ECSS-E-ST-10-09C
31 July 2008

Space engineering

Reference coordinate system

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards. Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

This Standard has been prepared by the ECSS-E-10-09C Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

Disclaimer

Published by: ESA Requirements and Standards Division
ESTEC, P.O. Box 299,
2200 AG Noordwijk
The Netherlands

Change log

ECSS-E-ST-10-09A	Never issued
ECSS-E-ST-10-09B	Never issued
ECSS-E-ST-10-09C 31 July 2008	First issue

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Introduction

Clear definition of reference directions, coordinate systems and their inter-relationships is part of the System Engineering process. Problems caused by inadequate early definition, often pass unnoticed during the exchange of technical information.

This Standard addresses this by separating the technical aspects from the issues connected with process, maintenance and transfer of such information. Clause 4 provides some explanation and justification, applicable to all types of space systems, missions and phases. Clause 5 contains the requirements and recommendations. Helpful and informative material is provided in the Annexes.

1 Scope

The objective of the Coordinate Systems Standard is to define the requirements related to the various coordinate systems, as well as their related mutual interrelationships and transformations, which are used for mission definition, engineering, verification, operations and output data processing of a space system and its elements.

This Standard aims at providing a practical, space-focused implementation of Coordinate Systems, developing a set of definitions and requirements. These constitute a common reference or “checklist” of maximum utility for organising and conducting the system engineering activities of a space system project or for participating as customer or supplier at any level of system decomposition.

This standard may be tailored for the specific characteristics and constraints of a space project in conformance with ECSS-S-ST-00.

2
Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revisions of any of these publications, do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references the latest edition of the publication referred to applies.

ECSS-S-ST-00-01	ECSS system– Glossary of terms
ECSS-M-ST-10	Space project management – Project planning and implementation

3 Terms, definitions and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply.

NOTE 1 Some terms are taken from other documents, referenced in square brackets in the References.

NOTE 2 There is no agreed convention for usage of combinations of the words "reference, coordinate, frame and system". These terms are often used interchangeably in practice. In 1989, Wilkins' [1] made a proposal. This Standard adopts a simpler terminology, which is more in line with everyday practice.

3.2 Terms specific to the present standard

3.2.1 coordinate system

method of specifying the position of a point or a direction with respect to a specified frame

NOTE E.g. Cartesian or rectangular coordinates, spherical coordinates and geodetic coordinates.

3.2.2 frame

triad of axes, together with an origin

3.2.3 inertial frame

non-rotating frame

NOTE 1 Inertial reference directions are fixed at an epoch.

NOTE 2 The centre of the Earth can be considered as non-accelerating for selecting the origin, in some applications.

3.2.4 J2000.0

astronomical standard epoch 2000 January 1.5 (TT)

NOTE equivalent to JD2451545.0 (TT).

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
AIT	assembly integration and test
AIV	assembly integration and verification
BCRS	barycentric celestial reference system
BIPM	Bureau International des Poids et Mesures – international bureau of weights and measures
CAD	computer aided design
CCSDS	Consultative Committee for Space Data Systems
CoM	centre of mass
CSD	coordinate systems document
DoF	degree of freedom
DRD	document requirements definition
GCRS	geocentric celestial reference system
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICD	interface control document
ICRF	international celestial reference frame
ICRS	international celestial reference system
IERS	international Earth rotation and reference service
IMCCE	Institut de Mécanique Céleste et de Calcul des Ephémérides
ISO	International Organization for Standardization
ITRF	international terrestrial reference frame
ITRS	international terrestrial reference system
IUGG	International Union of Geodesy and Geophysics
J2000.0	epoch 2000 January 1.5 (TT)
JPL DExxx	Jet Propulsion Laboratory development ephemeris, number xxx
L/V	launch vehicle
MICD	mechanical interface control document
RCS	reaction control system
SEP	system engineering plan
SI	système international
STR	star tracker
TAI	temps atomique international – international atomic time
ToD	true of date

TT	terrestrial time
UTC	coordinated universal time -temps universel coordonné
WGCCRE	Working Group on Cartographic Coordinates and Rotational Elements
w.r.t.	with respect to

4 Objectives, process and principles

4.1 General

This Clause provides the background to the requirements and recommendations stated in Clause 5, from the conceptual, process and technical points of view.

4.2 Concepts and processes

4.2.1 Process

The coordinate systems used within a project are identified early in the lifecycle of a project. These coordinate systems are then related via a chain of transformations to allow the transformation of coordinates, directions and other geometric parameters into any coordinate system used within the project at any time in the project life.

4.2.2 Documentation

Besides the ICDs, CAD drawings and SRD, a specific document for all coordinate systems and their inter-relationships, throughout the product tree and the project life, are created, maintained and configured. The Coordinate System Document (CSD) takes shape before the end of phase-A.

4.2.3 Coordinate system chain analysis

A chain of transformations is constructed using chain elements or links. A link is composed of two coordinate systems together with the transformation between them. The product tree can be mapped into a set of connected chains. For any analysis, the appropriate connected chain is used, even if other paths within the tree are later found to be useful for satellite integration, operations or processing. For subsystem or unit analysis, any link may be decomposed into a sub-chain containing intermediate coordinate systems. The relationship between two coordinate systems can involve kinematics, dynamics, measurement or constraints. See Annex B for some examples.

The main mission chain typically includes inertial, rotating planet-centred orbital, spacecraft mechanical, instrument and product (i.e. post-processing related) coordinate systems."

4.2.4 Notation

Experts working together within a project need to have a common understanding of the parameters and variables. Specific coordinate systems are used to obtain a convenient formulation of the kinematic and dynamic equations involved. A shared understanding of all the coordinate systems and their parameterisations is therefore paramount. This necessitates the definition of a notational convention for naming variables, coordinate systems and their inter-relationships.

