPOCH_inclination_deg = 0.0049000000 EPOCH_right_asc_acnd_node_deg = 223.9821000000

EPOCH_eccentricity = 0.0002051000 EPOCH_argument_of_perigee_deg = 110.2671000000

EPOCH_mean_anomaly_deg = 354.6468000000 EPOCH_mean_motion_rev_per_day = 1.0027226500

EPOCH_revolution = 140 EPOCH_node_condition = 1

Earth_stn_latitude_deg = 23.25993 Earth stn longitude_deg = 77.41261 Earth surface height_meter = 494.70000

Earth stn tower_height_meter = 15.00000 Earth stn_height_meter = 509.70000 Earth stn min EL look_angle_deg = -5.00000

Note : EPOCH Corresponds to UT year = 2014, month = 5, day = 26, hr = 0, min = 45, sec = 36.59731 which is Greenwich meam time ie GMT

Converted to Local Meam Time at Earth Stn Longitude, as regular Calender date : year = 2014, month = 5, day = 26, hr = 5, min = 55, sec = 15.62

At this instant Sun Position as seen from Earth Stn Longitude : Sun angles EL deg = 7.79, AZ deg = 70.35,

Sun Surface distance km = 9151.22, Radial km = 151543715.47, Sun Rise D:26, H:05, M:17, S:33 Sun Set D:26, H:18, M:39, S:23

Move to Compute Satellie Orbital parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins, and Earth Stn location.

01. Input EPOCH_year and EPOCH_days_decimal_of_year, Converted into UT YY MM DD hh min sec & Julian day.

S01 011. Input UT year = 2014, month = 5, day = 26, hr = 0, min = 45, sec = 36.59731, and julian_day = 2456803.5316735799

02. Finding Satellite orbit Semi major axis in km, Ignoring and also Considering earth oblatenes .

(a) Semi major axis (SMA) km at time t Ignoring earth oblatenes .

Inputs : SAT mean_motion rev per day at time t, GM_EARTH .

Outputs : SAT Orbit semi major axis km in km and constant_A, constant_k1 .

S02A 011. Satellite orbit Semi major axis in km at time t, Ignoring earth oblatenes = 42164.59740,

(b) Semi major axis (SMA) in km at time_t Considering earth oblatenes

Inputs : SAT mean_motion rev per day at time_t, GM_EARTH , inclination deg at time_t, eccentricity at time_t, constant_k2

Outputs : SAT Orbit semi major axis km in km at time_t and constant_A, constant_k1, constant_k3 .

S02B 011. Satellite orbit Semi major axis km at time t, Considering earth oblatenes = 42165.63953,

03. Finding Satellite Mean motion in rev per day, Ignoring and also Considering earth oblatenes .

(a) Nominal mean motion rev per day at time_t Ignoring earth oblateness .

Inputs : SAT Orbit semi major axis in km ignoring oblateness at time_t, constant_k1 .

Outputs : SAT nominal mean motion in rev_per_day at time_t, ignoring earth oblateness

S03A 011. Satellite Nominal Mean motion in rev_per_day at time_t using SMA Ignoring earth oblateness = 1.00272,

(b) Mean motion rev per day at time_t Considering earth oblatenes

Inputs : SAT nominal mean motion rad per day at time_t Ignoring_oblateness, constant_k2, constant_k3,

SAT orbit semi major axis in km considering oblateness at time_t.

Outputs : SAT mean motion rev per day at time_t, considering earth oblatenes .

S03B 011. Satellite Mean motion in rev_per_day at time t using SMA Considering earth oblatenes = 1.00276,

Note - This calculted value is slightly less than the mean motion rev_per_day as EPH input from NORAD TLE

04. Finding Satellite Orbit Time Period in minute at time_t Considering earth oblatenes .

Inputs : SAT orbit semi major axis in km considering oblateness at time_t, GM_EARTH .

Outputs : SAT orbit time period in minute at time_t considering earth oblatenes .

S04 011. Satellite orbit Time Period in minute at time_t using SMA Considering earth oblatenes = 1436.14327,

05. Finding Satellite Rate of change of Right Ascension and Argument of Perigee in deg per_day at time_t.

(a) Rate of change of Right Ascension in deg per day at time_t .

Inputs : SAT mean motion rev per day at time_t considering earth oblatenes, constant_k2, SAT orbit eccentricity at time_t,

SAT semi major axis km considering oblateness at time_t, SAT orbit inclination deg at time_t .

Outputs : SAT rate of change of right ascension in deg per day at time_t and constant_k_deg_per_day

S05A 011. Satellite Rate of change of Right Ascension in deg per day at time_t = -0.01338,

(b) Rate of change of Argument of Perigee in deg per_day at time_t .

Inputs : SAT orbit constant_k_deg_per_day, SAT orbit inclination deg at time_t

SAT orbit semi major axis km considering oblateness at time_t

Outputs : SAT rate of change of argument of perigee in deg per day at time_t

S05B 011. Satellite Rate of change of Argument of Perigee in deg per day at time_t = 0.02677,

06. Finding Satellite Mean anomaly, Eccentric anomaly, True anomaly in deg at time_t considering earth oblateness.

Inputs : SAT mean anomaly rad at time_t, mean_motion_rad_per_day_at_time_t considering_oblateness, SAT orbit eccentricity_at_time_t

Outputs : SAT mean anomaly, eccentric anomaly, and true anomaly in deg at time_t onsidering earth oblateness.

S06A 011. Satellite Mean anomaly in deg at time_t = 354.64680, same as EPH mean anomaly

S06A 011. Satellite Eccentric anomaly in deg at time_t = 354.64570,

S06A 011. Satellite True anomaly in deg at time_t = 354.64461,

Note - 1. Here after, the Earth Oblateness is always considered for the computation of satellite orbit parameters, and not repeatedly mentioned.

Satellite to Earth, the Position Vectors coordinate and the Vector Coordinate Transforms are in PQW, IJK, SEZ frames .

- Perifocal Coordinate System (PQW) is Earth Centered Inertial coordinate frame defined in terms of Kepler Orbital Elements.
- Geocentric Coordinate System(IJK) is Earth Centered Inertial (ECI) frame, a Conventional Inertial System (CIS).
- Topocentric Horizon Coordinate System(SEZ), is Non-Inertial coordinate frame, known as Earth-Centered Earth-Fixed Coordinates (ECEF).

Each of these coordinate system were explained in detail before and therefore not repeated any more.

07. Finding Satellite position vector[rp, rq] from Earth center(EC) to Sat in PQW frame, perifocal coordinate system.

Inputs : SAT orbit semi-major axis (SMA), SAT orbit eccentricity, SAT eccentric anomaly, SATtrue anomaly at time_t

Outputs : Vector(r, rp rq) in PQW frame

S07A 011. r Satellite pos vector magnitude EC to Sat km in PQW frame perifocal cord at time_t = 42157.02910

S07B 011. rp Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = 41973.0106897037

S07C 011. rq Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = -3934.6506542903

08. Satellite Position Vector Earth Ceter(EC) to Satellite(SAT) - finding Range Vector(rI rJ rK r) Components in km in frame IJK

Note - Transform_1 : EC to SAT Vector(rp, rq) in frame PQW To EC to SAT Vector(rI rJ rK r) in frame IJK.

Inputs : Vector(rp, rq) EC to Sat in km in frame PQW, SAT right ascension of ascending node at time_t,

SAT argument of perigee rad at time_t, SAT orbit inclination rad at time_t .

Outputs : Vector(rI, rJ, rK, r) EC to SAT in km in frame IJK

S08A 011. rI Satellite pos vector component EC to Sat km frame IJK at at time_t = 36095.3223130873

S08B 011. rJ Satellite pos vector component EC to Sat km frame IJK at at time_t = -21779.4122305000

S08C 011. rK Satellite pos vector component EC to Sat km frame IJK at at time_t = 3.4839025250

S08D 011. r Satellite pos vector magnitude EC to Sat km frame IJK at at time_t = 42157.0290951495

Note - r Satellite pos vector magnitude EC to Sat km in PQW frame is same as that computed above in PQW frame.

