The Consultative Committee for Space Data Systems

CCSDS Historical Document

This document's Historical status indicates that it is no longer current. It has either been replaced by a newer issue or withdrawn because it was deemed obsolete. Current CCSDS publications are maintained at the following location:

http://public.ccsds.org/publications/

Consultative Committee for Space Data Systems

RECOMMENDATION FOR SPACE DATA SYSTEM STANDARDS

RADIO METRIC AND ORBIT DATA

CCSDS 501.0-B-1

BLUE BOOK

JANUARY 1987

AUTHORITY

```
* * * * * * * * * * * * * * * * * * * * * * * * *
*         Issue:        Blue Book, Issue 1       *
*         Date:         January 1987             *
*         Location:     CCSDS Plenary Meeting    *
*                       November 1986            *
*                       Frascati, Italy          *
* * * * * * * * * * * * * * * * * * * * * * * * *
```

This Recommendation reflects the consensus technical agreement of the following member Agencies of the Consultative Committee for Space Data Systems (CCSDS):

- o Centre National D'Etudes Spatiales (CNES)/France.
- o Deutsche Forschungs-u. Versuchsanstalt fuer Luft und Raumfahrt e.V (DFVLR)/West Germany.
- o European Space Agency (ESA)/Europe.
- o Indian Space Research Organization (ISRO)/India.
- o Instituto de Pesquisas Espaciais (INPE)/Brazil.
- o National Aeronautics and Space Administration (NASA)/USA.
- o National Space Development Agency of Japan (NASDA)/Japan.

The following observer Agencies also concur with this Recommendation:

- o British National Space Centre (BNSC)/United Kingdom.
- o Chinese Academy of Space Technology (CAST)/People's Republic of China.
- o Department of Communications, Communications Research Centre (DOC-CRC)/Canada.

This Recommendation is published and maintained by:

CCSDS Secretariat
Communications and Data Systems Division (Code-TS)
National Aeronautics and Space Administration
Washington, DC 20546, USA

STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of member space Agencies. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed **RECOMMENDATIONS** and are not considered binding on any Agency.

This RECOMMENDATION is issued by, and represents the consensus of, the CCSDS Plenary body. Agency endorsement of this RECOMMENDATION is entirely voluntary. Endorsement, however, indicates the following understandings:

- Whenever an Agency establishes a CCSDS-related STANDARD, this STANDARD will be in accord with the relevant RECOMMENDATION. Establishing such a STANDARD does not preclude other provisions which an Agency may develop.

- Whenever an Agency establishes a CCSDS-related STANDARD, the Agency will provide other CCSDS member Agencies with the following information:

  - The STANDARD itself.

  - The anticipated date of initial operational capability.

  - The anticipated duration of operational service.

- Specific service arrangements shall be made via memoranda of agreement. Neither this RECOMMENDATION nor any ensuing STANDARD is a substitute for a memorandum of agreement.

No later than five years from its date of issuance, this Recommendation will be reviewed by the CCSDS to determine whether it should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or (3) be retired or cancelled.

FOREWORD

This document is a technical Recommendation for standardization of radio metric and orbit data generated by space data systems of Agencies of the Consultative Committee for Space Data Systems (CCSDS).

The topic areas covered herein include radio metric data, spacecraft orbital elements, solar system ephemeris, tracking station locations, astrometric data, reference systems, astrodynamic constants and spacecraft dynamics parameters. This Recommendation deals explicitly with the technical definitions and conventions associated with inter-Agency cross-support situations involving the transfer of orbital elements and ground-based conventional radio metric data, i.e., doppler and range.

Through the process of normal evolution, it is expected that expansion, deletion or modification of this document will occur. This Recommendation is therefore subject to CCSDS document and change control procedures which are defined in Reference [1].

Questions relative to the contents or status of this document should be addressed to the CCSDS Secretariat.

CCSDS HISTORICAL DOCUMENT

DOCUMENT CONTROL

Document	Title	Date	Status/Remarks
CCSDS 501.0-B-1	Recommendation for Space Data System Standards: Radio Metric and Orbit Data, Issue 1	January 1987	Original Issue

CCSDS HISTORICAL DOCUMENT

CONTENTS

REFERENCES

[1] "Procedures Manual for the Consultative Committee for Space Data Systems", Issue1, Consultative Committee for Space Data Systems, August 1985 or later issue.

[2] "Introduction of the Improved IAU System of Atronomical Constants, Time Scales, and Reference Frames into the Astronomical Almanac", Supplement to the *Astronomical Almanac 1984*, U.S. Government Printing Office, Washington, D.C., 1983.

[3] "Time Code Formats", Recommendation CCSDS 301.0-B-1, Issue 1, Blue Book, Consultative Committee for Space Data Systems, January 1987 or later issue.

The latest issues of CCSDS documents may be obtained from the CCSDS Secretariat at the address indicated on page i.

1 INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this document is to establish common recommendations for adequately exchanging data involved in orbit computation (extrapolation, reconstitution,...) to provide cross-support among missions and facilities of member Agencies of the Consultative Committee for Space Data Systems (CCSDS). In addition, it provides focusing for the development of multi-mission support capabilities within the respective Agencies to eliminate the need for arbitrary, unique capabilities for each mission.

