CH-GFZ-RS-002

CHAMP Reference Systems, Transformations and Standards

	Name
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1. Spacecraft system:

The spacecraft system $X_{S/C}$, $Y_{S/C}$, $Z_{S/C}$ is body-fixed. The components are defined as followes:

Origin:	Spacecraft Centre of Gravity
$X_{S/C}$:	Aligned with the long side of the spacecraft towards the boom, in nominal attitude pointing in flight direction (roll axis)
$Y_{S/C}$:	Forming a right-handed system with $X_{S/C}$ and $Z_{S/C}$ (pitch axis)
$Z_{S/C}$:	Nadir pointing in nominal attitude (yaw axis)

2. Accelerometer instrument reference system

The accelerometer instrument reference system X_{ACC}, Y_{ACC}, Z_{ACC} is instrument-fixed. The axes and rotations are defined as followes (misalignments between the spacecraft and the accelerometer systems are small and have to be determined):

Origin:	Accelerometer proof-mass centre = (nominal) Spacecraft Centre of Gravity
X_{ACC} :	Anti-parallel to $Z_{S/C}$ (less sensitive axis)
Y_{ACC} :	Parallel to $X_{S/C}$
Z_{ACC} :	Anti-parallel to $Y_{S/C}$
Φ :	Rotation about X_{ACC}
Θ :	Rotation about Y_{ACC}
Ψ:	Rotation about Z_{ACC}

3. Advanced Stellar Compass

The attitude measurements are carried out by the CHAMP **A**dvanced **S**tellar **C**ompass (ASC). There are two units, one on the boom (ASC_A) and another mounted on the spacecraft body (ASC_B). Readings of the former are used for the interpretation of the magnetometer readings and the latter for instruments on the body. Each ASC unit comprises two **C**amera **H**ead **U**nits (CHU_i), where the index i runs from 1 to 4. The first two are assigned to ASC_A and the last two to ASC_B. The CHU_i have their own reference systems X_{ASCi}, Y_{ASCi} , Z_{ASCi} , where the components of these systems are defined as follows:

Origin:	Intersection of the CCD plane with optical axis of the camera
X_{ASCi} :	Along the rows of the CCD, almost parallel or anti-parallel to the $X_{S/C}$, completing the triad
Y_{ASCi} :	Along the columns of the CCD, having a negative component along $Z_{S/C}$
Z_{ASCi} :	Aligned with the camera head bore sight, pointing outward

The ASC_A Level-2 data contain the attitude of the boom optical bench in the Common Reference (CR) frame, which is fixed to the optical bench. This reference system is defined as the mean value between the frames of CHU_1 and CHU_2. The corresponding components X_{CF}, Y_{CF}, Z_{CF} may be transformed into ther spacecraft system by applying the three Euler angles Φ = 0.20°, Θ = 0.20°, Ψ = 0.96° in a 1 - 2 - 3 fashion. These rotation angles may vary by some hundreth of a degree due to flexing of the boom.

The readings from the CHU_3 and CHU_4 (body) are transformed into the spacecraft system (and merged if both sensor heads are simultaneously actice) by processing on ground, i.e. the attitude data given in the Level (1 and) 2 accelerometer file describe to a good approximation the orientation of the spacecraft system with respect to the stellar positions, given in the **I**nternational **C**elestial **R**eference **S**ystem (ICRS = true equator and equinox at epoch 2000.0).

The attitude measurements obtained by the ASCs are given in the form of quaternions (q_1, q_2, q_3, q_4). The following quaternion convention is used:

$$q_1 = e_x \cdot \sin\frac{\delta}{2}$$

$$q_2 = e_y \cdot \sin\frac{\delta}{2}$$

$$q_3 = e_z \cdot \sin\frac{\delta}{2}$$

$$q_4 = \cos\frac{\delta}{2},$$

where e_x, e_y and e_z are the direction cosines of the rotation axis and δ is the rotation angle. The obtained attitude is based on the Hipparcos star catalogue using star positions at the epoch 2002.0

4. Sensor reference points, given in the Spacecraft System

Antenna/Sensor	X(mm)	Y(mm)	Z(mm)
GPS PDO-Antenna Main*	-1488.0	0.0	-392.8
GPS POD-Antenna Reserve*	-1738.9	0.0	-260.6
GPS Occultation helix antenna**	-1643.1	0.0	-64.6
GPS Altimetry helix antenna**	857.0	241.0	233.0
LRR reference point***	0.0	0.0	250.0

*The coordinates refer to the middle point of the antenna. Phase centre offsets have to be determined.