09. Finding GST Greenwich sidereal time and GHA Greenwich hour angle in 0 to 360 deg, at input at time_t .

Note - for GST, the year 1900 JAN day_1 hr 1200 is ref for time difference in terms of julian_century,

for GHA, the year 2000_JAN_day_1 hr_1200 is ref for time difference in terms of julian days.

Inputs : Time t UT year = 2014, month = 5, day = 26, hour = 0, minute = 45, seconds = 36.59731

Outputs : GST & GHA in 0-360 deg over Greenwich.

S09A 011. GST Greenwich sidereal time in 0-360 deg, over Greenwich = 254.92064, hr = 16, min = 59, sec = 40.95379

S09B 011. GHA Greenwich hour angle in 0 to 360 deg, over Greenwich = 254.92098, deg = 254, min = 55, sec = 15.51883

10. Satellite(SAT) Orbit point direction : Finding Right Ascension(Alpha) deg and Declination(Delta) deg using angles

Inputs : SAT orbit inclination deg at_time_t, EPH right ascension ascending node deg,

SAT argument of perigee deg at time_t, SAT true anomaly deg calculated at time_t

Outputs : SAT Right Ascension(Alpha) and Declination(Delta) in deg at time_t

S10A 011. SAT Right Ascension(Alpha) in deg = 328.8938068030

S10B 011. SAT Declination(Delta) in deg = 0.0047349853

11. Finding Satellite Longitude & Latitude in deg at time_t; (ie Sub-Sat point log & lat on earth surface).

Inputs : SAT right ascension ascending node deg at time_t, GST in 0-360 deg over Greenwich at time_t

Outputs : Satellite (Sub-Sat point) longitude 0 to 360 deg at time_t.

S11A 011. Satellite longitude 0 to 360 deg at time_t = 328.89 ie deg = 328, min = 53, sec = 37.70

Inputs : argument of_perigee rad at_time_t, inclination rad at time_t, true anomaly rad calculated at time_t.

Outputs : Satellite (Sub-Sat point) latitude +ve or -ve in 0 to 90 deg at time_t.

S11B 011. Satellite latitude +ve or -ve in 0 to 90 deg at time_t = 0.00 ie deg = 0, min = 0, sec = 17.05

12. Finding Satellite height in km from EC to Sat and from Earth surface to Sat at time_t.

(a) Satellite height in km from EC to Sat; (ie Sat orbit radius EC to Sat in km at time_t).

Note - This is SAME as r sat pos vector magnitude EC to Sat in frame IJK calculated above in TRANSFORN_1 .

Inputs : SAT true anomaly at time_t, semi_major_axis_km, inclination at time_t .

Outputs : Sub-Sat point longitude 0 to 360 deg at time_t.

S12A 011. Satellite orbital radious EC to SAT in km using SAT true anomaly at time_t = 42157.03

(b) Satellite height in km from earth surface.

Inputs : Sub-Sat point latitude +ve or -ve in 0 to 90 deg at time_t, earth_equator_radious_km .

Outputs : Sat height in km from earth surface.

S12B 011. Satellite height in km from earth surface at time_t = 35778.89

13. Finding Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface at time_t .

Inputs : Sub-Sat point lat & log, ES lat & log .

Outputs : Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface

S13 011. Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface = 11907.14680

14. Finding Local sidereal time(LST) and Local mean time(LMT) over Sub-Sat point Longitude on earth .

(a) Local sidereal time(LST) in 0 to 360 deg over Sub-Sat point Longitude on earth .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, satellite log in 0 to 360 deg at time_t .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14A 011. Local sidereal time(LST) over Sub-Sat point Longitude at time_t = 223.81

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Sub-Sat point Longitude on earth .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Sat longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14B 011. Local sidereal time(LST) in 0 to 360_deg over Sub-Sat point Longitude at time_t = 223.81

S14C 011. LST over Sub-Sat Log, with date adj to CD expressed in JD = 2456804.12, ie YY = 2014, MM = 5, DD = 26, hr = 14, min = 55, sec = 15.56

S14D 011. LMT over Sub-Sat Log, with date adj to CD expressed in JD = 2456803.45, ie YY = 2014, MM = 5, DD = 25, hr = 22, min = 41, sec = 11.11

15. Finding Local sidereal time(LST) and Local mean time(LMT) Over Earth stn (ES) or Earth point(EP) Longitude .

(a) Local sidereal time(LST) in 0 to 360 deg over Earth stn(ES) Longitude .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn(ES) longitude at time_t.

S15A 011. Local sidereal time(LST) over Earth stn(ES) Longitude at time_t = 332.33

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Earth stn(ES) Longitude .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn (ES) longitude at time_t.

S15B 011. Local sidereal time(LST) in 0 to 360_deg over Earth stn (ES) Longitude at time_t = 332.33

S14C 011. LST over ES Log, with date adj to CD expressed in JD = 2456804.42, ie YY = 2014, MM = 5, DD = 26, hr = 22, min = 9, sec = 20.07

S15D 011. LMT over ES Log, with date adj to CD expressed in JD = 2456803.75, ie YY = 2014, MM = 5, DD = 26, hr = 5, min = 55, sec = 15.62

16. Earth Stn (ES) Position Vector from Earth Center(EC) to Earth Stn(ES) : Finding Range Vector(RI, RJ, RK, R) Components in IJK frame

Note - Transform_2 : ES position cord(lat, log, hgt) To EC to ES position Vector(RI, RJ, RK, R) in frame IJK .

Inputs : ES latitude positive_negative 0 to 90 deg, ES longitude in 0 to 360_deg,

ES height in meter (is earth surface + tower hgt), LST in 0 to 360 deg at ES log at time_t .

Outputs : ES Position Vector(RI, RJ, RK, R) Components EC to ES in km in IJK frame .

S16A 011. RI_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 5187.4709555096

S16B 011. RJ_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = -2719.6434583296

S16C 011. RK_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 2517.6372173288

S16D 011. R_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 6375.3284317570

17. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvI, rvJ, rvK, rv) Components in km in IJK frame

Note - Transform_3 SAT Pos Vct(rI rJ rK) and ES Pos Vct(RI RJ RK) To SAT Pos Vct(rvI, rvJ, rvK, rv)

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK ,

ES Position Vector(RI RJ RK) EC to ES in km in IJK frame.

Outputs : SAT Position Range Vector(rvI, rvJ, rvK, rv) Components ES to Sat in km in IJK frame

S17A 011. rv_I range vector component ES to SAT km frame IJK = 30907.8513575778

S17B 011. rv_J range vector component ES to SAT km frame IJK = -19059.7687721703

S17C 011. rv_K range vector component ES to SAT km frame IJK = -2514.1533148038

S17D 011. rv range vector component ES to SAT km frame IJK = 36399.0525712011

18. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvS, rvE, rvZ, rv) Components in km in SEZ frame

Note - Transform_4 SAT Pos Vct(rvI, rvJ, rvK, rv) in IJK frame To SAT Pos Vct(rvS, rvE, rvZ, rv) in SEZ frame

Inputs : ES latitude positive_negative 0 to 90_deg, LST in 0 to 360 deg at ES longitude at time_t

SAT PositionRange Vector(rvI, rvJ, rvK, rv) ES to Sat in km in IJK frame

Outputs : SAT Position Range(rvS, rvE, rvZ, rv) Components ES to Sat in km in SEZ frame

S18A 011. rvS range_vector component ES to SAT km_frame SEZ = 16614.7553985861

S18B 011. rvE range_vector component ES to SAT km_frame SEZ = -2529.1545484668

S18C 011. rvZ range_vector component ES to SAT km_frame SEZ = 32286.9061446925

S18D 011. rv range_vector component ES to SAT km_frame SEZ = 36399.0525712011

19. Finding Elevation(EL) and Azimuth(AZ) angles of Satellite and Sun : Steps 1, 2, 3 AT UT TIME t

Rem: Sub-SAT point lat deg = 0.00, log deg = 328.89 YY = 2014, MM = 5, DD = 25, hr = 22, min = 41, sec = 11.11

ES or EP point lat deg = 23.26, log deg = 77.41 YY = 2014, MM = 5, DD = 26, hr = 5, min = 55, sec = 15.62

Note : Step 1 is for Satellite EL & AZ angles. Steps 2 & 3 are for Sun EL & AZ angles

Results verified from other sources; Ref URLs

Geoscience Australia **http://www.ga.gov.au/geodesy/astro/smpos.jsp#intzone** ,

NOAA Research **http://www.esrl.noaa.gov/gmd/grad/solcalc/** ,

Xavier Jubier, Member IAU **http://xjubier.free.fr/en/site_pages/astronomy/ephemerides.html**

Elevation(EL) & Azimuth(AZ) angle of SAT at Earth Observation point EP : Step 1.