4.3 Technical issues

4.3.1 Frame and coordinate system

Transformations between frames, having orthogonal axes, the same handedness (right or left) and unit vectors along each axis, enjoy the properties of unitary matrices, which facilitate the calculation of inverse transformations between these frames.

The method for constructing a triad of orthogonal axes needs to be agreed and specified. The definition requires at least two non-parallel directions, which may be derived from physical elements, theoretical considerations or mathematical definitions. In general, a set of (physical) directions is not likely to be orthogonal.

By definition of a coordinate system, the position of a point can be expressed by a set of coordinates with respect to its frame. The concept of coordinates requires a unit and an origin in addition to the directions as defined by the selected frame.

Several mathematical representations exist to describe a position or direction, each with their own advantages. The Cartesian vector representation, being a common representation, is selected for this standard. Other parameterisations (e.g. geodetic coordinates and topocentric direction) can be also used to describe a position or direction.

Formal parameterisation is specified in vector notation using an explicit mathematical relationship.

4.3.2 Transformation between coordinate systems

Accurate verbal, graphical and mathematical description of a transformation between two coordinate systems is essential for its correct interpretation.

In general, each transformation consists of a translation, a rotation and possibly a scale factor operation. The specification of the order of operations is important, even when the nominal translation is assumed to be the null vector. A theoretically null translation can later, in the project life or in more precise calculations, become non-null.

Quaternions, Euler angles, mechanical and other parameters can be used to describe transformations between coordinate systems. In this standard, matrix representation is selected for the mathematical definition of a rotational transformation.

4.3.3 IERS definition of a transformation

The general transformation of the Cartesian coordinates of a point from frame 1 to frame 2 is given by the following equation, see Reference [2], page 21 from Bibliography.

$$\vec{X}^{(2)} = \vec{T}_{1,2} + \lambda_{1,2} \times R_{1,2} \times \vec{X}^{(1)}$$

where:

$\vec{T}_{1,2}$ is the translation vector,

$\lambda_{1,2}$ is the scale factor, and

$R_{1,2}$ is the rotation matrix.

This relates two Cartesian coordinate systems, by defining the coordinates of the origin and the three unit vectors of one of them in the other one.

4.3.4 Time

Certain coordinate systems are time dependent. A unique specification of the time standard is necessary. Such a definition includes the mathematical relationship between each of the time standards used within the project.

5
Requirements

5.1 Overview

This clause contains process requirements, covering the management and utilisation of coordinate systems throughout the life cycle of space missions; general requirements, covering applicability, terminology, notation, figures and illustrations; and technical requirements, covering the definition of coordinate systems and their parameterisation, and of the transformations between coordinate systems.

5.2 Process requirements

5.2.1 Responsibility

a. The responsibility for the task of system-level definition of the coordinate systems and their inter-relationships, applicable to the whole product tree and to be used throughout the lifetime a project, shall be identified.

NOTE 1 See ECSS-M-ST-10, subclause 4.3.4 and 5.3 and Annex B of this document for product tree. See also ECSS-S-ST-00-01 for the definition of product tree.

NOTE 2 The product tree includes the space segment, the launcher, the ground segment and associated processors, the user segment, operations, and the engineering tools and models such as simulators, emulators and test benches.

5.2.2 Documentation

a. The Coordinate Systems Document (CSD) shall be produced in conformance with Annex A.

NOTE The CSD is intended for reviews.

b. The CSD shall identify the specified coordinate systems and time scales used throughout the project, by two or more subsystems or organisations, together with their inter-relationships (in a parametric form).

NOTE Subsystems (or organisations) are free to make specifications within their area of responsibility, so long as the specific (internal) coordinate system or time scale is not used by another subsystem (or organisation).

c. For a spacecraft project, a preliminary version of the CSD shall be produced before the end of phase A.

d. The CSD (and related database) shall be put under configuration control at the beginning of phase B.

e. At each phase of the project, the coordinate systems and their inter-relationships shall be re-examined.

f. The CSD shall include the new coordinate systems and transformations following the progress of the project development.

NOTE During the project, new details and elements are defined (e.g. equipment, methods and algorithms).

5.2.3 Analysis

a. The elements, which need coordinate systems, shall be identified.

NOTE This involves iterative analysis of the functional and product trees as well as the interfaces, at each phase.

b. Each identified element of the system shall have its coordinate systems defined.

c. A transformation chain structure shall be built to link coordinate systems used by two or more subsystems

NOTE See Annex B for guidelines and examples.

d. The nominal value, in numeric or parametric form, of the transformation between two coordinate systems shall be specified.

5.3 General requirements

5.3.1 Applicability

a. Applicable parts of the international standards and conventions listed in Annex C shall be selected and specified in the CSD.

NOTE Such organisations maintain, for example, definitions of certain reference coordinate systems, and of time.

b. Applicable non compliant external conventions shall be converted into the project's convention.

c. The conversion of 5.3.1b shall be specified.

5.3.2 Notation

a. A coordinate system shall be identified by a unique descriptive name.

b. Recognised international names should not be used if the exact definition is not followed.

NOTE E.g. the name “Pseudo True of Date” can be used if the conventional definition of ToD is not strictly followed.

c. A unique mnemonic shall be derived from the descriptive name of the coordinate system.

d. The transformation from one coordinate system to another shall be identified by a unique name, which also indicates the direction of the transformation.

e. The convention for naming coordinate systems and transformations shall be specified.

f. The notation convention shall be specified.

g. Sign conventions shall be identified and defined.

NOTE E.g. rotation around an axis.

5.3.3 Figures

a. A figure shall show the relationship of a coordinate system with equipment, spacecraft or mission.

b. The origin and axes of a coordinate frame shall be identified in figures using the reference mnemonic as indicated in 5.3.2c.

c. A figure should show the relationship of a coordinate system to at least one other already defined coordinate system, once the first has been defined.

d. If two or more rotations are used in a transformation between coordinate systems, they should be indicated on the figure with intermediate rotation axes.

e. Symbols used within illustrations, figures and supporting diagrams shall be defined.

f. In an engineering drawing, the applicable projection system shall be indicated.

