1. Candidate VALUEs FOR SANA REGISTRY Pertaining to TIME SYSTEMs, reference frames, orbit elements and covariance-RELATED KEYWORDS  
     
   (Normative)

The values in this document represent the set of acceptable values for the TIME\_SYSTEM, REF\_FRAME, OEB\_FRAME, MAN\_REF\_FRAME, ORB\_REF\_FRAME, COV\_REF\_FRAME and STM\_REF\_FRAME keywords in the OPM, OMM, OEM and OCM. (For details and description of these time systems, see reference [L1]) If exchange partners wish to use different settings, the settings should be documented in the ICD.

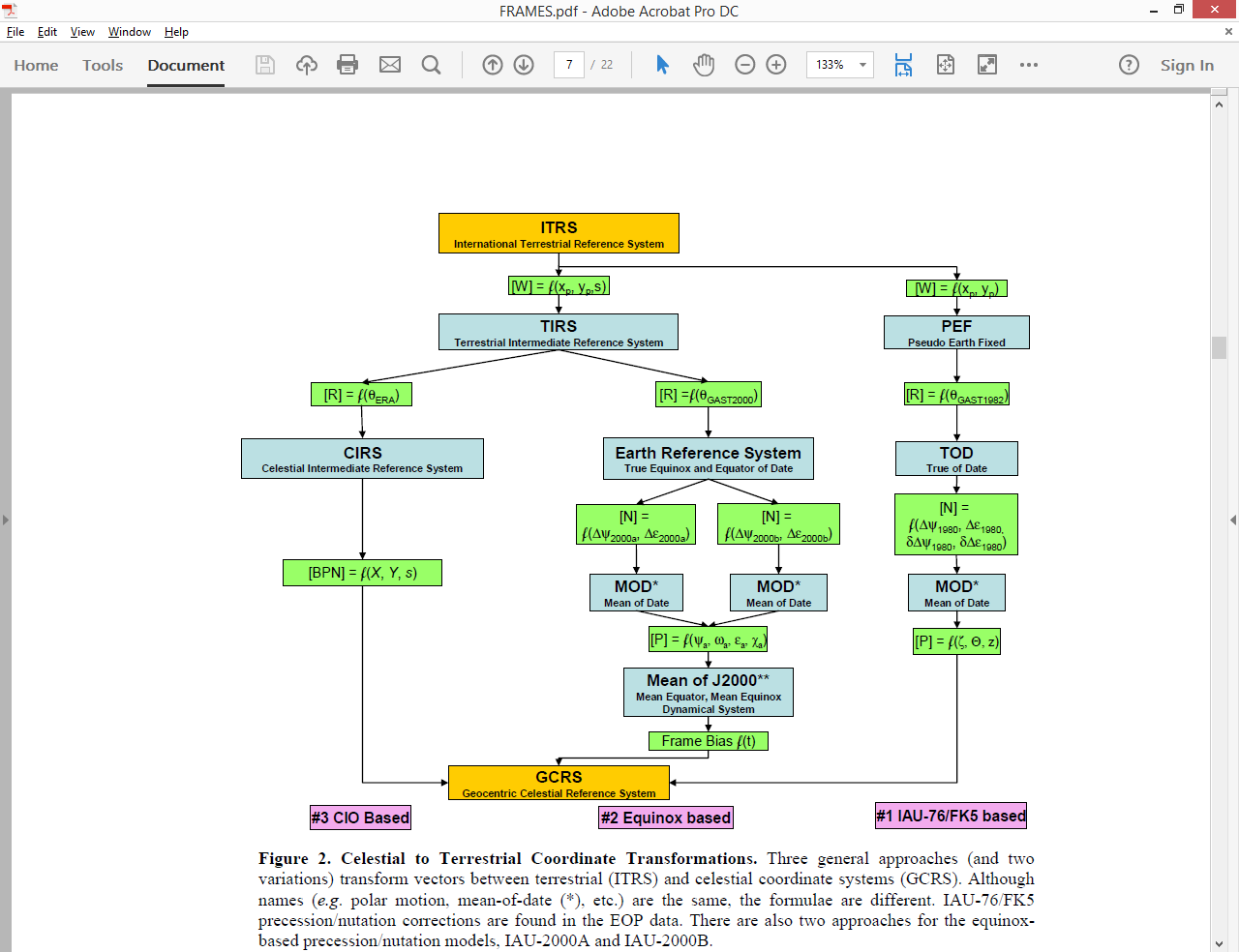
* 1. TIME\_SCALES Metadata Keyword

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Description and reference** | **Nomenclature** | **Default Units/Type** |
| BEIDOU | BeiDou Time (BDT) is a continuous time scale starting at 0h UTC on January 1st, 2006 and is synchronized with UTC within 100 ns (modulo one second). |  |  |
| GALILEO | Galileo System Time (GST) is a continuous time scale maintained by the Galileo Central Segment and synchronized with TAI with a nominal offset below 50 ns. The GST start epoch is 0h UTC on Sunday, 22 August 1999 (midnight between 21 and 22 August). |  |  |
| GLONASS | GLONASS Time (GLONASST) is generated by the GLONASS Central Synchronizer and the difference http://www.navipedia.net/images/math/8/1/a/81a69207104f00baaabd6f84cafd15a0.png between the UTC(SU) and GLONASST should not exceed 1 millisecond plus three hours (the difference between Moscow Time and Greenwich Mean Time (GMT)), but http://www.navipedia.net/images/math/8/1/a/81a69207104f00baaabd6f84cafd15a0.png is typically better than 1 microsecond. Note: Unlike GPS, Galileo or BeiDou, GLONASS time scale implements leap seconds, like UTC. |  |  |
| GAST | Greenwich Apparent Sidereal Time is measured from the true vernal equinox relative to the Greenwich meridian, which includes secular and periodic contributions to the motion of the vernal equinox. |  |  |
| GMST | Greenwich Mean Sidereal Time is the hour angle from the vernal equinox to the Greenwich meridian. |  |  |
| GPS | Global Positioning System Time (GPS) is the background (reference) time scale of that satellite-based navigation system; ideally, it is steered to lag TAI by nineteen (19) seconds, i.e., GPS Time = TAI - 19 s. GPS Time is natively expressed as elapsed time since the GPS epoch of 6 January 1980 00:00:00:00 UTC. The elapsed time is presented in terms of weeks and seconds into the week (1434:43214.000). |  |  |
| GPSZ | GPS time expressed as elapsed time since the GPS epoch of 6 January 1980 00:00:00:00 UTC. The elapsed time is presented in terms of Z counts (1.5 second increments) (578217609.333). Note that this differs from normal GPS convention where the Z count is represented as the number of whole weeks since the GPS epochs and the number of 1.5 second increments into the week. |  | 1.5s increments |
| MET | Mission Elapsed Time (note) |  |  |
| MRT | Mission Relative Time (note) |  |  |
| NAVIC | NAVIC (Navigation with Indian Constellation) is an autonomous regional [satellite navigation](https://en.wikipedia.org/wiki/Satellite_navigation) system in the Indian Regional Navigation Satellite System (IRNSS) that will provide accurate real-time positioning and timing services. The system is expected to be fully operational in 2018. |  |  |