Inputs : Range vector component ES to SAT rv_S, rv_E, rv_Z, in frame_SEZ,

EP and Sub_sat point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SAT at EP

S19A 011. Elevation angle deg of Satellte at Earth point EP at time_t = 62.50188 ie deg = 62, min = 30, sec = 6.78

S19B 011. Azimuth angle deg of Satellte at Earth point EP at time_t = 188.65531 ie deg = 188, min = 39, sec = 19.13

Elevation(EL) & Azimuth(AZ) angle of SUN at Sub_Satellite point on earth surface : Step 2.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of Sun at Sub_Sat

S19C 011. Elevation angle deg of SUN at Sub_Sat point at time_t = -61.9436264693

S19D 011. Azimuth angle deg of SUN at Sub_Sat point at time_t = 319.8944977041

Elevation(EL) & Azimuth(AZ) angle of SUN at Satellite height : Step 3.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SUN at SAT

S19E 011. Elevation angle deg of Sun at Satellite height at time_t = -61.94999

S19F 011. Azimuth angle deg of Sun at Satellite height at time_t = 319.89450

20. Finding Satellite Velocity meter per sec in orbit .

Note : Results computed using 2 different formulations, each require different inputs.

(a) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK.

Outputs : SAT Velocity magnitude and component Xw Yw in frame PQW in meter per sec

S20A 011. Satellite Velocity magnitude meter per sec at UT time = 3075.2344215913

(b) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, SAT orbit eccentricity_at_time_t,

SAT eccentric anomaly deg calculated at time_t.

Outputs : Satellite Velocity components Xw Yw in frame PQW in meter per sec

S20B 011. Satellite Velocity components Xw in frame PQW in meter per sec = 286.9628865990

S20C 011. Satellite Velocity components Yw in frame PQW in meter per sec = 3061.8162991033

21. Finding Satellite(SAT) Velocity Vector (vX, vY, vZ) in meter per sec in orbit in frame XYZ.

Note - Transform_5 SAT Vel Vct(Xw, Yw) in frame PQW To SAT Vel Vct(vX, vY, vZ) in frame XYZ

Inputs : SAT velocity vectors(Xw, Yw), SAT Right Ascension Alpha, SAT Argument of perigee,

SAT orbit inclination at_time_t, SAT eccentric_anomaly_deg_calculated_at_time_t.

Outputs : earth velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ

S21A 011. vX Sat Velocity vector component in meter per sec = 1588.6953038064

S21B 011. vY Sat Velocity vector component in meter per sec = 2633.0807004007

S21C 011. vZ Sat Velocity vector component in meter per sec = -0.0676820819

S21D 011. vR Sat Velocity magnitude meter in meter per sec = 3075.2344215913

22. Finding Satellite(SAT) Pitch and Roll angles

Inputs : Earth equator radious km, ES lat, ES log, Sub_Sat point lat, Sub_Sat point log,

Sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK,

Outputs : SAT Pitch and Roll angles

S22A 011. pitch_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = -7.2287185764

S22B 011. roll_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = 3.2458714002

23. Finding Satellite State Vectors - Position [X, Y, Z] in km and velocity [Vx, Vy, Vz] in meter per sec at time_t .

Note - same as values of rI rJ rK r for pos and vX vY vZ vR for vel

(a) Satellite State Position Vector [X, Y, Z] in km at time_t

Inputs : position vector(rI, rJ, rK, r) in frame IJK values assiged to state position vector

Outputs : State Position Vector(X, Y, Z, R) in km, frame XYZ

S23A 011. State vector position X km at time_t = 36095.3223130873

S23B 011. State vector position Y km at time_t = -21779.4122305000

S23C 011. State vector position Z km at time_t = 3.4839025250

S23D 011. State vector position R km at time_t = 42157.0290951495

(b) Satellite State Velocity Vector [Vx, Vy, Vz] in meter per sec at time input UT.

Inputs : velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ values assiged to state velocity vector

Outputs : state velocity vector(Vx, Vy, Vz, V) meter per sec, frame XYZ

S23E 011. State vector velocity Vx meter per sec at time_t = 1588.6953038064

S23F 011. State vector velocity Vy meter per sec at time_t = 2633.0807004007

S23G 011. State vector velocity Vz meter per sec at time_t = -0.0676820819

S23H 011. State vector velocity V meter per sec at time_t = 3075.2344215913

24. Satellite Direction ie right ascension alpha deg and declination delta deg using sat position vector .

Note - results same as that using angles incl, RA, Aug of peri, true anomaly

Inputs : SAT State Vectors Position(X, Y, Z, R) in km , in frame XYZ

Outputs : SAT right ascension alpha deg and declination delta deg

S24A 011. Satellite direction right_asc alpha deg at time_t = 328.8938068030

S24B 011. Satellite direction_declination_delta_deg_at_time_t = 0.0047349853

25. Satellite Angular momentum km sqr per sec : finding Hx Hy Hz H from state vector pos and vel .

Inputs : SAT State Vectors Position(X, Y, Z, R) in km and Velocity (vX, vY, vZ, vR) meter per sec, in frame XYZ

Outputs : SAT angular momentum (Hx Hy Hz H) componts in km sqr per sec

S25A 011. Satellite angular momentum Hx in km sqr per sec at time_t = -7.6993205387

S25B 011. Satellite angular momentum Hy in km sqr per sec at time_t = 7.9778661408

S25C 011. Satellite angular momentum Hz in km sqr per sec at time_t = 129642.7464875925

S25D 011. Satellite angular momentum H in km sqr per sec at time_t = 129642.7469616872

26. Satellite Orbit normal Vector : finding Wx Wy Wz W Delta Alpha from r_sat_pos frame IJK, i, RA

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK , inclination_deg_at_time_t, right_ascension_ascending_node_deg_at_time_t

Outputs : SAT orbit normal vector (Wx, Wy, Wz, W) in km , RA , i

S26A 011. Satellite Orbit normal_W in km = 42157.0290951495

S26B 011. Satellite Orbit normal_Wx in km = -2.5036532129

S26C 011. Satellite Orbit normal_Wy in km = 2.5942302435

S26D 011. Satellite Orbit normal_Wz in km = 42157.0289409842

S26E 011. Satellite Orbit normal_Delta_W in deg = 89.9951000000

S26F 011. Satellite Orbit interpreted inclination i = 0.0049000000

S26G 011. Satellite Orbit normal_Alpha_W in deg = -46.0179000000

S26H 011. Satellite Orbit interpreted RA of asc node = 223.9821000000

Transform Satellite State Vectors to Keplerian elements.

27. Finding Satellite position Keplerian elements computed using State Vector, at time input UT.

Inputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

Outputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee,
mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

S27A 011. Keplerian elements year = 2014, days_decimal_of_year = 145.03167, revolution no = 140, node = 1 ie ascending

S27B 011. inclination_deg = 0.0049000000

S27C 011. right ascension ascending node deg = 223.9821000000

S27D 011. eccentricity = 0.0002051000

S27E 011. argument of perigee_deg = 110.2671000002

S27F 011. mean anomaly deg = 354.6467999998

S27G 011. mean_motion rev per day = 1.0027226500

S27H 011. mean angular velocity rev_per_day = 1.0026854765

S27I 011. mean motion rev per day using SMA considering oblateness = 1.0027598249

Transform Satellite Keplerian elements to State Vectors .