NOTE The projection system is generally European or American.

g. In a 3D figure, the axes above, within and below a plane shall be differentiated.

NOTE 1 An axis pointing out of the plane of the paper can be depicted by a circle with a dot in it; an axis pointing into the paper by a circle with a cross.

NOTE 2 Shadowing and dotted lines can be used in 3D figures.

5.4 Technical requirements

5.4.1 Frame

a. The origin of the frame shall be specified.

b. The derivation of the origin of a frame from reference points shall be defined.

c. The derivation of the axes of a frame from reference directions shall be defined.

d. The axes of a frame shall be orthogonal.

e. The orientation of the axes of a frame shall be defined according to the right hand rule.

NOTE 1 Sometimes left handed frames cannot be avoided, because of imported off-the-shelf equipment.

NOTE 2 E.g. raw measurements or actuator commands may be given in a left handed frame.

f. Any imported left handed frame shall be specified.

g. Any left handed frame shall be associated with a system reference right handed frame with the related transformation, for project development use.

NOTE This avoids a "change of sign" in the software without a change of variable.

h. The epoch of an inertial frame shall be defined.

5.4.2 Coordinate system

a. If a coordinate system is time dependent, then its time scale shall be defined.

b. The position of a point shall be definable by a set of coordinates with respect to a selected frame.

5.4.3 Unit

a. Dimensionless quantities shall be explicitly denoted as such.

b. The units or physical dimensions of all non-dimensionless parameters, including angles, shall be defined.

NOTE E.g. Units for angles include radians and degrees.

5.4.4 Time

a. The unit of time shall be defined.

b. The relationship between all time scales used shall be defined.

NOTE E.g. The relationship between local clocks on a group of spacecraft and UTC on Earth.

5.4.5 Mechanical frames

a. The frame for a mechanical system shall be related to its material structure definition.

b. For alignment, integration and test purposes, the origin and axes of the coordinate systems shall be defined using physical and accessible points, including marks and targets.

c. The process of constructing the origin and axes of a mechanical reference frame using the physical points shall be specified.

d. The mathematical relationship between the coordinate system and physical points, as used in 5.4.5c above, shall be defined.

e. The spacecraft interface frame w.r.t. its launcher adapter shall be specified.

NOTE 1 This frame often coincides with the spacecraft mechanical reference frame.

NOTE 2 The spacecraft mechanical reference frame, defined in the CSD, can be replicated in the MICD.

f. The mechanical reference frames for the spacecraft, adapter and launch vehicle should be parallel and have the same positive direction.

NOTE This is sometimes not possible because clocking the satellite inside the launcher can impose an angle around the vertical axis of the launcher.

5.4.6 Planet coordinates

a. The specification of geodetic/planetocentric coordinates shall include the parameters of the ellipsoid used, direction and origin of longitude, and definition of the North Pole.

5.4.7 Coordinate system parameterisation

a. Any parameterisaton of a position or direction vector shall be specified mathematically.

b. Permitted parameterisations of a coordinate system shall be specified in the CSD.

5.4.8 Transformation decomposition and parameterisation

a. A transformation between coordinate systems shall be decomposed into a translational transformation and a rotational transformation, in a given order.

b. The order of decomposition of a transformation between coordinate systems shall be the same throughout a project.

c. If rotation is composed of three elementary rotations, the order of rotations shall be specified.

d. Positive angles about an axis should be defined in a right handed sense.

e. Any left handed rotation convention shall be highlighted in the CSD.

f. An elementary rotation shall be defined by a rotation axis and an angle.

g. If the rotation is represented by a quaternion, the order and mathematical definition of the quaternion parameters shall be specified in the CSD.

NOTE E.g. possibilities for the parameter order and the scalar part of a quaternion representation include:

1. [q0, q1, q2, q3], with q0 = cos(Φ/2)

2. [q1, q2, q3, q4], with q1 = cos(Φ /2)

3. [q1, q2, q3, q4], with q4 = cos(Φ /2)

h. The rotation error quaternion shall be expressed with a positive scalar part.

NOTE This constrains the rotation angle to $[-\pi, +\pi]$.

i. Any parameterisation of a rotation shall be specified as a matrix in terms of the parameters.

j. If the rotation is represented by a 3x3 matrix, each matrix element shall be defined.

5.4.9 Transformation definition

a. A transformation between coordinate systems shall be defined in the parent coordinate system in three ways: verbally, mathematically and graphically.

NOTE E.g. see Table B-1 and Table B-2 in Annex B.

b. Any simplification of a transformation shall be specified, as well as its assumptions and validity.

c. The mathematical expression of the transformation between coordinate systems shall define the vector used for the translation, the method used for the rotation, and the order of the transformation.

d. The rows and columns of a transformation matrix shall be identified.

e. The transformation between coordinate systems shall be defined by a mathematical expression relating the coordinates of a point in one frame with its coordinates in the other frame.

f. The numerical values of the elements of a rotation matrix shall be consistent with the precision required by the users of the data.

g. Any alternative representation of a rotation between coordinate systems shall be specified in its matrix representation.

NOTE 1 Typical ways to represent a rotation include direction cosine matrix, elementary Euler rotations and quaternions.

NOTE 2 Quaternion multiplication is sometimes preferred to matrix multiplication, when combining rotations in software calculations.

NOTE 3 The uncertainty of transformed quantities is not the transformation of the uncertainties. See [3] for pointing errors and [4] for measurement errors.

h. The time dependency of a transformation between coordinate systems shall be defined.