The topic areas to be covered include radio metric data, spacecraft orbital elements, solar systems ephemerides, tracking station locations, astrometric data, reference systems, astrodynamic constants, and spacecraft dynamic parameters. These parameters define the scope of the panel activities, and all should deal explicitly with the technical definitions and conventions associated with inter-agency cross-support involving the transfer of orbital elements and ground-based conventional radio metric data, i.e., doppler and range.

1.2 APPLICABILITY

This Recommendation applies to the exchange of processed radio metric and orbital parameters between CCSDS Agencies in cross-support situations. In addition, it serves as a guideline for the development of compatible internal Agency standards in this field. This Recommendation is not retroactive, nor does it commit any Agency to implement the recommended radio metric and orbit data concepts at any future time. Nevertheless, all CCSDS Agencies accept the principle that all future implementations of radio metric and orbit data exchange which are used in cross-support situations will be based on this Recommendation.

Where preferred options or mandatory capabilities are clearly indicated herein, the indicated sections of the specification must be implemented when this Recommendation is used as a basis for cross-support. Where optional subsets or capabilities are allowed or implied in this specification, implementation of these options or subsets is subject to specific bilateral cross-support agreements between the Agencies involved.

The recommendations in this document are in be invoked through the normal standards programs of each member Agency, and are applicable to those missions for which cross-support, based on capabilities described in these recommendations, is anticipated.

2 TRANSFER OF SPACECRAFT ORBITAL ELEMENTS FROM ONE AGENCY TO ANOTHER

It is recognized that transfers of spacecraft orbital element from one Agency to another are useful for purposes such as:

(1) Pre-flight planning of a mission support, covariance analysis, tracking station viewperiods, etc.,

(2) In-flight inter-agency comparison of estimated spacecraft trajectories, software compatibility checks, solutions comparisons, etc.,

(3) Tracking station predicts in support of radio metric data interchanges.

In all cases it is important that Agencies participating in the interchange of orbital elements have a common understanding of the choice of parameters and the reference systems employed. The required resolution of each parameter is dependent on its intended use and should be jointly specified. The major items of the consensus proposal of the CCSDS are provided below:

(1) Orbital parameters interchanged between Agencies should be osculating rather than mean elements.

(2) The fundamental coordinates should be cartesian state (position and velocity) elements x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ at chosen time t.

(3) A secondary set of elements should accompany the primary cartesian set. These should be the Keplerian set a, e, i, Ω, ω and υ, the true anomaly at time t. The transformation to the Keplerian set should be performed at time t using a selected mass constant μ, which is also to be provided in the interchange.

(4) Units for x, y, z and a are to be kilometers; $\dot{x}$, $\dot{y}$, $\dot{z}$ in kilometers/second. Units of i, Ω, ω, and υ are to be in degrees and decimal fractions; μ in km^3/s^2.

(5) Time t is to be specified in Coordinated Universal Time (UTC) and given by year, month, day of month, hour, minute, seconds and decimal fractions of seconds. For deep space trajectories, which are normally numerically integrated in Barycentric Dynamical Time (TDB), which is essentially the same as Ephemeris Time (ET), an approximate UTC is suggested. This is derived from the simplified equations shown in Annex A. Alternatively, time t may be specified as a continuous count of seconds and subseconds. Suitable time code formats are given in Reference [3].

(6) The origin of the reference system should be selected as the center of body of a major gravity force and should be so specified in the interchange.

(7) The area/mass ratio in m^2/kg and the unitless drag coefficient should be provided when appropriate for drag computation.

(8) The area/mass ratio in m^2/kg and unitless solar reflectivity coefficient for solar pressure computations should be provided when appropriate.

(9) Other model parameters may be needed for some applications. Possible examples include solar flux and magnetic indicies for the atmospheric model, and gravitational terms.

3 REFERENCE SYSTEM

The following is a list of recommendations for reference system parameters to be exchanged between Agencies.

(1) Interchanged orbital elements (cartesian vector at time t) should be referred to one of the following four systems:

(a) The mean equator and equinox of J2000.0.[1]

(b) The mean equator and equinox of the date defined by t using the precession adopted in the J2000 system.

(c) The true equator and equinox of the date defined by t using precession an nutation adopted in the IAU J2000 system. This is an instantaneously-fixed system.

(d) The Earth-fixed system, which uses the true equator as defined in (c), above, but is rotating with the Earth and has the x-axis fixed with the prime meridian. The velocity is with respect to the rotating system.

(2) Gravity parameters and the particular choice of JPL planetary ephemeris should not be standardized, since these are updated on a periodic basis and Agencies will often want to use the latest most modern values. Agencies which provide gravity parameters and ephemerides are encouraged to:

(a) Provide products referenced to the J2000 system.

(b) Provide thorough and up-to-date documentation of any new product.

