CUBESPACE

CubeWheel Gen 2

Product Description

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PREPARED BY	C. LEIBBRANDT
REVIEWED BY	LV, DS, JM
APPROVED BY	W. Morgan
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Reference Documents

The following documents are referenced in this document.

[1] CS-DEV.PD.CA-01 CubeADCS Product Description Ver.1.01 or later

[2] CS-DEV.ICD.CW-01 CubeWheel ICD Ver.1.00 or later

[3] CS.DEV.UM.CW-01 CubeWheel User Manual Ver.1.00 or later

List of Acronyms/Abbreviations

ACP	ADCS Control Program
ADCS	Attitude Determination and Control System
CAN	Controller Area Network
COTS	Commercial Off The Shelf
CSS	Coarse Sun Sensor
CVCM	Collected Volatile Condensable Materials
DUT	Device Under Test
EDAC	Error Detection and Correction
EHS	Earth Horizon Sensor
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FDIR	Fault Detection, Isolation, and Recovery
FM	Flight Model
FSS	Fine Sun Sensor
GID	Global Identification
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GYR	Gyroscope
I2C	Inter-Integrated Circuit
ID	Identification
LTDN	Local Time of Descending Node
LEO	Low Earth Orbit
MCU	Microcontroller Unit
MEMS	Microelectromechanical System
MTM	Magnetometer
MTQ	Magnetorquer
NDA	Non-Disclosure Agreement
OBC	On-board Computer
PCB	Printed Circuit Board
RTC	Real-Time Clock
RWA	Reaction Wheel Assembly

RW	Reaction Wheel
SBC	Satellite Body Coordinate
SOFIA	Software Framework for Integrated ADCS
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
SSP	Sub-Satellite Point
STR	Star Tracker
TC	Telecommand
TCTLM	Telecommand and Telemetry (protocol)
TID	Total Ionizing Dose
TLM	Telemetry
TML	Total Mass Loss
UART	Universal Asynchronous Receiver/Transmitter

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1 Introduction

This document presents and describes the CubeWheel as a standalone product which may be integrated with a client satellite system.

This document is a prelude to the CubeWheel ICD (see[2]) and standard CubeWheel Product User manual (see [3]), providing further detail.

This CubeWheel product description henceforth documents all its features, characteristics and capabilities to serve as an introduction of the product.

Different client scenarios are catered for, namely:

1. Purchasing of a CubeWheel offering by a knowledgeable client who requires no further assistance,
2. Purchasing of a CubeWheel where the client initially requires CubeSpace consultation and suggestions to be able to make an informed decision on which CubeWheel variant to choose to optimally fulfil the client's requirements.

2 CubeWheel Context

An integrated CubeADCS is made up of several sub-systems, also referred to as CubeProducts.

CubeADCS, and therefore also the CubeWheel as a subsystem of the CubeADCS, is designed with modularity in mind. CubeProducts are typically mass manufactured, resulting in short production times and increased reliability through repeatability.

The integrated CubeADCS consists of an ADCS computer (the CubeComputer subsystem) and various other subsystems -sensors and -actuators, also referred to as nodes, connected via harnesses. The CubeWheel is defined as a subsystem of type actuator.

In such an integrated CubeADCS, the satellite OBC will interface with the CubeComputer, which will, in turn, interface with the CubeWheel described in this document. However, each CubeProduct is offered as a standalone product and allows for direct interfacing to a client system/client ADCS, utilising the electrical-, -electronic and mechanical interfacing normally utilized for interfacing to the CubeADCS.

All electrical and mechanical interfacing details for the CubeWheel are presented in [2].

A software library is available for inclusion in OBC source code, to facilitate communication with the CubeProduct and to ensure messages are formatted correctly. API and protocol details are also provided, should the client wish to develop their own interfacing code.

The CubeWheel User Manual (see [3]), is also provided, both typically post-order placement, to guide the client user to be able to conduct a health check test after receipt of the physical item and to enable the user to set the CubeWheel to work within the client system/environment.