28. Finding Satellite position State Vectors, computed using Keplerian elements at time input UT
(computed again to validate model equations, Keplerian elements to State Vectors & back)

Inputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee,
mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

Outputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

S28A 011. State vectors year = 2014, days_decimal_of_year = 145.03167, revolution no = 140, node = 1 ie decending

S28B 011. state vector position X km = 36095.3223130876, state vector velocity Vx meter per sec = 1588.6953038064

S28C 011. state vector position Y km = -21779.4122304995, state vector velocity Vy meter per sec = 2633.0807004007

S28D 011. state vector position Z km = 3.4839025250, state vector velocity Vz meter per sec = -0.0676820819

S28E 011. state vector position R km = 42157.0290951495, state vector velocity V meter per sec = 3075.2344215913

Move on to next Satellite.

Next Section - 6.6 Computing Orbital & Positional parameters for Satellite MOON

Satellite MOON : Computing Orbital & Positional parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins.

(f) MOON 'Two-Line Elements'(TLE) downloaded on Jun 14, 2014, 16:14 hrs IST, Natural Satellite

```
1 00000U 00000A   14143.16621081  .00000000  00000-0  00000-0 0  3574
2 00000  18.7965 352.4777 0512000 316.1136  40.2074 00.036600996 0006
```

From this TLE, the data relevant for the purpose are manually interpreted & extracted :

Satellite number 00000, MOON ,

EPOCH_year = 2014 EPOCH_days_decimal_of_year = 142.1662108168

EPOCH_inclination_deg = 18.7965000000 EPOCH_right_asc_acnd_node_deg = 352.4777000000

EPOCH_eccentricity = 0.0512000000 EPOCH_argument_of_perigee_deg = 316.1136000000

EPOCH_mean_anomaly_deg = 40.2074000000 EPOCH_mean_motion_rev_per_day = 0.0366009960

EPOCH_revolution = 0 EPOCH_node_condition = 1

Earth_stn_latitude_deg = 23.25993 Earth stn longitude_deg = 77.41261 Earth surface height_meter = 494.70000

Earth stn tower_height_meter = 15.00000 Earth stn_height_meter = 509.70000 Earth stn min EL look_angle_deg = -5.00000

Note : EPOCH Corresponds to UT year = 2014, month = 5, day = 23, hr = 3, min = 59, sec = 20.61457 which is Greenwich meam time ie GMT

Converted to Local Meam Time at Earth Stn Longitude, as regular Calender date : year = 2014, month = 5, day = 23, hr = 9, min = 8, sec = 59.64

At this instant Sun Position as seen from Earth Stn Longitude : Sun angles EL deg = 51.13, AZ deg = 85.66,

Sun Surface distance km = 4326.36, Radial km = 151461044.87, Sun Rise D:23, H:05, M:18, S:26 Sun Set D:23, H:18, M:37, S:54

Move to Compute Satellie Orbital parameters corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins, and Earth Stn location.

01. Input EPOCH_year and EPOCH_days_decimal_of_year, Converted into UT YY MM DD hh min sec & Julian day.

S01 011. Input UT year = 2014, month = 5, day = 24, hr = 3, min = 59, sec = 20.61457, and julian_day = 2456800.6662108167

02. Finding Satellite orbit Semi major axis in km, Ignoring and also Considering earth oblatenes .

(a) Semi major axis (SMA) km at time t Ignoring earth oblatenes .

Inputs : SAT mean_motion rev per day at time t, GM_EARTH .

Outputs : SAT Orbit semi major axis km in km and constant_A, constant_k1 .

S02A 011. Satellite orbit Semi major axis in km at time t, Ignoring earth oblatenes = 383183.29902,

(b) Semi major axis (SMA) in km at time_t Considering earth oblatenes

Inputs : SAT mean_motion rev per day at time_t, GM_EARTH , inclination deg at time_t, eccentricity at time_t, constant_k2

Outputs : SAT Orbit semi major axis km in km at time_t and constant_A, constant_k1, constant_k3 .

S02B 011. Satellite orbit Semi major axis km at time t, Considering earth oblatenes = 383183.39622,

03. Finding Satellite Mean motion in rev per day, Ignoring and also Considering earth oblatenes .

(a) Nominal mean motion rev per day at time_t Ignoring earth oblateness .

Inputs : SAT Orbit semi major axis in km ignoring oblateness at time_t, constant_k1 .

Outputs : SAT nominal mean motion in rev_per_day at time_t, ignoring earth oblateness

S03A 011. Satellite Nominal Mean motion in rev_per_day at time_t using SMA Ignoring earth oblateness = 0.03660,

(b) Mean motion rev per day at time_t Considering earth oblatenes

Inputs : SAT nominal mean motion rad per day at time_t Ignoring_oblateness, constant_k2, constant_k3,
SAT orbit semi major axis in km considering oblateness at time_t.

Outputs : SAT mean motion rev per day at time_t, considering earth oblatenes .

S03B 011. Satellite Mean motion in rev_per_day at time t using SMA Considering earth oblatenes = 0.03660,

Note - This calculted value is slightly less than the mean motion rev_per_day as EPH input from NORAD TLE

04. Finding Satellite Orbit Time Period in minute at time_t Considering earth oblatenes .

Inputs : SAT orbit semi major axis in km considering oblateness at time_t, GM_EARTH .

Outputs : SAT orbit time period in minute at time_t considering earth oblatenes .

S04 011. Satellite orbit Time Period in minute at time_t using SMA Considering earth oblatenes = 39343.20661,

05. Finding Satellite Rate of change of Right Ascension and Argument of Perigee in deg per_day at time_t.

(a) Rate of change of Right Ascension in deg per day at time_t .

Inputs : SAT mean motion rev per day at time_t considering earth oblatenes, constant_k2, SAT orbit eccentricity at time_t,
SAT semi major axis km considering oblateness at time_t, SAT orbit inclination deg at time_t .

Outputs : SAT rate of change of right ascension in deg per day at time_t and constant_k_deg_per_day

S05A 011. Satellite Rate of change of Right Ascension in deg per day at time_t = -0.00001,

(b) Rate of change of Argument of Perigee in deg per_day at time_t .

Inputs : SAT orbit constant_k_deg_per_day, SAT orbit inclination deg at time_t

SAT orbit semi major axis km considering oblateness at time_t

Outputs : SAT rate of change of argument of perigee in deg per day at time_t

S05B 011. Satellite Rate of change of Argument of Perigee in deg per day at time_t = 0.00001,

06. Finding Satellite Mean anomaly, Eccentric anomaly, True anomaly in deg at time_t considering earth oblateness.

Inputs : SAT mean anomaly rad at time_t, mean_motion_rad_per_day_at_time_t considering_oblateness, SAT orbit eccentricity_at_time_t

Outputs : SAT mean anomaly, eccentric anomaly, and true anomaly in deg at time_t onsidering earth oblateness.

S06A 011. Satellite Mean anomaly in deg at time_t = 40.20740, same as EPH mean anomaly

S06A 011. Satellite Eccentric anomaly in deg at time_t = 42.17705,

S06A 011. Satellite True anomaly in deg at time_t = 44.18593,

Note - 1. Here after, the Earth Oblateness is always considered for the computation of satellite orbit parameters, and not repeatedly mentioned.

Satellite to Earth, the Position Vectors coordinate and the Vector Coordinate Transforms are in PQW, IJK, SEZ frames .

- Perifocal Coordinate System (PQW) is Earth Centered Inertial coordinate frame defined in terms of Kepler Orbital Elements.
- Geocentric Coordinate System(IJK) is Earth Centered Inertial (ECI) frame, a Conventional Inertial System (CIS).
- Topocentric Horizon Coordinate System(SEZ), is Non-Inertial coordinate frame, known as Earth-Centered Earth-Fixed Coordinates (ECEF).

Each of these coordinate system were explained in detail before and therefore not repeated any more.