NOTE The transformation from ICRS to a spacecraft CoM coordinate frame can entail relativistic models.

i. For time dependent transformations the method of interpolation shall be specified.

NOTE E.g. Inter-sample value of a quaternion.

Annex A (normative) Coordinate Systems Document (CSD) - DRD

A.1 DRD identification

A.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-10-09, requirement 5.2.2a.

A.1.2 Purpose and objective

Proper documentation and maintenance of coordinate systems and their inter-relationships, throughout the product tree and the project/mission life, shall be initiated with sufficient detail. Standard requirements for the document and related database would help to regularise conventions even earlier.

A.2 Expected response

A.2.1 Scope and content

<1> Introduction

a. The CSD shall describe the purpose, objective and the reason prompting its preparation (e.g. programme, project and phase).

<2> Applicable and reference documents

a. The CSD shall list the applicable and reference documents supporting the generation of the document.

<3> Convention and Notation

a. The CSD shall specify the international conventions used within the project for coordinate systems and transformations.

b. The CSD shall define the naming, notation and acronym rules for coordinate systems, as well as for transformations.

c. The CSD shall define notation conventions for the transfer of coordinates and transformation data.

<4> Units

a. The CSD shall specify the units pertaining to the coordinate systems and parameterisations used within the project.

<5> Time standards

a. The CSD shall specify the time standards used within the project and shall specify the relationship between them.

<6> Coordinate system, overview

a. The CSD shall present the overview of the various coordinate systems.

b. The overview shall contain a brief description of at least the following coordinate systems, if applicable:

1. Inertial Coordinate Systems
2. Orbital Coordinate Systems
3. Launcher Coordinate Systems
4. Satellite-fixed Coordinate System (generic platform and payload)
5. Body-fixed Rotation (planet) Coordinate Systems
6. Topocentric Coordinate Systems
7. Test facility Coordinate Systems
8. Simulator Coordinate Systems
9. Processing / Product Coordinate Systems

c. The description shall refer to the theory and conventions applied in between the various coordinate systems (e.g. precession, nutation, polar motion).

<7> Parameterisations

a. The CSD shall describe all parameterisations used within a coordinate system (e.g. azimuth, elevation), including the applicable type of coordinate systems where this parameterisation is allowed.

b. The CSD shall describe all parameterisations used within a transformation (e.g. quaternions, Euler angles), including the applicable type of coordinate systems where this parameterisation is allowed.

<8> Diagrams

a. The CSD shall describe in a graphical representation the top-level chain of transformations for the project.

b. The diagram of <8a> shall include any additional constraints between coordinate systems, as well as measurements.

c. The CSD shall describe in a graphical representation the lower level chains of transformations.

d. Each individual coordinate system, identified in <9> below, shall be graphically represented.

e. These diagrams shall contain any additional constraints between coordinate systems, as well as measurements.

<9> Coordinate systems, details

a. The CSD shall give the detailed description of all Coordinate Systems used in the project.

b. The transformation between coordinate systems shall be defined in the one that is the parent coordinate system.

c. Parameterisations within a coordinate system shall be identified and specified.

NOTE E.g. right ascension and declination.

d. The parameterisation of a transformation shall be identified and specified.

NOTE E.g. quaternions.

e. Any source document for a coordinate system shall be identified in the CSD.

A.2.2 Special remarks

The CSD can be part of the SEP (as defined in ECSS-E-ST-10).

Annex B (informative) Transformation tree analysis

B.1 General

Issues involved in the definition of coordinate systems and the transformations between them are illustrated via examples below.

B.2 Transformation examples

A coordinate system can be defined using a "Franck" template to ensure that all relevant and necessary items have been covered. See the examples of Table B-1 and Table B-2, in which the transformation between a coordinate system and its parent coordinate system is also defined.

NOTE Use of a Franck template helps to show that the combination of successive transformations is not, in general, purely a product of matrices.

B.3 Tree analysis

Transformation chain analysis starts with a decomposition of the system into a product tree, see Figure B-1. This is followed by identification of the chains of transformations at a particular system level. The analysis is repeated at lower levels of the product tree, with the introduction of intermediate coordinate systems, if more detail is needed, see Figure B-2.

B.4 Franck diagrams

A "Franck" diagram of transformation chains is a directed graph, composed of nodes connected by arrows. Each node is a frame, having an origin and axes. The arrow points from the parent frame to the child frame. A parent can be natural (i.e. from the definition of the child frame) or adopted (i.e. by decision). The arrow thus indicates the forward direction of the translational and rotational transformation.

A connected graph is one in which it is possible to find a path from any node to any other node, not necessarily following the direction of the arrows. The graph can have a loop or closed path. This can occur when, for example, a robot grapples the body to which it is physically connected, or when two spacecraft are docked together. Additional arrows (broken lines) can be added to indicate measurement or estimation.

Figure B-3 shows a Franck diagram for a spacecraft, whilst Figure B-4 shows a preliminary Franck diagram for star tracker alignment.