3 CubeWheel detailed description

3.1 Overview

A range of robust reaction wheels with built-in driver- and interface electronics are available. The CubeWheel offers improved vibration tolerance to withstand demanding mission requirements, compared to the generation 1 offering.

CubeSpace achieved this robust design through high-load space-rated bearings coupled with precision balancing. Integrated into each wheel is a radiation-tolerant electronic drive circuit and speed controller. The ease of use, together with the robust design, makes the CubeWheel the perfect reaction wheel for satellites with strict performance requirements and high reliability demands.

The main features of CubeWheel include:

- Robust mechanics
- Magnetically shielded with internal mu-metal shielding
- Integrated drive electronics
- Gen2 common node design with in-orbit re-programmability
- Robust mounting with threaded holes and stainless steel helicoil inserts

Depending on the application, a satellite may benefit from either a single momentum wheel, 3 wheels mounted orthogonally, or 4 wheels in a pyramid configuration.

A single momentum wheel enables a satellite to be stabilized so that the attitude can be maintained in the presence of disturbances. Three-axis orthogonal wheels enable the satellite to perform arbitrary manoeuvres such as sun tracking, target tracking and roll, pitch and yaw reference following. Redundancy against failures is aided by including a 4th wheel in a pyramid configuration. In such a configuration the satellite can still meet pointing requirements even if one wheel fails.

An overview of the CubeWheel and its physical configuration options available is presented in Table 1.

Table 1: CubeWheel description

ITEM	DESCRIPTION	
CubeWheel (Sub-System) 	Description	Balanced reaction- or momentum wheel
	Details	Individually balanced to specification, Excellent zero-crossing behaviour, Available in various sizes (CW0017, CW0057 and CW0162) to suit a wide range of missions
	Generic Term	Reaction Wheel (RWL)
	CS Name and acronym	CubeWheel (CW)
CubeWheel Pyramid (Sub-System) 	Description	4 Wheels mounted in pyramid structure
	Details	Mounts all four wheels at optimal angles for redundancy
	Generic Term	N/A
	CS Name and acronym	CubeWheel Pyramid (CW pyramid)

10 Elektron Rd, Techno Park, Stellenbosch, 7600, South Africa

3.2 Subsystem diagram

Figure 1 provides a high-level block diagram of the CubeWheel.