07. Finding Satellite position vector[rp, rq] from Earth center(EC) to Sat in PQW frame, perifocal coordinate system.

Inputs : SAT orbit semi-major axis (SMA), SAT orbit eccentricity, SAT eccentric anomaly, SATtrue anomaly at time_t

Outputs : Vector(r, rp rq) in PQW frame

S07A 011. r Satellite pos vector magnitude EC to Sat km in PQW frame perifocal cord at time_t = 368644.28111

S07B 011. rp Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = 264348.1020492621

S07C 011. rq Satellite pos vector component EC to Sat km in PQW frame perifocal cord at time_t = 256941.0184081715

08. Satellite Position Vector Earth Ceter(EC) to Satellite(SAT) - finding Range Vector(rI rJ rK r) Components in km in frame IJK

Note - Transform_1 : EC to SAT Vector(rp, rq) in frame PQW To EC to SAT Vector(rI rJ rK r) in frame IJK.

Inputs : Vector(rp, rq) EC to Sat in km in frame PQW, SAT right ascension of ascending node at time_t,

SAT argument of perigee rad at time_t, SAT orbit inclination rad at time_t .

Outputs : Vector(rI, rJ, rK, r) EC to SAT in km in frame IJK

S08A 011. rI Satellite pos vector component EC to Sat km frame IJK at at time_t = 365705.5648844948

S08B 011. rJ Satellite pos vector component EC to Sat km frame IJK at at time_t = -46450.6213911481

S08C 011. rK Satellite pos vector component EC to Sat km frame IJK at at time_t = 620.9529484744

S08D 011. r Satellite pos vector magnitude EC to Sat km frame IJK at at time_t = 368644.2811134813

Note - r Satellite pos vector magnitude EC to Sat km in PQW frame is same as that computed above in PQW frame.

09. Finding GST Greenwich sidereal time and GHA Greenwich hour angle in 0 to 360 deg, at input at time_t .

Note - for GST, the year 1900 JAN day_1 hr 1200 is ref for time difference in terms of julian_century,

for GHA, the year 2000_JAN_day_1 hr_1200 is ref for time difference in terms of julian days.

Inputs : Time t UT year = 2014, month = 5, day = 23, hour = 3, minute = 59, seconds = 20.61457

Outputs : GST & GHA in 0-360 deg over Greenwich.

S09A 011. GST Greenwich sidereal time in 0-360 deg, over Greenwich = 300.52971, hr = 20, min = 2, sec = 7.13045

S09B 011. GHA Greenwich hour angle in 0 to 360 deg, over Greenwich = 300.53198, deg = 300, min = 31, sec = 55.13594

10. Satellite(SAT) Orbit point direction : Finding Right Ascension(Alpha) deg and Declination(Delta) deg using angles

Inputs : SAT orbit inclination deg at_time_t, EPH right ascension ascending node deg,

SAT argument of perigee deg at time_t, SAT true anomaly deg calculated at time_t

Outputs : SAT Right Ascension(Alpha) and Declination(Delta) in deg at time_t

S10A 011. SAT Right Ascension(Alpha) in deg = 352.7612555840

S10B 011. SAT Declination(Delta) in deg = 0.0965103811

11. Finding Satellite Longitude & Latitude in deg at time_t; (ie Sub-Sat point log & lat on earth surface).

Inputs : SAT right ascension ascending node deg at time_t, GST in 0-360 deg over Greenwich at time_t

Outputs : Satellite (Sub-Sat point) longitude 0 to 360 deg at time_t.

S11A 011. Satellite longitude 0 to 360 deg at time_t = 352.76 ie deg = 352, min = 45, sec = 40.52

Inputs : argument of_perigee rad at_time_t, inclination rad at time_t, true anomaly rad calculated at time_t.

Outputs : Satellite (Sub-Sat point) latitude +ve or -ve in 0 to 90 deg at time_t.

S11B 011. Satellite latitude +ve or -ve in 0 to 90 deg at time_t = 0.10 ie deg = 0, min = 5, sec = 47.44

12. Finding Satellite height in km from EC to Sat and from Earth surface to Sat at time_t.

(a) Satellite height in km from EC to Sat; (ie Sat orbit radius EC to Sat in km at time_t).

Note - This is SAME as r sat pos vector magnitude EC to Sat in frame IJK calculated above in TRANSFORN_1 .

Inputs : SAT true anomaly at time_t, semi_major_axis_km, inclination at time_t .

Outputs : Sub-Sat point longitude 0 to 360 deg at time_t.

S12A 011. Satellite orbital radious EC to SAT in km using SAT true anomaly at time_t = 368644.28

(b) Satellite height in km from earth surface.

Inputs : Sub-Sat point latitude +ve or -ve in 0 to 90 deg at time_t, earth_equator_radious_km .

Outputs : Sat height in km from earth surface.

S12B 011. Satellite height in km from earth surface at time_t = 362266.14

13. Finding Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface at time_t .

Inputs : Sub-Sat point lat & log, ES lat & log .

Outputs : Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface

S13 011. Distance of Sub-Sat point To Earth Stn(ES) in km over Earth surface = 9467.59402

14. Finding Local sidereal time(LST) and Local mean time(LMT) over Sub-Sat point Longitude on earth .

(a) Local sidereal time(LST) in 0 to 360 deg over Sub-Sat point Longitude on earth .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, satellite log in 0 to 360 deg at time_t .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14A 011. Local sidereal time(LST) over Sub-Sat point Longitude at time_t = 293.29

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Sub-Sat point Longitude on earth .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Sat longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at SAT longitude at time_t.

S14B 011. Local sidereal time(LST) in 0 to 360_deg over Sub-Sat point Longitude at time_t = 293.29

S14C 011. LST over Sub-Sat Log, with date adj to CD expressed in JD = 2456801.31, ie YY = 2014, MM = 5, DD = 23, hr = 19, min = 33, sec = 9.92

S14D 011. LMT over Sub-Sat Log, with date adj to CD expressed in JD = 2456800.65, ie YY = 2014, MM = 5, DD = 23, hr = 3, min = 30, sec = 23.32

15. Finding Local sidereal time(LST) and Local mean time(LMT) Over Earth stn (ES) or Earth point(EP) Longitude .

(a) Local sidereal time(LST) in 0 to 360 deg over Earth stn(ES) Longitude .

Inputs : GST sidereal_time in 0 to 360 deg at Greenwich at time_t, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn(ES) longitude at time_t.

S15A 011. Local sidereal time(LST) over Earth stn(ES) Longitude at time_t = 17.94

(b) Local sidereal time(LST) and local Mean time(LMT) adjusted to calendar date(CD) over Earth stn(ES) Longitude .

Note - The LST and LMT in hr min sec with YY MM DD adjusted to calendar date (CD) of longitude at time_t .

Here LST in deg is re-calculated alterately in terms of Julian Day (JD) that account for calendar date (CD) of longitude.

Inputs : GMT_JD, Earth stn(ES) longitude_in_0_to_360_deg .

Outputs : LST local sidereal time in 0 to_360 deg at Earth stn (ES) longitude at time_t.

S15B 011. Local sidereal time(LST) in 0 to 360_deg over Earth stn (ES) Longitude at time_t = 17.94

S14C 011. LST over ES Log, with date adj to CD expressed in JD = 2456801.55, ie YY = 2014, MM = 5, DD = 24, hr = 1, min = 11, sec = 46.25

S15D 011. LMT over ES Log, with date adj to CD expressed in JD = 2456800.88, ie YY = 2014, MM = 5, DD = 23, hr = 9, min = 8, sec = 59.64

16. Earth Stn (ES) Position Vector from Earth Center(EC) to Earth Stn(ES) : Finding Range Vector(RI, RJ, RK, R) Components in IJK frame

Note - Transform_2 : ES position cord(lat, log, hgt) To EC to ES position Vector(RI, RJ, RK, R) in frame IJK .

Inputs : ES latitude positive_negative 0 to 90 deg, ES longitude in 0 to 360_deg,

ES height in meter (is earth surface + tower hgt), LST in 0 to 360 deg at ES log at time_t .