Table B-1: Example of mechanical body frame

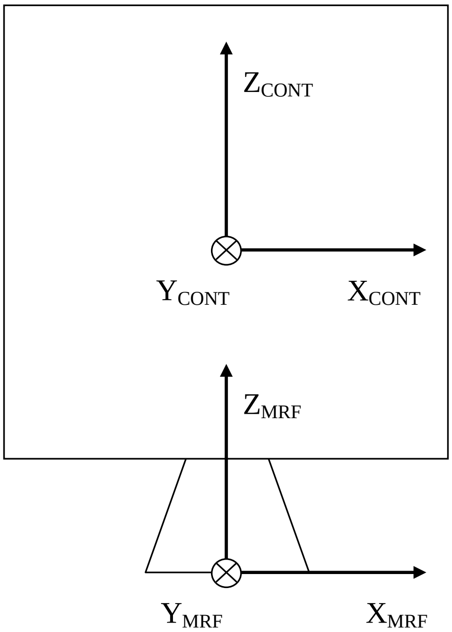
<table>
<tr><td>TYPE :
Spacecraft fixed</td><td>Title/Name :
Attitude control frame</td><td>Mnemonic :
CONT</td><td>ID :
S/C-CONT-01</td></tr>
<tr><td colspan="4">Definition :
Origin at spacecraft centre of mass
Axes parallel to the Mechanical Reference Frame (MRF) axes and with the same sign</td></tr>
<tr><td colspan="4">Rationale : The coordinates of a point in S/C-MRF-01 are related its coordinates in S/C-CONT-01</td></tr>
<tr><td colspan="4">Transformation :
from MRF, S/C-MRF-01
Translation : defined by the coordinates of the centre of mass of the spacecraft in MRF
Rotation : none
Order : not applicable</td></tr>
<tr><td colspan="4">Comments/limitations : This centre of mass frame is applicable for the idealised case of a rigid body. The null rotation is included here explicitly, as an example. In general, it may take other values.</td></tr>
<tr><td colspan="4">Formula :
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{MRF} = \underbrace{\begin{bmatrix} X_{COM} \\ Y_{COM} \\ Z_{COM} \end{bmatrix}_{MRF}}_{\text{Translation}} + \underbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{\text{Rotation}} \times \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{CONT}$$</td></tr>
<tr><td colspan="4">Diagram:

</td></tr>
</table>

Table B-2: Example of orbital coordinate system

TYPE : Pseudo-inertial	**Title/Name :** Equatorial coordinate frame	**Mnemonic :** E	**ID :** IN-E-01

Definition :

Origin is at the centre of the Earth.

The X axis lies in the equatorial plane and passes through the intersection of the equator with the meridian line at Kourou longitude.

The Z axis is the rotation axis of the Earth

The Y axis completes the right handed triad

Rationale : The equatorial coordinate frame is used to depict the trajectory of the launcher from Earth to Orbit. Navigation and Guidance data (position, velocity and attitude) may be provided in this frame.

Transformation :

from True of Date frame (TOD), IN-TOD-01

Translation : none

Rotation : defined by the following matrix

$$M_{E2TOD} = \begin{bmatrix} \cos(\theta_{E2TOD}) & \sin(\theta_{E2TOD}) & 0 \\ -\sin(\theta_{E2TOD}) & \cos(\theta_{E2TOD}) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where θ_{E2TOD} is the angle (in radians) between the X axis of the equatorial coordinate frame and the true line of equinox directed towards the Sun at the vernal equinox

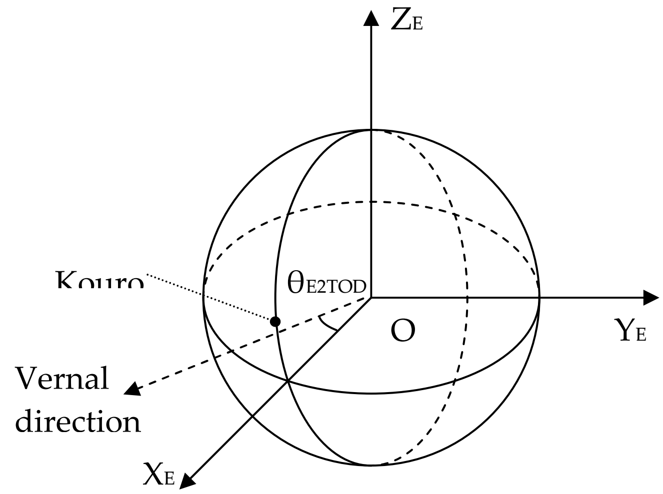
Order : not applicable

Comments/limitations : This equatorial frame is frozen at a given time.

Formula :

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{TOD} = \underbrace{\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}_{TOD}}_{\text{Translation}} + \underbrace{M_{E2TOD}}_{\text{Rotation}} \times \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{E}$$

Diagram :