| SCLK | Spacecraft Clock (receiver) (requires rules for interpretation in ICD) |  |  |
| TAI | International Atomic Time (TAI) is a physical time scale affected by the Earth's gravitational and rotational potential, and deduced from a weighted average of various international frequency standards. Relative weighting is based on the historical stability of the individual standards. TAI is maintained by the Bureau International des Poids et Mesures (BIPM) and is the basis of other time scales. |  |  |
| TCB | Barycentric Coordinate Time (TCB), where TCB is related to TT through a complex sequence of relativistic transformations. |  |  |
| TDB | Barycentric Dynamical Time (TDB) is intended to serve as the independent argument of barycentric ephemerides and equations of motion. It is defined as being linearly related to Barycentric Coordinate Time (TCB) The linear relationship between TDB and TCB is chosen such that the rate of TDB closely matches TT for the time span covered by the JPL Development Ephemerides. TDB is sometimes designated as Barycentric Ephemeris Time (Teph) when used as the time scale of the JPL ephemerides. |  |  |
| TCG | Geocentric Coordinate Time is defined in the context of the [general theory of relativity](https://en.wikipedia.org/wiki/General_relativity). It is defined by a 1991 IAU resolution. |  |  |
| TT | Terrestrial Time (TT) is a theoretically ideal time at the Earth geoid. A practical realization is TT = TAI + 32.184 s. ΔT = TT - UT1 is the difference between this ideal time scale and the rotation of the Earth. TT has also been known as Terrestrial Dynamical Time (TDT) when considered as a coordinate time for geocentric orbits. TT is the successor of pre-relativistic Ephemeris Time (ET). |  |  |
| UT1 | Universal Time (UT1) is the angular measure of Earth rotation inferred from observations. Earth-rotation angle provides a sequentially increasing continuum that is everlasting and widely apparent, and serves as the astronomical basis of civil time of day. The angular rate of modern-day UT1 has been defined to closely follow Newcomb's convention for mean solar time, based on the mean motion of the Sun reduced from 19th-century observations. |  |  |
| UTC | Coordinated Universal Time (UTC) is a broadcast time standard providing both astronomical time of day and atomic-time interval. UTC is kept within +/-0.9 s of UT1 by the introduction of leap seconds and is therefore a legally recognized proxy for Universal Time in most countries. UTC is always offset from TAI by an integer number of seconds, and is thus a carrier of precision frequency and time interval for broadcast standards based on the SI second. Note: Zulu time is synonymous with UTC. |  |  |
| ICD | Other timing system, as defined in ICD |  |  |

If MET or MRT is chosen as the TIME\_SYSTEM, then the epoch of either the start of the mission for MRT, or of the event for MET, should either be given in a comment in the message or provided in an ICD. The time system for the start of the mission or the event should also be provided in the comment or the ICD. If these values are used for the TIME\_SYSTEM, then the times given in the file denote a time offset from the mission start or event. However, for clarity, an ICD should be used to fully specify the interpretation of the times if these values are employed.