Outputs : ES Position Vector(RI, RJ, RK, R) Components EC to ES in km in IJK frame .

S16A 011. RI_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 5572.3086624356

S16B 011. RJ_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 1804.3535200274

S16C 011. RK_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 2517.6372173288

S16D 011. R_earth_stn_pos_vector_component_EC_to_ES_km_frame_IJK = 6375.3284317570

17. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvI, rvJ, rvK, rv) Components in km in IJK frame

Note - Transform_3 SAT Pos Vct(rI rJ rK) and ES Pos Vct(RI RJ RK) To SAT Pos Vct(rvI, rvJ, rvK, rv)

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK ,

ES Position Vector(RI RJ RK) EC to ES in km in IJK frame.

Outputs : SAT Position Range Vector(rvI, rvJ, rvK, rv) Components ES to Sat in km in IJK frame

S17A 011. rv_I range vector component ES to SAT km frame IJK = 360133.2562220591

S17B 011. rv_J range vector component ES to SAT km frame IJK = -48254.9749111755

S17C 011. rv_K range vector component ES to SAT km frame IJK = -1896.6842688544

S17D 011. rv range vector component ES to SAT km frame IJK = 363356.7148849698

18. Satellite(SAT) Position Range Vector from Earth Stn(ES) to SAT : Finding Range Vector(rvS, rvE, rvZ, rv) Components in km in SEZ frame

Note - Transform_4 SAT Pos Vct(rvI, rvJ, rvK, rv) in IJK frame To SAT Pos Vct(rvS, rvE, rvZ, rv) in SEZ frame

Inputs : ES latitude positive_negative 0 to 90_deg, LST in 0 to 360 deg at ES longitude at time_t

SAT PositionRange Vector(rvI, rvJ, rvK, rv) ES to Sat in km in IJK frame

Outputs : SAT Position Range(rvS, rvE, rvZ, rv) Components ES to Sat in km in SEZ frame

S18A 011. rvS range_vector component ES to SAT km_frame SEZ = 131173.4240060395

S18B 011. rvE range_vector component ES to SAT km_frame SEZ = -156850.6627498179

S18C 011. rvZ range_vector component ES to SAT km_frame SEZ = 300365.6183411674

S18D 011. rv range_vector component ES to SAT km_frame SEZ = 363356.7148849697

19. Finding Elevation(EL) and Azimuth(AZ) angles of Satellite and Sun : Steps 1, 2, 3 AT UT TIME t

Rem: Sub-SAT point lat deg = 0.10, log deg = 352.76 YY = 2014, MM = 5, DD = 23, hr = 3, min = 30, sec = 23.32

ES or EP point lat deg = 23.26, log deg = 77.41 YY = 2014, MM = 5, DD = 23, hr = 9, min = 8, sec = 59.64

Note : Step 1 is for Satellite EL & AZ angles. Steps 2 & 3 are for Sun EL & AZ angles

Results verified from other sources; Ref URLs

Geoscience Australia **http://www.ga.gov.au/geodesy/astro/smpos.jsp#intzone** ,

NOAA Research **http://www.esrl.noaa.gov/gmd/grad/solcalc/** ,

Xavier Jubier, Member IAU **http://xjubier.free.fr/en/site_pages/astronomy/ephemerides.html**

Elevation(EL) & Azimuth(AZ) angle of SAT at Earth Observation point EP : Step 1.

Inputs : Range vector component ES to SAT rv_S, rv_E, rv_Z, in frame_SEZ,

EP and Sub_sat point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SAT at EP

S19A 011. Elevation angle deg of Satellte at Earth point EP at time_t = 55.75523 ie deg = 55, min = 45, sec = 18.85

S19B 011. Azimuth angle deg of Satellte at Earth point EP at time_t = 230.09443 ie deg = 230, min = 5, sec = 39.95

Elevation(EL) & Azimuth(AZ) angle of SUN at Sub_Satellite point on earth surface : Step 2.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of Sun at Sub_Sat

S19C 011. Elevation angle deg of SUN at Sub_Sat point at time_t = -33.8802777238

S19D 011. Azimuth angle deg of SUN at Sub_Sat point at time_t = 64.9100330114

Elevation(EL) & Azimuth(AZ) angle of SUN at Satellite height : Step 3.

Inputs : Range vector component Sub_sat to Sun rv_S, rv_E, rv_Z, in frame_SEZ,

Sub_sat point and Sun_Sun point latitude & longitude

Outputs : Elevation(EL) & Azimuth(AZ) of SUN at SAT

S19E 011. Elevation angle deg of Sun at Satellite height at time_t = -33.99390

S19F 011. Azimuth angle deg of Sun at Satellite height at time_t = 64.91003

20. Finding Satellite Velocity meter per sec in orbit .

Note : Results computed using 2 different formulations, each require different inputs.

(a) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK.

Outputs : SAT Velocity magnitude and component Xw Yw in frame PQW in meter per sec

S20A 011. Satellite Velocity magnitude meter per sec at UT time = 1059.3802758296

(b) Inputs : SAT orbit semi-major axis SMA, GM_EARTH, SAT orbit eccentricity_at_time_t,

SAT eccentric anomaly deg calculated at time_t.

Outputs : Satellite Velocity components Xw Yw in frame PQW in meter per sec

S20B 011. Satellite Velocity components Xw in frame PQW in meter per sec = -711.8057186065

S20C 011. Satellite Velocity components Yw in frame PQW in meter per sec = 784.6140374578

21. Finding Satellite(SAT) Velocity Vector (vX, vY, vZ) in meter per sec in orbit in frame XYZ.

Note - Transform_5 SAT Vel Vct(Xw, Yw) in frame PQW To SAT Vel Vct(vX, vY, vZ) in frame XYZ

Inputs : SAT velocity vectors(Xw, Yw), SAT Right Ascension Alpha, SAT Argument of perigee,

SAT orbit inclination at_time_t, SAT eccentric_anomaly_deg_calculated_at_time_t.

Outputs : earth velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ

S21A 011. vX Sat Velocity vector component in meter per sec = 161.8765603889

S21B 011. vY Sat Velocity vector component in meter per sec = 989.7819390712

S21C 011. vZ Sat Velocity vector component in meter per sec = 341.1953415596

S21D 011. vR Sat Velocity magnitude meter in meter per sec = 1059.3802758296

22. Finding Satellite(SAT) Pitch and Roll angles

Inputs : Earth equator radious km, ES lat, ES log, Sub_Sat point lat, Sub_Sat point log,

Sat_orbit pos r_vector_EC_to_SAT_km_frame_IJK,

Outputs : SAT Pitch and Roll angles

S22A 011. pitch_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = -0.9076449658

S22B 011. roll_angle_deg_for_earth_stn_at_sat_lat_log_at_time_t = 0.3917892859

23. Finding Satellite State Vectors - Position [X, Y, Z] in km and velocity [Vx, Vy, Vz] in meter per sec at time_t .

Note - same as values of rI rJ rK r for pos and vX vY vZ vR for vel

(a) Satellite State Position Vector [X, Y, Z] in km at time_t

Inputs : position vector(rI, rJ, rK, r) in frame IJK values assiged to state position vector

Outputs : State Position Vector(X, Y, Z, R) in km, frame XYZ

S23A 011. State vector position X km at time_t = 365705.5648844948

S23B 011. State vector position Y km at time_t = -46450.6213911481

S23C 011. State vector position Z km at time_t = 620.9529484744

S23D 011. State vector position R km at time_t = 368644.2811134813

(b) Satellite State Velocity Vector [Vx, Vy, Vz] in meter per sec at time input UT.