** The reference point is the geometric centre of the cone of the antenna helix

*** The reference point is defined as the crossing point of the optical axes of all four cube corner prisms

5. Overhauser Magnetometer

The magnetic field magnitude is measured by the Overhauser Magnetometer (OVM). This instrument directly gives the magnetic field every second with a resolution of one hundredth of a Nanotesla. The OVM is regarded as the reference instrument for the magnetic field measurements. The applied gyro-magnetic ratio is

$$\gamma_p = 42.5763752 \text{ MHz/T}$$

and it is one of the CHAMP Standards. The orbit data going together with the OVM readings are given in the **C**onventional **T**errestrial **R**eference **S**ystem (CTRS).

6. Fluxgate Magnetometer

The three components of the magnetic field vector are measured by the Fluxgate Magnetometer (FGM). This instrument is rigidly mounted together with the ASC_A on the boom optical bench. The data, sampled at a high rate of 50 Hz, are averaged to 1 or 5 samples per sec for the Level 2 or 3 products, respectively.

The important instrument parameters (scale factor, bias and misalignment) are determined regulerly with the help of an OVM/FGM in-flight calibration procedure.

The vector magnetic field data are provided in two different reference frames. On of them is the Sensor System, which is rather similar to the Spacecraft System. For transforming the components of the Sensor System, X_{SS}, Y_{SS}, Z_{SS}, into the spacecraft frame the three Euler angles $\Phi = 0.251°$, $\Theta = 1.776°$, $\Psi = 0.474°$ have to be applied in a (1 - 2 - 3) fashion.

Transforming the magnetic field readings into a geophysical coordinate system (e.g. the local North, East, Centre (NEC) system, as done with the second set of vector fields) requires the application of ASC_A Level 2 attitude data. As a first step the magnetic field readings have to be transformed from the Sensor System into the boom optical bench Common Reference frame. Initial values for this rotation were determined during ground calibration (TMO test: see table below). Varifications/improvements of these angles are obtained as a by-product of the magnetic main field modelling.

Optical bench/sensor system transformation, Euler angles (1 - 2 - 3):

	Effective	**Φ**	**Θ**	**Ψ**
Initial values(TMO test)	2001-05-15	0.0893°	1.589°	-0.4814°
Early modelling results	2001-08-01	0.0550°	1.590°	-0.5050°

7. CHAMP-OG Reference Systems

CCRS (Conventional Celestial Reference System)	mean equator and equinox of J2000.0 (ICRF = International Celestial Reference Frame: IAU, IERS)
CDRS (Conventional Dynamical Reference System)	planetary and lunar ephemerides JPL DE403/LE403, planetary masses, astronom. constants
Precession	IAU 1976
Nutation	IAU 1980 + EOP(IERS)C04 daily corrections,
Earth rotation	EOP(IERS)C04 daily Earth orientation parameters
CTRS: (Conventional Terrestrial Reference System) speed of light time evolution scale	geocentric (centre of whole Earth mass), ITRF96 (International Terrestrial Reference Frame) with IERS reference pole (IRP ~ CIO) and IERS reference meridian (IRM ~ BTS) c = 299792458 m/s no-global-net-rotation w.r.t. NNR-NUVEL1A consistent with TT
Earth Reference Ellipsoid	R = 6378136.46 m (equatorial radius of Earth) 1/f = 298.25765 (inverse flattening of reference ellipsoid) $\omega = 0.7292115 \cdot 10^{-4}$ rad s^{-1} (nominal 1994 mean angular velocity of Earth) $\dot{\omega} = -4.5 \cdot 10^{-22}$ rad s^{-2} (1.7 ms/cy in LOD) GM = 398600.4415 km^3/s^2 (TT)

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values/models according to IERS conventions (1996) plus errata, constants transformed to 'tide-free' system

8. CHAMP Panel Areas (Macro Model)

1. column: area [m^2]
2.-4. column: normalized vector normal to the area in the **Accelerometer instrument reference system**

1.2920	1.00000000	0.00000000	0.00000000	CHAMP Top
3.6239	-1.00000000	0.00000000	0.00000000	CHAMP Bottom
3.1593	0.70700000	0.00000000	0.70700000	CHAMP Left Solar Panel
0.3020	-0.70700000	0.00000000	-0.70700000	CHAMP Left Solar Panel apron
3.1593	0.70700000	0.00000000	-0.70700000	CHAMP Right Solar Panel
0.3020	-0.70700000	0.00000000	0.70700000	CHAMP Right Solar Panel apron
0.4902	-0.34200000	-0.93970000	0.00000000	CHAMP Aft Panel
1.2199	-0.93970000	0.34200000	0.00000000	CHAMP Front Panel
0.9300	1.00000000	0.00000000	0.00000000	CHAMP Top Boom
0.9300	-1.00000000	0.00000000	0.00000000	CHAMP Bottom Boom
0.9300	0.00000000	0.00000000	-1.00000000	CHAMP Left Boom
0.9300	0.00000000	0.00000000	1.00000000	CHAMP Right Boom
0.0529	0.00000000	1.00000000	0.00000000	CHAMP Front Boom