* 1. Reference Frame KEYWORDs

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Description and reference** | **Nomenclature** | **Default Units/Type** |
| ALIGN\_CB | **For all central bodies except Earth,** the central body’s fixed frame evaluated at some specified epoch, rather than evolving in time. This frame does not rotate with respect to the inertial frame. |  |  |
| ALIGN\_EARTH | **For the Earth system only,** the Earth’s fixed frame evaluated at some specified epoch, rather than evolving in time. This frame does not rotate with respect to the Inertial frame. |  |  |
| B1950 | **For the Earth system only,** these axes are associated with the FK4 star catalog and its theory modeling the mean equator and mean equinox. The epoch is the beginning of the Besselian year 1950, corresponding to 31 Dec 1949 22:09:46.866 or JD 2433282.4234591. The B1950 axes are realized by a constant rotation offset from the J2000 axes, using a formula available from the Explanatory Supplement to the Astronomical Almanac. |  |  |
| DTRFyyyy | The DTRFyyyy is the realization of the ITRS computed at DGFI-TUM. Only two other VLBI centers compute these realizations, the others being IGN in Paris and JPL in Pasadena. The DTRF considering corrections for non-tidal atmospheric and hydrological loading, as of year “yyyy” (e.g. 2000). | e.g., DTRF2000 |  |
| EFG | Earth-Fixed Greenwich (EFG) frame. The EFG reference frame is defined as the Earth Fixed frame after polar motion is removed. Some sources refer to this as a pseudo-Earth Fixed frame. | E, F, G, Edot, Fdot, Gdot, PEF |  |
| GCRFyyyy | The Geocentric Celestial Reference Frame is the standard inertial coordinate system for the Earth, with origin at the geocenter (i.e Earth’s center of mass location). The GCRF is the geocentric counterpart of the ICRF. | e.g., GCRF2000 |  |
| FIXED\_CB | **The Fixed frame for all central bodies except Earth**. The Fixed frame is the frame in which its topography is expressed. For gaseous planets (Jupiter, Saturn, Uranus, Neptune), the Fixed frame identifies the planet’s magnetic field instead. The Earth’s Moon realizes its Fixed frame (by default) as its MeanEarth frame; all other central bodies realize their Fixed frames using the transformational algorithm and parameters contained in Report of the IAU/IAG Working Group on cartographic coordinates and rotational elements: 2009, B.A. Archinal et al., Celest. Mech Dyn Astr 109 (2), 101-135 (DOI: 10.1007/s10569-010-9320-4). |  |  |
| FIXED\_EARTH |  |  |  |
| ICRFyyyy | The International Celestial Reference Frame is the standard Barycentric reference system. The ICRF is periodically reevaluated, such that each realization must be annotated (i.e., year “yyyy” as 2000). The ICRF axes are defined as the inertial (i.e., kinematically non-rotating) axes associated with a general relativity frame centered at the solar system barycenter (often called the BCRF). The IAU (International Astronomical Union) is the authority for the definition of the ICRF. The ICRF frame is realized by its transformational algorithm between it and the Earth Fixed frame.  Note that the term ‘ICRF coordinate system’ is not restricted to the system whose origin is at the solar system barycenter--- rather, the term describes a coordinate system whose origin is determined from context (i.e., for a central body, its center of mass location) whose axes are aligned with the axes of the BCRF. In fact, the IAU uses the term GCRF to refer to the system with origin at the geocenter (i.e Earth’s center of mass location) with axes parallel to the BCRF. [Note that ‘aligned’ here refers to directions in Euclidean space – not in a curved space governed by general relativity.] | e.g., ICRF2000 |  |
| Inertial\_CB | Inertial definition for all **central bodies except the Moon, Sun and Earth**. Each central body defines its own Inertial frame computed as a constant rotation from the ICRF frame. Earth and Sun both define their Inertial frames as ICRF itself (i.e., no rotation) and do not provide an additional frame named Inertial. Due to potential vagaries in definition, the use of “Inertial\_CB” is not recommended unless a more definitive frame is not available or applicable (i.e. ICRF2000, J2000) |  |  |
| ITRFyyyy | Earth realizes its Fixed frame from the transformation algorithm between it and the ICRF. The transformation includes precession, nutation, and rotation effects, as well as pole wander and frame corrections. International Terrestrial Reference Frame solution as of year “yyyy” (e.g. 1993, 1997, 2000) | e.g., ITRF2000 |  |
| J2000 | Mean Equator and Mean Equinox of the J2000 epoch (JD 2451545.0 TDB which is 1 Jan 2000 12:00:00.000 TDB). The J2000 frame is realized by the transformational algorithm (also known as the FK5 IAU76 theory) between it and the Earth Fixed frame. The algorithm uses the 1976 IAU Theory of Precession, the 1980 Nutation model, and the Greenwich Mean apparent Sidereal Time (expressed as a function of time in UT1), updated by IERS Technical Note No. 21 to include an adjustment to the equation of the equinoxes.  Note that the term ‘J2000 coordinate system’ is not restricted to the system whose origin is at Earth’s center--- rather, the term describes a coordinate system whose origin is determined from context (i.e., for a central body, its center of mass location) whose axes are parallel to the axes of the J2000 system defined at the Earth. |  |  |
| J2000\_ECLIPTIC | The mean ecliptic system evaluated at the J2000 epoch. The mean ecliptic plane is defined as the rotation of the J2000 XY plane about the J2000 X axis by the mean obliquity defined using FK5 IAU76 theory. |  |  |
| MCI | Mars Centered Inertial |  |  |
| MOD\_CB | **Mean of Date definition for all central bodies except Earth and Moon.**  The same computation as TOD\_CB except that when the Fixed frame Z axis is computed, any oscillatory terms in the formulas for the right ascension and declination are ignored. |  |  |
| MOD\_EARTH | **Mean of Date definition for the Earth.**  Mean Equator and Mean Equinox of date. The transformation between J2000 and MeanOfDate is computed using a sequence of Euler rotations. Rotation angles are computed using cubic polynomials of time past the J2000 epoch in JED according to the 1976 IAU Theory of Precession angles and rates, as found in the US Naval Observatory circular No. 163. The MeanOfDate Z axis is the Earth’s mean spin axis; the MeanOfDate X axis defines the mean vernal equinox |  |  |
| MOD\_MOON | **Mean of Date definition for the Moon.**  The Z axis aligns with the IAU2003 Z axis, and the X axis aligns with the vector that is the cross product of the ICRF Z axis and the IAU2003 Z axis, evaluated at each given time. However, when computing the IAU2003 Z axis, the oscillatory terms are ignored. |  |  |