Inputs : velocity vector(vX, vY, vZ, vR) meter per sec in frame XYZ values assiged to state velocity vector

Outputs : state velocity vector(Vx, Vy, Vz, V) meter per sec, frame XYZ

S23E 011. State vector velocity Vx meter per sec at time_t = 161.8765603889

S23F 011. State vector velocity Vy meter per sec at time_t = 989.7819390712

S23G 011. State vector velocity Vz meter per sec at time_t = 341.1953415596

S23H 011. State vector velocity V meter per sec at time_t = 1059.3802758296

24. Satellite Direction ie right ascension alpha deg and declination delta deg using sat position vector .

Note - results same as that using angles incl, RA, Aug of peri, true anomaly

Inputs : SAT State Vectors Position(X, Y, Z, R) in km , in frame XYZ

Outputs : SAT right ascension alpha deg and declination delta deg

S24A 011. Satellite direction right_asc alpha deg at time_t = 352.7612555840

S24B 011. Satellite direction_declination_delta_deg_at_time_t = 0.0965103811

25. Satellite Angular momentum km sqr per sec : finding Hx Hy Hz H from state vector pos and vel .

Inputs : SAT State Vectors Position(X, Y, Z, R) in km and Velocity (vX, vY, vZ, vR) meter per sec, in frame XYZ

Outputs : SAT angular momentum (Hx Hy Hz H) componts in km sqr per sec

S25A 011. Satellite angular momentum Hx in km sqr per sec at time_t = -16463.3436446211

S25B 011. Satellite angular momentum Hy in km sqr per sec at time_t = -124676.5173935477

S25C 011. Satellite angular momentum Hz in km sqr per sec at time_t = 369488.0299592165

S25D 011. Satellite angular momentum H in km sqr per sec at time_t = 390303.3178906982

26. Satellite Orbit normal Vector : finding Wx Wy Wz W Delta Alpha from r_sat_pos frame IJK, i, RA

Inputs : SAT Position Vector(rI rJ rK) EC to Sat in km in frame IJK , inclination_deg_at_time_t, right_ascension_ascending_node_deg_at_time_t

Outputs : SAT orbit normal vector (Wx, Wy, Wz, W) in km , RA , i

S26A 011. Satellite Orbit normal_W in km = 368644.2811134813

S26B 011. Satellite Orbit normal_Wx in km = -15549.7460677369

S26C 011. Satellite Orbit normal_Wy in km = -117757.8642545590

S26D 011. Satellite Orbit normal_Wz in km = 348984.0924757304

S26E 011. Satellite Orbit normal_Delta_W in deg = 71.2035000000

S26F 011. Satellite Orbit interpreted inclination i = 18.7965000000

S26G 011. Satellite Orbit normal_Alpha_W in deg = 82.4777000000

S26H 011. Satellite Orbit interpreted RA of asc node = 352.4777000000

Transform Satellite State Vectors to Keplerian elements.

27. Finding Satellite position Keplerian elements computed using State Vector, at time input UT.

Inputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

Outputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee, mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

S27A 011. Keplerian elements year = 2014, days_decimal_of_year = 142.16621, revolution no = 0, node = 1 ie ascending

S27B 011. inclination_deg = 18.7965000000

S27C 011. right ascension ascending node deg = 352.4777000000

S27D 011. eccentricity = 0.0512000000

S27E 011. argument of perigee_deg = 316.1136000000

S27F 011. mean anomaly deg = 40.2074000000

S27G 011. mean_motion rev per day = 0.0366009960

S27H 011. mean angular velocity rev_per_day = 0.0366009821

S27I 011. mean motion rev per day using SMA considering oblateness = 0.0366010099

Transform Satellite Keplerian elements to State Vectors .

28. Finding Satellite position State Vectors, computed using Keplerian elements at time input UT

(computed again to validate model equations, Keplerian elements to State Vectors & back)

Inputs : Keplerian elements : year, days decimal of year, revolution, node, inclination, right ascension, eccentricity, argument of perigee, mean anomaly, mean motion rev per day, mean angular velocity rev per day, mean motion rev per_day from SMA considering oblateness

Outputs : State vector year, days decimal of year, revolution, node, State Position Vector [X, Y, Z], State Velocity Vector [Vx, Vy, Vz]

S28A 011. State vectors year = 2014, days_decimal_of_year = 142.16621, revolution no = 0, node = 1 ie decending

S28B 011. state vector position X km = 365705.5648844945, state vector velocity Vx meter per sec = 161.8765603889

S28C 011. state vector position Y km = -46450.6213911481, state vector velocity Vy meter per sec = 989.7819390712

S28D 011. state vector position Z km = 620.9529484743, state vector velocity Vz meter per sec = 341.1953415596

S28E 011. state vector position R km = 368644.2811134810, state vector velocity V meter per sec = 1059.3802758296

End of Computing Orbital & Positional Parameters of Six Satellites.

A Summary of Computing Orbital & Positional Parameters are presented next.

Next Section - 6.7 Concluding Orbital & Positional parameters of the six Satellites

Summary of Orbital & Positional parameters of the six Satellites computed above.

Summary of Computed Orbital & Positional parameters of six Earth Orbiting Satellites in previous Sections (6.1 to 6.6) :

(a) Computed the Orbital & Positional parameters for four LEO, one GEO and one natural satellite around earth.
The Input for each satellite, is NASA/NORAD 'Two-Line Elements'(TLE) Bulletin and the Earth Stn Location.
The Output is Satellite around earth the Orbital & Positional parameters at Epoch, considering earth oblateness .

(b) The Orbital & Positional parameters computed were : Orbit Semi major axis in km, Sat Mean motion in rev per day,
Sat Time Period in minute, Sat Rate of change of Right Ascension & Argument of Perigee in deg per_day,
Sat Mean, Eccentric & True anomalies in deg, Sat Position, Range & Velocity Vectors from earth center & earth station
in PQW, IJK & SEZ frams, Sat Altitude (Alt) & Distance in km over Earth surface, SAt Elevation(EL) & Azimuth(AZ)
angles in deg at Earth station, Sun Elevation(EL) & Azimuth(AZ) at Sub-Sat point on Earth surface,
Local sidereal time(LST) & Local mean time(LMT) over Sub-Sat point & Earth station Longitude,
Keplerian elements & State Vectors, and more.

(c) The parameters are large in numbers. Few parameters are recalculated from different input considerations.
Readers may examine the parameter values computed for different satellites and compare the variations,
that would answer to their many specific questions.

End of Computing Six Satellites Orbital & Positional parameters at Epoch corresponding to input NASA/NORAD 'Two-Line Elements'(TLE) Bulletins.

Next Section - 7 Satellite Pass for Earth Stn, Prediction of Ground Trace & Look Angles at UT and Local Time.

REFERENCES : TEXT BOOKS & INTERNET WEB LINKS.

Books

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5. Howard Curtis, 'Orbital Mechanics: For Engineering Students', Aerospace Engineering, Butterworth-Heinemann, , pp 1 - 704, 2004.
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Internet Weblinks

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5. Christopher D. Hall, 'Orbits', Satellite Attitude Dynamics, Appendix A , accessed on January 12, 2003,
   URL http://www.aoe.vt.edu/~cdhall/courses/aoe4140/a_orbits.pdf
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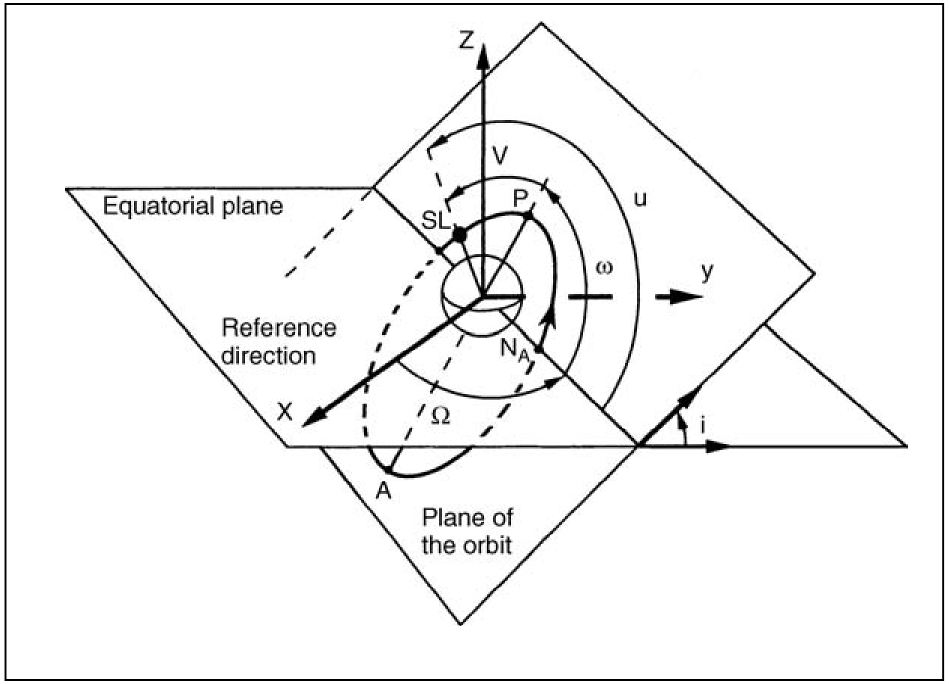
   URL http://www.satcom.co.uk/article.asp?article=29&section=2
8. RPC Telecommunications, 'Satellite Orbits', Satellite School / Satellite Orbits, Submitted on November 11, 2002,
   URL http://www.satcom.co.uk/article.asp?article=11
9. 'Section 4: The Basics of Satellite Orbits', accessed on May 22, 2015, URL http://www.amacad.org/publications/Section_4.pdf