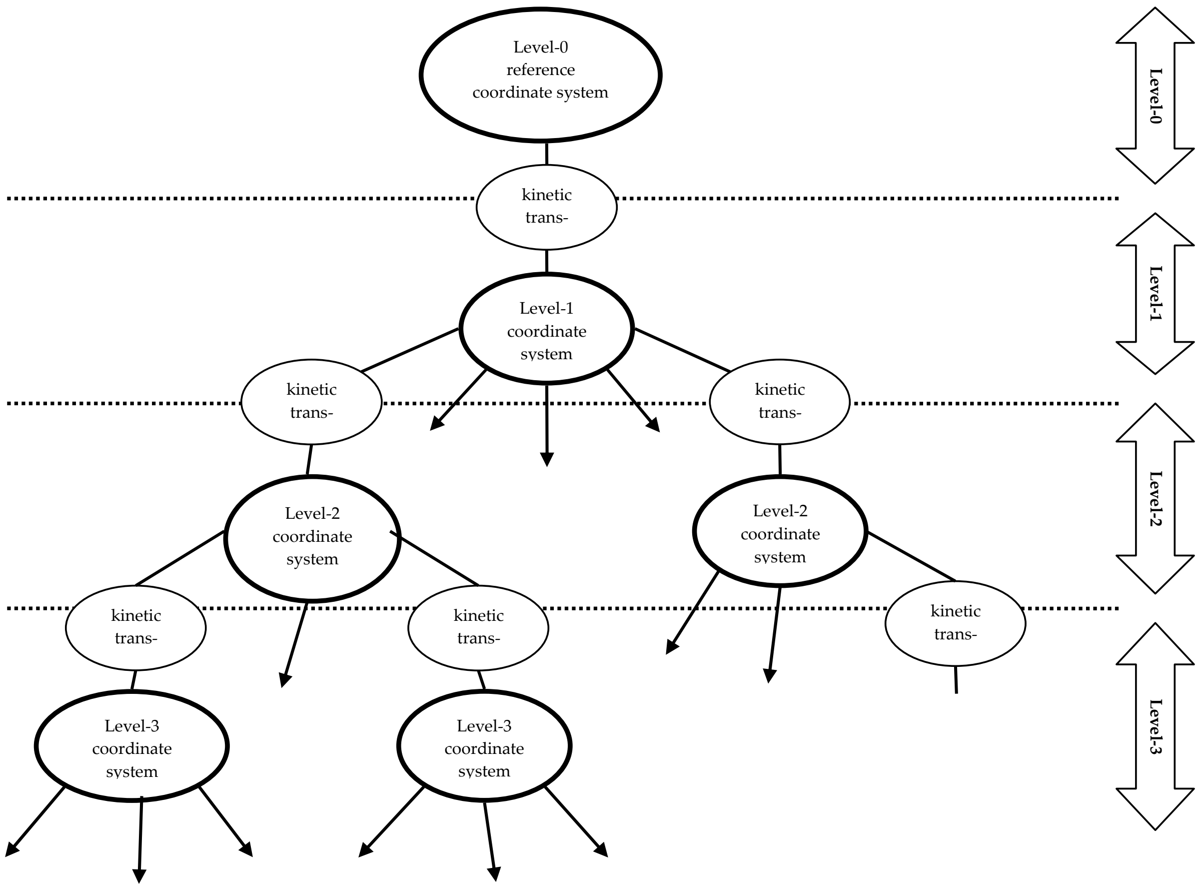
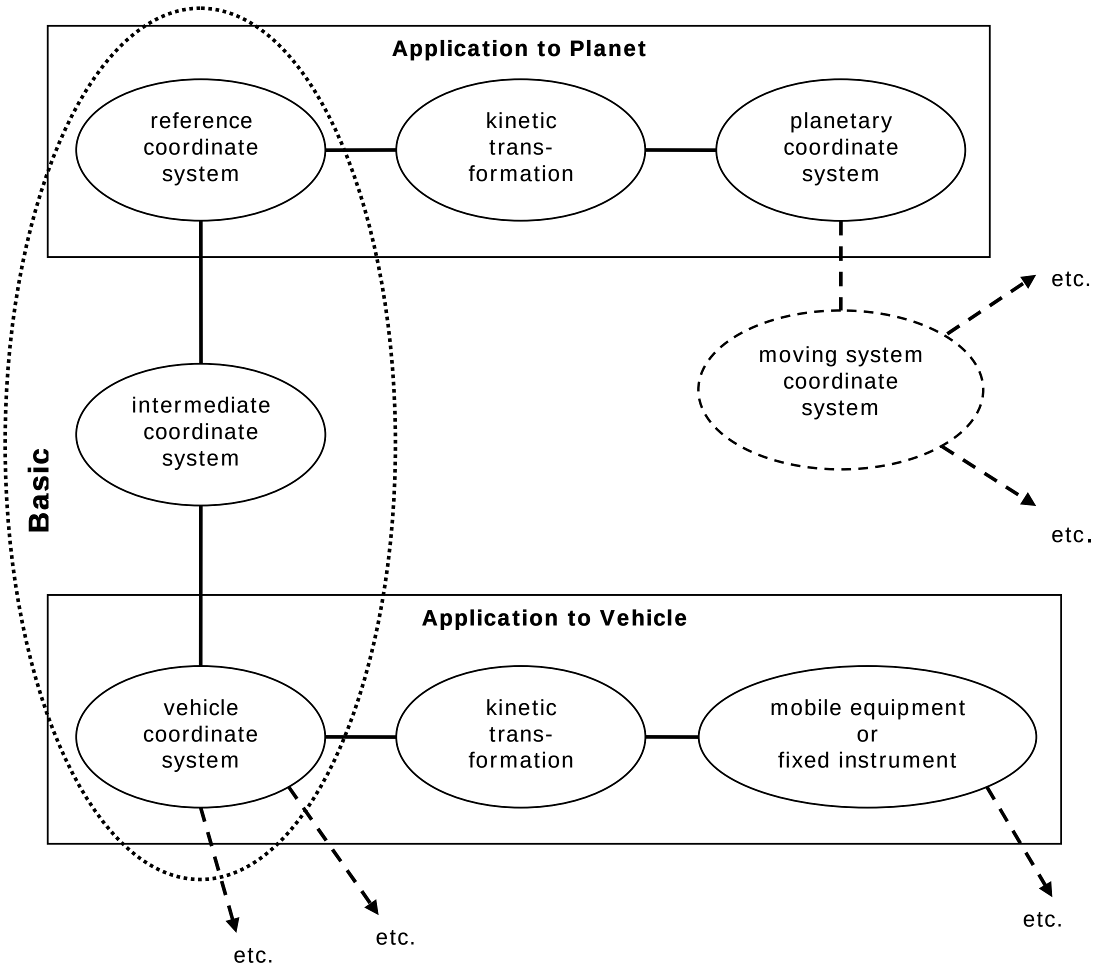


Figure B-1: General tree structure illustrating a product tree



NOTE A kinetic transformation can have some fixed or constrained degrees of freedom (DoF).