| MOE\_CB | **Mean of Epoch** definition for all central bodies except Earth. The MeanOfDate system evaluated at some specified epoch, rather than evolving in time. This frame does not rotate with respect to the Inertial frame. |  |  |
| MOE\_EARTH | **Mean of Epoch definition for the Earth**. The Earth’s MeanOfDate system evaluated at some specified epoch, rather than at each given time. This frame does not rotate with respect to the J2000 frame. |  |  |
| MOE\_MOON? |  |  |  |
| MOON\_ME | **Moon Mean Earth (ME) frame.** This is the preferred lunar frame for associating lunar topography. It is defined as a constant rotation from a PrincipalAxes frame. Typically, the X axis pointed along the mean direction to the center of the Earth and the Z axis pointing to the mean direction of rotation. The ME frame is typically used to specify the location of objects on the Moon. |  |  |
| MOON\_MEIAUE | **Moon-Centered, Moon Mean Equator and IAU-Node of Epoch frame** as specified in [L11, Fig. 6-2]. |  |  |
| MOON\_PA403 | **Moon Principal Axis (PA) frame**. This frame is aligned with the Moon’s principal inertia axes with the Z axis along the maximum inertia and the X axis along the minimum inertia. The PA frame is developed in conjunction with the development of the ephemerides for the Moon: hence, the frame depends on the source JPL DE file being used. The PA frame is used as the basis for Lunar gravity models, in the numerical integration of the planetary ephemerides, and as the reference for modern moon gravity solutions. Euler angles supplied as part of the JPL DE planetary ephemerides relate the MOON\_PA frame to ICRF. |  |  |
| MOON\_PA430 | **Moon Principal Axis (PA) frame.** The Z axisaligns with the Fixed Z axis, and the X axis aligns with the vector that is the cross product of the ICRF Z axis and the Fixed Z axis, evaluated at each given time. The TrueOfDate frame is very close to the Mean Lunar Equator and IAU Node of Date (Lunar Constants and Model Document, JPL D-32296, Sept 2005). If the Moon’s Fixed frame were to be set to use the IAU2003 frame, then the two frames would be identical. |  |  |
| MOON\_PA421 | **Moon Principal Axis (PA) frame.** Alternative definition of the Moon fixed axes: IAU2003 axes, which is based on the formulation in the IAU 2003 report, and the principal (fixed) axes as defined in the DE data set DE421. |  |  |
| MOON\_PA421 | **Moon Principal Axis (PA) frame.** Alternative definition of the Moon fixed axes: IAU2003 axes, which is based on the formulation in the IAU 2003 report, and the principal (fixed) axes as defined in the DE data set DE421. |  |  |
| TEMEOFDATE | **For the Earth system only, specifies True Equator Mean Equinox of date.** This is an intermediate frame associated with the transformation from Earth’s MeanOfDate to Earth’s TrueOfDate axes. The TEMEOfDate Z axis is aligned with the TrueOfDate Z axis; the TEMEOfDate X axis is close to (but not identical to) the MeanOfDate X axis. This is the underlying frame upon which the NORAD Two-Line Element Sets (TLEs) are based. |  |  |
| TEMEOFEPOCH | **For the Earth system only, specifies True Equator Mean Equinox of epoch.** Earth’s TEMEOfDate frame evaluated at some specified epoch rather than evolving in time. The frame does not rotate with respect to the J2000 frame. |  |  |
| TOD\_CB | **True of Date definition for all central bodies except Earth and Moon.**  The Z axis aligns with the central body’s Fixed Z axis, and the X axis aligns with the vector that is the cross product of the ICRF Z axis and the Fixed Z axis, evaluated at each given time. If the cross product is zero, then the Y axis aligns with the cross product of the Fixed Z axis and the ICRF X axis. |  |  |
| TOD\_EARTH | **True of Date definition for the Earth.**  True Equator and True Equinox of date. The transformation between Earth’s MeanOfDate to Earth’s TrueOfDate axes uses the mean obliquity, the nutation in longitude, and the nutation in obliquity, computed according to the 1980 Nutation model, and then applies the update to the equation of the equinoxes. By default, the nutation values are obtained by interpolating values contained in the JPL DE file rather than evaluating the model directly. The TrueOfDate Z axis would be the Earth’s spin axis if pole wander were ignored; the TrueOfDate X axis defines the true vernal equinox. |  |  |
| TOD\_MOON | **True of Date definition for the Moon.**  The Z axis aligns with the Fixed Z axis, and the X axis aligns with the vector that is the cross product of the ICRF Z axis and the Fixed Z axis, evaluated at each given time. The TrueOfDate frame is very close to the Mean Lunar Equator and IAU Node of Date (Lunar Constants and Model Document, JPL D-32296, Sept 2005). If the Moon’s Fixed frame were to be set to use the IAU2003 frame, then the two frames would be identical. |  |  |
| TOE\_CB | **True of Epoch** definition for all central bodies except Earth and Moon. The central body’s TrueOfDate system (TOD\_CB) evaluated at some specified epoch, rather than evolving over time. This frame does not rotate with respect to the ICRF frame. |  |  |
| TOE\_EARTH | **True of Epoch definition for the Earth**. The Earth’s TrueOfDate system (TOD\_EARTH) evaluated at some specified epoch, rather than evolving over time. This frame does not rotate with respect to the ICRF frame. |  |  |
| TOE\_MOON | **True of Epoch definition for the Moon**. The Moon’s TrueOfDate system (TOD\_MOON) evaluated at some specified epoch, rather than evolving over time. This frame does not rotate with respect to the ICRF frame. |  |  |
| TRUE\_ECLIPTIC | **The true ecliptic system, evolving in time.** The true ecliptic plane is defined as the rotation of the J2000 XY plane about the J2000 X axis by the true obliquity defined using FK5 IAU76 theory. |  |  |
| UVW\_GI | **Launch go-inertial reference frame**, with U in local horizon plane along inertial launch azimuth (downrange), W along the geodetic vertical and V completing the set (cross-range). In typical use the go-inertial epoch should be specified in an accompanying comment field. |  |  |
| CIRS | **Celestial Intermediate Reference System.** Details in IERS TN32 5.11. Essentially the transformation for precession/nutation is based on the Celestial Intermediate Pole realized with the IAU2000A model rather than IAU1976/80 |  |  |
| TIRS | **Terrestrial Intermediate Reference System.** Details in IERS TN32 5.11. Essentially the transformation for precession/nutation is based on the Celestial Intermediate Pole realized with the IAU2000A model rather than IAU1976/80 |  |  |