ANNEXURE : A Collection of few OM-MSS related Diagrams / Help.



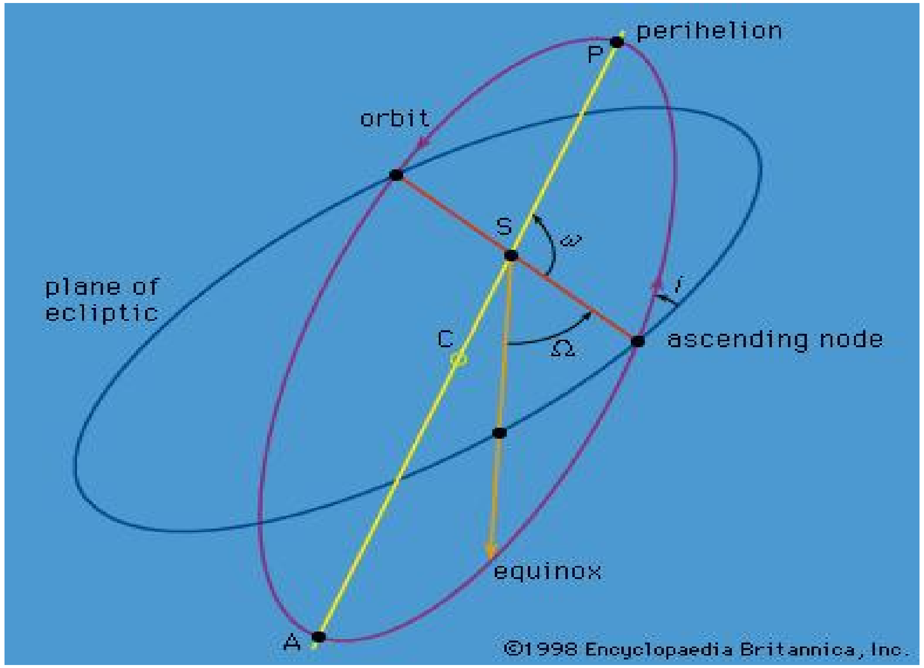


Fig- 4 & 5 Positioning of Orbit in Space

Orbit Position in Space at Epoch is defined by the Values of Kepler Orbit elements : (definations apply to both planets & Satellits)

1. Inclination 'i' of the orbit of a planet, is angle between the plane of planet's orbit and the plane containing Earth's orbital path (ecliptic).
2. Right ascension 'Ω' of the ascending node is the angle taken positively from 0 to 360 deg in the forward direction, between the reference direction and the ascending node of the orbit (the intersection of the orbit with the plane of the equator crossing this plane from south to north).
3. Argument of Perigee 'ω', specify angle between orbit's perigee and orbit's ascending node, measured in orbital plane and direction of motion.
4. Eccentricity '*e*' of an orbit shows how much the shape of an object's orbit is different from a circle;
5. Mean Anomaly '*v*' relates the position and time for a body moving in a Kepler orbit. The mean anomaly of an orbiting body is the angle through which the body would have traveled about the center of the orbit's auxiliary circle. 'M' grows linearly with time.

A knowledge of above five parameters completely defines the trajectory of an object or satellite in space. However, the Nodal angular elongation '*u*' can also be used to define the position of the satellite in its orbit. This is the angle taken positively in the direction of motion from 0 to 360 deg between the direction of the ascending node and the direction of the satellite **(*u* = ω + *v*).**

Source Book by Gerard Maral, Michel Bousquet, 'Satellite Communications Systems', Fifth Edition, John Wiley & Sons, chap. 2, Pg 29, 2002. &
http://www.britannica.com/EBchecked/topic/101285/celestial-mechanics/images-videos/2285/orbital-element-keplers-laws-of-planetary-motion

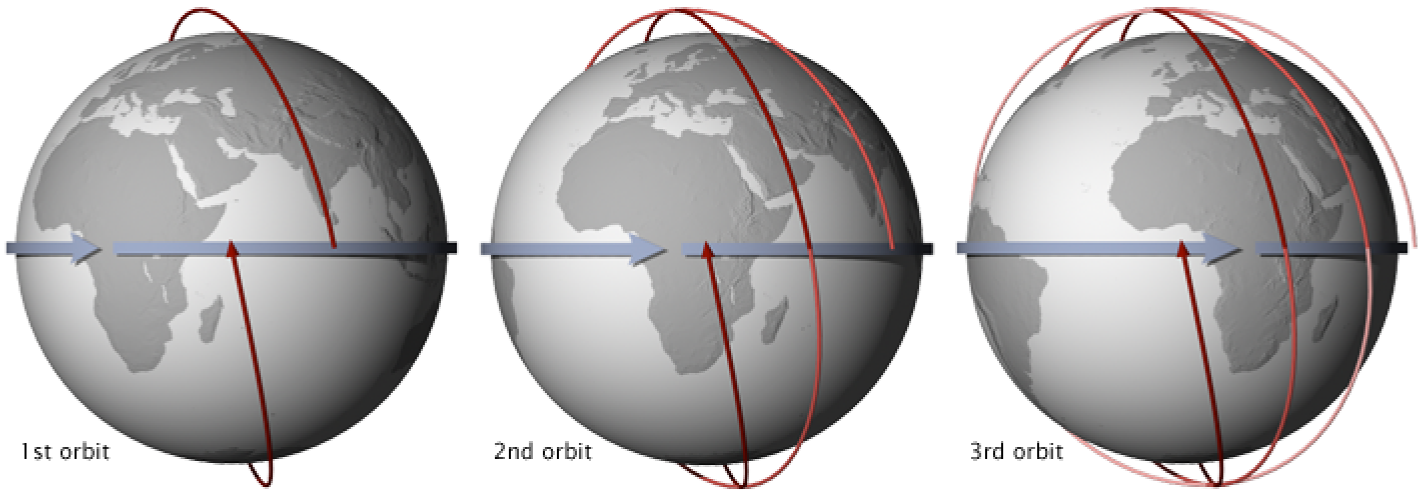


Fig-5. Three Successive Satellite Passes/Orbits Around Earth

The satellites move around the Earth, taking about 95 minutes to complete an orbit.

A satellite at 300 (km) altitude has orbital period about 90 (min). In 90 (min), the earth at equator rotates about 2500 (km). Thus, the satellite after one time period, passes over equator a point/place 2500 (km) west of the point/place it passed over in its previous orbit. To a person on the earth directly under the orbit, a satellite appears above horizon on one side of sky, crosses the sky, and disappears beyond the opposite horizon in about 10 (min). It reappears after 80 (min), but not over same spot, since the earth has rotated during that time.

Source Ref. http://earthobservatory.nasa.gov/Features/OrbitsCatalog/