---

[1] The J2000 system adopted by the International Astronomical Union (IAU) in 1984 (Reference[2]), defines coordinate axes associated with earth's mean dynamical equator and equinox of the Julian ephemeris date 2451545.0. The system adopts modern values for earth precession and nutation and a modern transformation from universal to sidereal time. It also defines an earth fixed reference system presently maintained by the BIH (Bureau International de l'Heure: circulars D) and referred to the CIO (Conventional International Origin) and a zero point in longitude. It should be noted that the MERIT campaign has adopted the J2000 system as its standard for use in the intercomparing of new methods for the measurements of the Earth Rotation.

4 TRACKING DATA

The objective here is to facilitate exchanges of tracking data. Tracking data, however, are submitted to a variety of different computational devices. The philosophy now should be more oriented to the simplicity of exchange and the nature of data transmitted. This would guarantee correct usage. The CCSDS recommends the following items relating to the exchange of tracking data:

(1) Tracking data should be available for inter-agency support with all parameters given in powers of 10.

(2) Data should be provided in a time-ordered sequence, and tagged in UTC by year, month, day, hour, minutes, seconds and decimal fractions of seconds.

(3) An Interface Control Document (ICD) should be jointly produced by both Agencies participating in a cross-support involving tracking data orbital elements. The ICD should precisely define the data to be transferred, the formats, calibrations for tracking data, a description of any ancillary data, and the complete description of the station location, including the earth-centered coordinates with their defining system, and the relative geometry of the tracking point and cross-axis of the antenna mount.

(4) Non-destruct doppler data should be provided as a time average of the frequency difference between the transmitted and received signals.

The doppler observable F, with units of hertz, is given by:

$$F = \frac{\Delta N}{\Delta t} = \frac{1}{\Delta t} \int_{t - \frac{1}{2}\Delta t}^{t + \frac{1}{2}\Delta t} (f_T - f_R)\, dt$$

where the effective transmitter frequency f_T is the actual constant transmitted frequency multiplied by any intermediate transponder frequency ratios, f_R is the frequency of the signal received at the receiving station and time t is the midpoint of the averaging interval Δt. The tag time (usually identified as the start, midpoint, or end of the averaging interval), the averaging interval Δt (in seconds), and the effective transmitter frequency f_T should be provided with the doppler observables. They also may be provided in the ICD, as appropriate.

(5) Range data should be provided as round trip light time in seconds and decimal fractions (one way light time when it is the case). The tag time (start or end of the round trip) should be specified with the range observables.

(6) Differenced observables,which may be derived when two stations are tracking (i.e., VLBI), should be provided in units analogous to doppler and range. They are, respectively, differential phase count per unit time, in hertz, and differential light time, in seconds.

(7) Tracking antenna angle data should be provided in degrees and decimal fractions in a system best suited to the antenna mount and defined in the ICD. For AZ-EL stations, it is recommended that the Azimuth be measured East from North.

(8) The location of the tracking station on earth should be specified by its geocentric spherical or cylindrical coordinates referred to the mean pole, equator, and zero degree meridian of 1903.0 (CIO). The x axis is along the intersection of the zero degree meridian (passing through the mean north pole of 1903.0) and the mean equator of 1903.0, the z axis is along the mean pole of 1903.0, directed north, and the y axis completes the right-handed rectangular coordinate system. The source of polar motion values (e.g., BIH or Naval Observatory) and their use should be included in the ICD.

(9) Agencies are encouraged to calibrate for tracking station delay in the tracking data, and define the calibrations in the ICD.

(10) Agencies are encouraged to provide local measurements of atmospheric conditions (temperature, pressure, and humidity) to aid users in their own media calibration. Further, ancillary data for the calibration of media effects are considered non-standard but can be provided if so desired if defined in the ICD.

(11) In general, all acquired data should be transferred in a cross-support activity, not just an edited data set, although flags can be set on some specific data to indicate that the generating agency believes those data to be sub-standard. Data sampling to reduce data volume is not precluded for high volume data if a previous agreement is documented in an ICD.

ANNEX A

TRANSFORMATION OF

BARYCENTRIC DYNAMICAL TIME (TDB)

TO APPROXIMATE

COORDINATED UNIVERSAL TIME (UTC)

(THIS ANNEX **IS NOT** PART OF THE RECOMMENDATION)

Purpose:

This Annex provides equations which can be used to convert Barycentric Dynamical Time to Approximate Coordinated Universal Time.

The conversion from Barycentric Dynamical Time (TDB) to Coordinated Universal Time (UTC) may be approximated by the equation:

$$UTC = TDB - (TDB - TAI) - (TAI - UTC)$$

where

TAI - UTC		=	integer number of seconds offset, from the BIH annual report (23 seconds as of July 1, 1985)
TDB - TAI (seconds)		=	$32.184 + 1.658 \times 10^{-3} \sin E$
ECCENTRIC ANOMALY	E	=	$M + e \sin M$
MEAN ANOMALY (radians)	M	=	$6.248291 + 1.99096871 \times 10^{-7}\, t$ t = TDB or TAI seconds past 1950 Jan 1, 0h
ECCENTRICTY OF EARTH'S ORBIT	e	=	.01672