* 1. Relative reference FRAME KEYWORDS

In addition to the above reference frames, maneuver and covariance data can be specified in the following relative frames:

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Description and reference** | **Nomenclature** | **Default Units/Type** |
| ACTUATOR\_x | Actuator reference frame (‘x’ = 0→9): could denote reaction wheels, solar arrays, thrusters, etc. | ACTUATOR |  |
| CSS\_xy | Coarse Sun Sensor (‘x’ = 0→9, ‘y’ = 0→9) | CSS |  |
| DSS\_x | Digital Sun Sensor (‘x’ = 0→9) | DSS |  |
| EQS | Equinoctial Coordinate System, with E aligned with the ascending node direction, W along the orbital angular momentum vector () and Q completing the set () | EQW |  |
| GYRO\_x | Gyroscope Reference Frame (‘x’ = 0→9) | GYRO |  |
| INSTRUMENT\_y | Instrument ‘y’ reference frame (‘y’ = A→Z, 0→9) | INSTRUMENT |  |
| NSW | “NADIR, Sun, Normal” – This frame aligns the x-axis in the NADIR direction, the y-axis as much as possible toward the Sun while still being normal to the x-axis, and the z-axis completing the right-hand set | NSW |  |
| NTW | A local orbital coordinate frame that has the x-axis along the Tangential (or velocity) vector, z-axis (“W”) along the orbital angular momentum vector (), and N completing the right handed system (i.e., for a circular orbit “N” generally points in the Nadir direction and for an eccentric orbit, “N” points as close to Nadir as possible while still being normal to the T-W plane). Note that while this frame has the same axes defined as in the TNW frame, the ordering of axes is different. | NTW |  |
| PQW | Perifocal Coordinate System, with P axis pointing to perigee, W along the orbital angular momentum vector () and Q completing the set () | PQW |  |
| RSW | A Radial, Along track, Cross track, local orbital coordinate frame, where the R axis always points out from the satellite along the central body’s radius vector to the satellite as it moves through the orbit. The S axis is in the direction of (but not necessarily parallel to) the velocity vector and is perpendicular to the radius vector. The W axis is aligned with the orbit angular momentum vector.  Note that this RSW frame is also referred to as:  Gaussian Coordinate System  LVLH  ‘Radial, In-track, Cross-track” (**RIC**)  ‘Radial, Transverse, Normal’ (**RTN**)  **UVW** (as employed in Conjunction Data Messages) | RSW |  |
| SC\_BODY\_x | Spacecraft Body Frame (‘x’ = 0→9); requires clear specification via ICD | SC\_BODY |  |
| SC\_BODY\_y | Spacecraft Body Frame of another object (‘y’ = A→Z); requires clear specification via ICD | SC\_BODY |  |
| SENSOR\_x | Sensor ‘x’ reference frame (‘x’ = A→Z, 0→9) | SENSOR |  |
| TOPOHORIZ | The SEZ system rotates with the observing site. The local horizon forms the fundamental plane, with the S axis pointing due south from the site (even in the Southern Hemisphere). The E axis points east from the site and is undefined at the North or South Poles. The Z axis (zenith) points radially outward from the site, along the site’s geodetic local vertical. | SEZ |  |
| STARTRACKER\_x | Star Tracker Reference Frame (‘x’ = 0→9) | STAR TRK |  |
| TAM\_x | Three Axis Magnetometer Reference Frame (‘x’ = 0→9) | TAM |  |
| TNW | A local orbital coordinate Tangential, Normal, Cross track frame that has the x-axis along the Tangential (or velocity) vector, z-axis (“W”) along the orbital angular momentum vector (), and N completing the right handed system (i.e., for a circular orbit “N” generally points in the Nadir direction and for an eccentric orbit, “N” points as close to Nadir as possible while still being normal to the T-W plane). Note that while this frame has the same axes defined as in the NTW frame, the ordering of axes is different (TNW). | TNW |  |
| VNC | A local orbital coordinate Velocity, Normal, Co-normal frame that has the x-axis along the Velocity (or tangential) vector, y-axis Normal to the orbit along the orbital angular momentum vector (), and z-axis is the “Co-normal” direction completing the right handed system (i.e., for a circular orbit “C” points in the radius vector direction whereas for an eccentric orbit, “C” points as close to radial as possible while still being normal to the V-N plane). Note that while this frame has the same axes defined as in the NTW frame, the ordering of axes is different (i.e., TWN). | VNC |  |

* 1. Element Set KEYWORDS

Orbit element states and/or time histories may be specified in the following element sets.

Orbit elements shall be interpreted as osculating elements unless pre-coordinated between the message originator and recipient to contain mean elements (e.g. singly- or doubly-averaged elements based upon Kozai, Brouwer or other theories).