Figure B-2: Transformation chain decomposition for coordinate systems

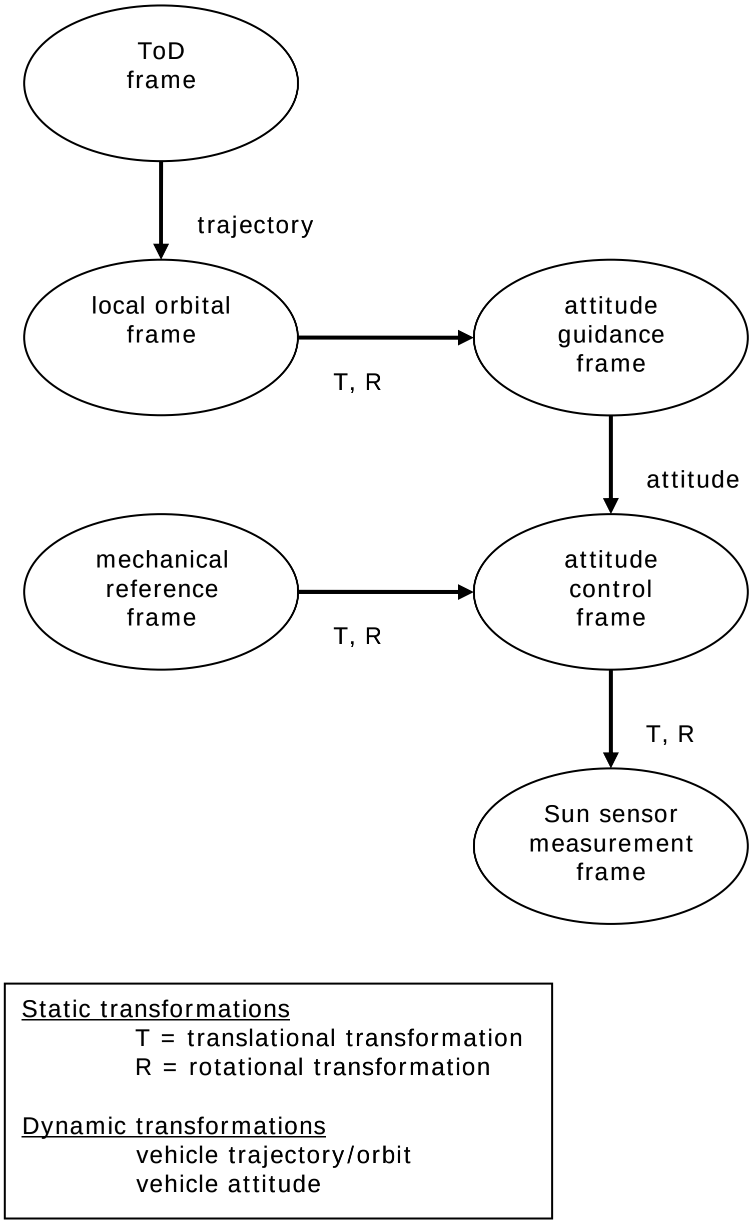


Figure B-3: Example of Franck diagram for a spacecraft

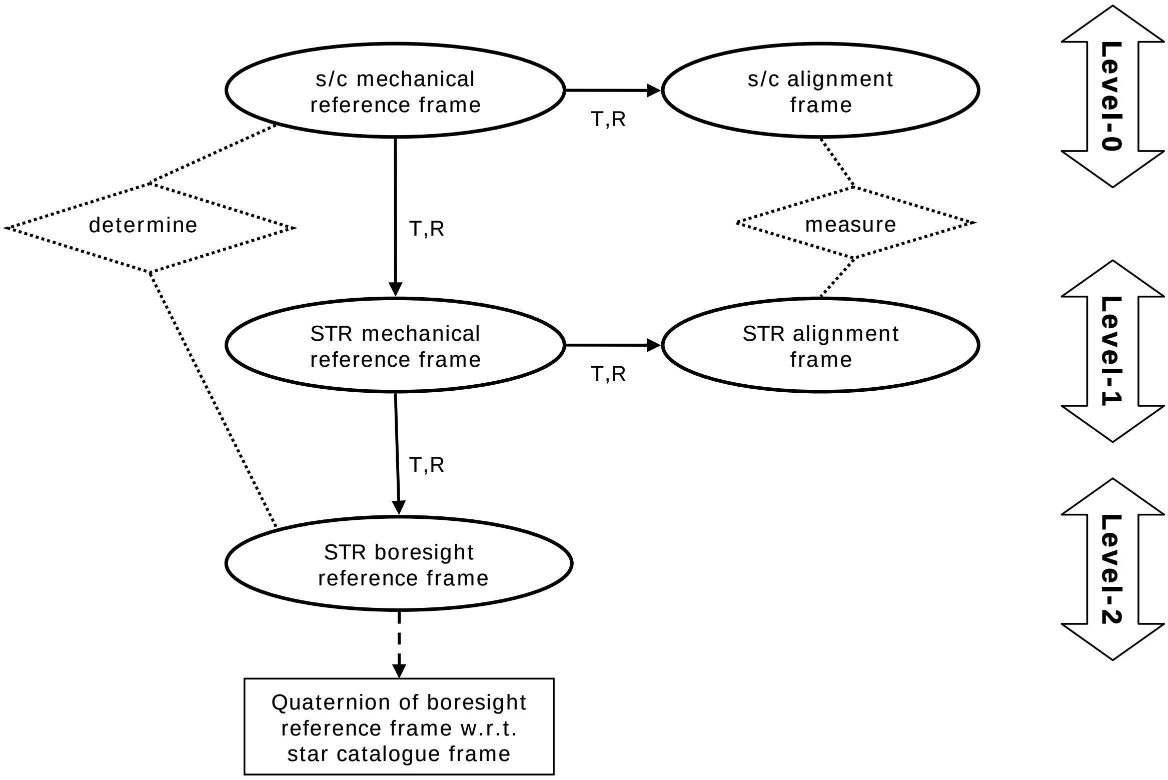


Figure B-4: Example of Franck diagram for a star tracker

Annex C (informative) International standards authorities

C.1 Standards

The international authorities listed below define and maintain reference information.

C.2 Time

C.2.1 United States Naval Observatory (USNO)

The Official Source of Time for the Department of Defense (DoD) and for the Global Positioning System (GPS), as well as a Standard of Time for the United States.