It is not allowed to specify non-inertial reference frames when employing inertial element sets, or to specify inertial reference frames when employing non-inertial element sets.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Name** | **Description and reference** | **Nomenclature** | **Default Units/Type** | |
| ADBARV | Spherical 6-element set comprised of: right ascension +E°, declination +N°, inertial flight path angle measured from the radial direction to inertial velocity direction (e.g. 90° for circular orbit), inertial azimuth angle, measured from local North to projection of inertial velocity in local horizontal plane, radius magnitude and velocity magnitude) |  | , | |
| CARTP | Cartesian 3-element position (only) orbit state | X, Y, Z |  | |
| CARTPV | Cartesian 6-element position and velocity orbit state | X, Y, Z, XD, YD, ZD | , | |
| CARTPVA | Cartesian 9-element position, velocity and acceleration orbit state | X, Y, Z, XD, YD, ZD, XDD, YDD, ZDD | ,  , | |
| DELAUNAY | Delaunay elements employ a set of canonical action-angle variables, which are commonly used in general perturbation theories. The element set consists of three conjugate action-angle pairs. Lower case letters represent the angles while upper case letters represent the conjugate actions. Delaunay variables coordinate type is not available if a Fixed coordinate system is selected. Elements L, G and H are expressed in terms of distance squared divided by time, where distance is measured in standard units and time is measured in seconds, where “L” is related to the two-body orbital energy, “G” is the magnitude of the orbital angular momentum, “H” is the Z component of the orbital angular momentum. The elements l, g and h are angles, where l is the mean anomaly, g is the argument of perigee and h is the right ascension of the ascending node. | L, G, H, l, g, h | , | |
| DELAUNAYMOD | Modified Delaunay variables, where the L, G and H “action” variables of the Delaunay element set defined above are divided by the square root of the central-body gravitational constant, yielding a geometric version of the Delaunay set that is independent of the central body. | Lm, Gm, Hm, lm, gm, hm | , | |
| EIGVAL3EIGVEC3 | 12-element eigenvalue/eigenvector representation time history corresponding to the 3x3 position covariance time history, with each line containing Time, the three (major, medium and minor) eigenvalues IN DESCENDING ORDER, and the corresponding three eigenvectors matching the major, medium and minor eigenvalues | EigMaj,  EigMed,  EigMin,  EigVecMaj,  EigVecMed,  EigVecMin | ,  , |
| EQUIN | Equinoctial elements (Broucke and Cefola, 1972) are popular because they do not suffer from the singularity problems that classical and other elements do. This standardized equinoctial seven-element set is adopted from the definition contained in Vallado [L9, 4th Ed.]. The first six equinoctial elements have a singularity for exact 180º inclinations, which is overcome by the addition of a seventh element which specifies the retrograde factor [fr = ±1, where fr = 1 denotes direct orbits (inclination<=90°), -1 for retrograde orbits (inclination>90°)]. Note that some centers switch the retrograde factor (-1) only for exact retrograde orbits (switching the singularity for that case to an inclination of 0º), while others switch this retrograde factor to (-1) for any/all retrograde orbits. | [a, af, ag, L=, χ, ψ, | ,  ,  ,  , | |
| EQUINMOD | Modified equinoctial seven-element set, where semi-major axis has been replaced by semi-latus rectum “p” = a (1-e2), and where Mean Anomaly has been replaced by True Anomaly in the “L” term. The seventh element specifies the retrograde factor [fr = ±1] as defined in Vallado [L9]. | [p = a(1-e2), af, ag, , χ, ψ, | ,  ,  ,  , | |
| GEODETIC | Geodetic elements (longitude, geodetic latitude, fixed frame flight path angle, fixed frame azimuth, altitude above oblate spheroid, and velocity relative to the fixed frame |  | , | |
| KEPLER | Keplerian 6-element classical set (semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee and true anomaly) |  | ,  , | |
| KEPLERM | Keplerian 6-element classical set (semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee and mean anomaly) |  | ,  , | |
| CIRC | Elements adapted to nearly circular orbit:  Sma, ecc \* cos(w), ecc \* sin(w), inc, RAAN, anomaly + w |  |  | |
| CIRCM | With mean anomaly |  |  | |
| LDBARV | Modified spherical 6-element set (Earth longitude +E°, declination +N°, inertial flight path angle measured from the radial direction to inertial velocity direction (e.g. 90° for circular orbit), inertial azimuth angle, measured from local North to projection of inertial velocity in local horizontal plane, radius magnitude and velocity magnitude) |  | , | |
| POINCARE | Canonical counterpart of equinoctial 6-element set. See Vallado [L9]) | gp, hp, Lp, Gp, Hp | ,  ,  , | |

* 1. Additional COVARIANCE SET KEYWORDS

In addition to the above orbit element sets, covariance data can be specified in the following orbit sets:

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Description and reference** | **Nomenclature** | **Default Units/Type** |
| TADBARV | 7x7: Time & Spherical 6-element set (: right ascension +E°, declination +N°, inertial flight path angle measured from the radial direction to inertial velocity direction (e.g. 90° for circular orbit), inertial azimuth angle, measured from local North to projection of inertial velocity in local horizontal plane, radius magnitude and velocity magnitude) errors | T, | ,  , |
| TCARTP | 4x4: Time & Cartesian 3-element position (only) errors (X, Y, Z) errors | T, X, Y, Z | , |
| TCARTPV | 7x7: Time & Cartesian 6-element position and velocity errors (X, Y, Z, XD, YD, ZD) errors | T, X, Y, Z, XD, YD, ZD | ,  , |
| TCARTPVA | 10x10: Time & Cartesian 9-element position, velocity and acceleration errors (X, Y, Z, XD, YD, ZD, XDD, YDD, ZDD) errors | T, X, Y, Z, XD, YD, ZD, XDD, YDD, ZDD | ,  ,  , |
| TDELAUNAY | 7x7: Time & Delaunay 6-element set (as defined above) errors | T, L, G, H, l, g, h | ,  , |
| TDELAUNAYMOD | 7x7: Time & Modified Delaunay variables errors, where the L, G and H “action” variables of the Delaunay element set defined above are divided by the square root of the central-body gravitational constant, yielding a geometric version of the Delaunay set that is independent of the central body. | T, Lm, Gm, Hm, lm, gm, hm | ,  , |
| TEIGVAL3EIGVEC3 | 13-element eigenvalue/eigenvector representation time history corresponding to the 3x3 position covariance time history, with each line containing Time, the three (major, medium and minor) eigenvalues IN DESCENDING ORDER, and the corresponding three eigenvectors matching the major, medium and minor eigenvalues | T,  EigMaj,  EigMed,  EigMin,  EigVecMaj,  EigVecMed,  EigVecMin | ,  ,  , |
| TEQUIN | 7x7: Time & Equinoctial 6-element set ([ahkλpq ] = [a, ag, af, L=, χ, ψ] as defined in Vallado [L9], omitting from the set) errors | [a, af, ag, L=, χ, ψ, | ,  ,  ,  ,  , |
| TEQUINMOD | 7x7: Time & Equinoctial 6-element modified set ([pfghkL ] = [a(1-e2), af, ag, χ, ψ, ] per Vallado [L9], omitting from the set) errors | T, [p = a(1-e2)], af, ag, , χ, ψ | ,  ,  ,  , |
| TGEODETIC | 7x7: Time & geodetic elements (longitude, geodetic latitude, fixed frame flight path angle, fixed frame azimuth, altitude above oblate spheroid, and velocity relative to the fixed frame) errors | T, | ,  , |
| TKEPLER | 7x7: Time & Keplerian 6-element classical set (semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee and true anomaly) errors | T, | ,  ,  , |
| TKEPLERM | 7x7: Time & Keplerian 6-element classical set (semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee and mean anomaly) errors | T, | ,  ,  , |
| TLDBARV | 7x7: Time & modified spherical 6-element set (Earth longitude +E°, declination +N°, inertial flight path angle measured from the radial direction to inertial velocity direction (e.g. 90° for circular orbit), inertial azimuth angle, measured from local North to projection of inertial velocity in local horizontal plane, radius magnitude and velocity magnitude) errors | T, | ,  , |
| TPOINCARE | 7x7: Time & canonical counterpart of equinoctial 6-element set errors. See Vallado [L9]) | T, gp, hp, Lp, Gp, Hp | ,  ,  ,  , |