See <http://tycho.usno.navy.mil/systime.html> for a concise summary of the definitions of time, e.g. Terrestrial Time (TT).

C.2.2 Bureau International des Poids et Mesures (BIPM)

The task of the BIPM is to ensure world-wide uniformity of measurements and their traceability to the International System of Units (SI). See <http://www.bipm.fr/en/home/>.

The link to time information and link to the ftp server is <http://www.bipm.org/en/scientific/tai/>. Click on “Circular T” for information on TAI and UTC.

Data for calculating TAI are available at <ftp://ftp2.bipm.org/pub/tai/>.

C.3 Ephemerides

C.3.1 Institut de Mécanique Céleste et de Calcul des Ephémérides (IMCCE)

The ephemerides of the planets and bodies of the solar system are produced at the IMCCE. See <http://www.imcce.fr/>.

Information on direct link to solar system ephemeris data is available at:

<ftp://ftp.imcce.fr/pub/ephem> and

<http://www.imcce.fr/inpop>.

C.3.2 Jet Propulsion Laboratory (JPL) ephemerides

Jet Propulsion Laboratory (JPL) provides ephemerides for planets, planetary satellites, comets and asteroids in the DExxx frame. The Moon ephemeris is in the LExxx frame. In addition, tools are provided for the correct interpretation of the data. See <http://ssd.jpl.nasa.gov/?ephemerides>.

C.4 Reference systems

C.4.1 International Earth Rotation and Reference Systems Service (IERS)

The IERS realises the definition, models and procedures for standard reference systems. These are based on resolutions of international scientific unions, such as the IAU and the IUGG. They include the celestial system, the terrestrial system, the transformation between the celestial and terrestrial systems, definition of time coordinates and time transformations, models of light propagation and motion of massive bodies. See <http://www.iers.org/>.

See <http://www.iers.org/documents/publications/tn/tn32/tn32.pdf> for Technical Note 32 [2], which is updated regularly by the IERS to account for geophysical modifications. Chapters 2 and 3 treat the ICRS and ITRS, whilst chapter 4 provides the transformation from the celestial frame to a conventional terrestrial frame.

Many ftp-links are provided for maintained software.

C.4.2 International Astronomical Union (IAU)

The IAU deals with all Solar system objects, whereas the IERS is concerned more specifically with the Earth. See <http://www.iau.org>.

The ICRS for the solar system and for the Earth are called the Barycentric Celestial Reference System (BCRS) and the Geocentric Celestial Reference System (GCRS) respectively, each having a “non-rotating” origin.

C.4.3 United States naval observatory (USNO)

The USNO also provides FORTRAN routines and data for the transformation between ITRS and GCRS.

See <ftp://maia.usno.navy.mil/conv2000/chapter5>.

At <http://maia.usno.navy.mil/index.html>, it is possible to get a snapshot definition of time and access the Earth rotation parameters, which are essential for the transformation between Earth-centred inertial coordinates and Earth-centred Earth-fixed coordinates. It is also possible to obtain IERS bulletins A, B and C automatically, by email.

C.4.4 National Imagery and Mapping Agency (NIMA)

The world geodetic system, WGS84 (valid until 2010), defines Earth reference frames for use in geodesy and navigation. Though rather old, it is used for GPS. It provides the most accurate geodetic and gravitational data and local datum transformation constants and formulae for transforming different data into WGS84, see
<http://earth-info.nga.mil/GandG/publications/tr8350.2/tr8350_2.html>.

C.5 Consultative Committee for Space Data Systems (CCSDS)

C.5.1 Navigation

Navigation data – definitions and conventions, informational report CCSDS 500.0-G-2, Green book, November 2005, see
<http://public.ccsds.org/publications/archive/500x0g2.pdf>.

Spacecraft navigation data are exchanged between CCSDS member agencies during cross support of space missions. The Green Book establishes a common understanding for the exchange of navigation data. It includes orientation and manoeuvre information as part of the spacecraft navigation process. See chapter 4 for coordinate frame identification, time and astrodynamic constants.

C.5.2 Orbit

Orbit data messages – CCSDS 502.0-B-1, Blue book, September 2004, see <http://public.ccsds.org/publications/archive/502x0b1.pdf>.

This recommendation specifies two standard message formats for use in transferring spacecraft orbit information between space agencies: the orbit parameter message and the orbit ephemeris message. The document includes sets of requirements and criteria that the message formats have been designed to meet. Another mechanism may be selected for exchanges where these requirements do not capture the needs of the participating agencies.

C.5.3 Attitude

Attitude data messages – CCSDS 504.0-B-1, Blue book, see

<http://public.ccsds.org/publications/archive/504x0b1.pdf>.

This document specifies two types of standard attitude data message formats for use in transferring spacecraft attitude information between space agencies: the attitude parameter message and the attitude ephemeris message.

C.6 IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE)

The WGCCRE issues a report, following three-yearly IAU meetings, describing the currently recommended models for the cartographic coordinates and rotational elements of all solar system bodies. See <http://astrogeology.usgs.gov/Projects/WGCCRE/>.

References

[1] "The past, present and future of reference systems for astronomy and geodesy", G.A. Wilkins, Proceedings of the 141st symposium on the International Astronomical Union, Leningrad, October 17-21, 1989, (Kluwer academic publishers), pp 39-46.

[2] IERS Technical Note 32 "IERS conventions (2003)", D.D. McCarthy and G. Petit (eds.), US Naval Observatory (USNO) and Bureau International des Poids et Mesures (BIPM), 2004.

[3] "ESA Pointing Error Handbook", ESA-NCR-502, 19 February 1993.

[4] "Guide to the expression of uncertainty in measurement", ISO et al. 1995

Bibliography

ECSS-S-ST-00	ECSS system – Description and implementation
ECSS-E-ST-10	Space engineering – System engineering general requirements