References

[-] *Navigation Data—Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-3. Green Book. Issue 3. Washington, D.C.: CCSDS, May 2010.

[-] *Organization and Processes for the Consultative Committee for Space Data Systems*. CCSDS A02.1-Y-3. Yellow Book. Issue 3. Washington, D.C.: CCSDS, July 2011.

[-] “CelesTrak.” Center for Space Standards & Innovation (CSSI). <http://celestrak.com/>

[-] David A. Vallado, et al. “Revisiting Spacetrack Report #3.” In *Proceedings of the AIAA/AAS Astrodynamics Specialist Conference and Exhibit* (21–24 August 2006, Keystone, Colorado). AIAA 2006-6753. Reston, Virginia: AIAA, 2006. <http://www.centerforspace.com/downloads/files/pubs/AIAA-2006-6753.pdf>

[-] *Attitude Data Messages*. Recommendation for Space Data System Standards, CCSDS 504.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 2008.

[-] “Documentation.” *SPICE: NASA’s Solar System Exploration Ancillary Information System*. Navigation and Ancillary Information Facility (NAIF). <http://naif.jpl.nasa.gov/naif/documentation.html>

[-] *Ground Network Tracking and Acquisition Data Handbook*. 453-HNDK-GN. Greenbelt, Maryland: Goddard Space Flight Center, May 2007.

[-] Oltrogge, D.L, et al, “Ephemeris Requirements for Space Situational Awareness,” AAS 11-151, February 2011.

[-] David A. Vallado, et al. *Fundamentals of Astrodynamics and Applications, 4th Ed*., Microcosm Press and Springer, ISBN 978-1881883180.

[-] Williams, J.G., Boggs, D.H., and Folkner, W.M., “DE430 Lunar Orbit, Physical Librations, and Surface Coordinates,” Jet Propulsion Laboratory Interoffice Memorandum, IOM 335-JW,DB,WF-20130722-016, 22 July 2013.

[-] Jet Propulsion Laboratory, “Lunar Constants and Models Document,” JPL D-32296, 23 Sept 2005.

[-] Oltrogge, D.L., North, P. and Nicholls, M., “Multi-Phenomenology Observation Network Evaluation Tool (MONET),” AMOS 2015 Space Situational Awareness Conference, Maui, HI, September 2015.

[-] Newhall, X.X., “Numerical Representation of Planetary Ephemerides,” Celestial Mechanics, vol. 45, pp. 305-310, 1989.

[-] Hoots, F.R. and France, R.G., “Hybrid Ephemeris Compression Model,” Astrodynamics Specialist Conference, AAS 97-690.

[-] Braun, V. and Klinkrad, H., “Providing Orbital Information for Objects in Earth Orbits as Chebyshev Polynomials,” in IAC-15, 2015.

[L-16] Woodburn, J., & Tanygin, S. (2002). Position covariance visualization. AIAA/AAS Astrodynamics Specialist Conference and Exhibit, Monterey, California

[L-17] Walker, M.J.H., Ireland, B., and Owens, J. (1985). A Set of Modified Equinoctial Orbit Elements, CMDA 1985 v36 pp 409-419.

[L-18] Vallado, D., Seago, J., Seidelmann, P. (2006). Implementation Issues Surrounding the New IAU Reference Systems for Astrodynamics. 16th AAS/AIAA Space Flight Mechanics Conference