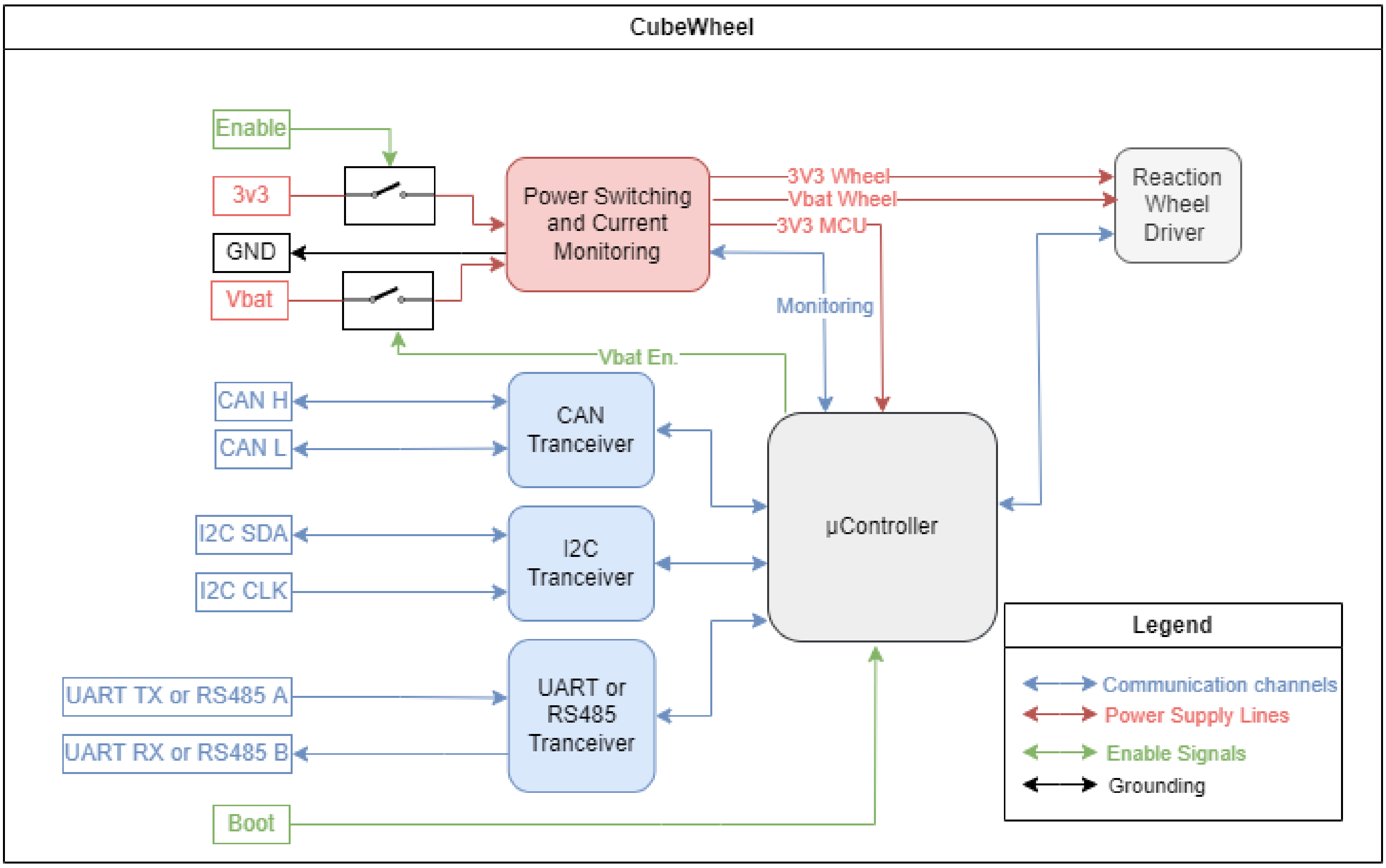

Figure 1: CubeWheel block diagram

3.3 Performance characteristics

The CubeWheel performance characteristics are presented in Table 2 below.

Table 2: CubeWheel performance characteristics

PERFORMANCE	CW0017	CW0057	CW0162	CW0500*	CW1200*	CW2500*	CW5000*
Nominal Motor Supply Voltage [V]	8	12	12	12	16	TBD	TBD
Supply Voltage for max speed [V]	6.4	11	11	12	12	TBD	TBD
Max Speed [RPM]	10000	10000	10000	10000	10000	10000	10000
Momentum @ 6000 RPM [mNms] ***	1.77	5.7	16.2	50	120	250	500
Saturation Torque [mNm]	0.23	2	7	16	20	27	37
Dynamic Imbalance [g.cm²]	<0.005	<0.014	<0.014	<0.05	TBD	TBD	TBD
Physical							
Mass [g]	60	115	144	310	TBD	TBD	TBD
Dimensions [WxHxL] [mm]	28x26x28	35x24x35	46x24x46	66x25.5x66	76x30x76	88x40x88	100x40x100
Power & Data							
Data Bus**	CAN/UART/RS-485						
Connector	Molex Micro-Lock Plus				Harwin Gecko SL		
Digital Supply Voltage [V]	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Motor Supply Voltage Range [V]	6.4-16.8	6.4-16.8	6.4-16.8	6.4-16.8	TBD	TBD	TBD
Average Power [@2000 rpm] [mW]	180	336	336	~800	TBD	TBD	TBD
Peak Power [Max Torque] [W] (includes digital power)	0.85	2.7	7.2	~15	TBD	TBD	TBD
Qualification Level							
Radiation	24 kRad						
Random Vibration	14.16 g RMS (NASA GEVS)						
Thermal vacuum [°C]	-20 to 80						
Thermal cold and hot start [°C]	-35 to 70						

* Preliminary Specification

** I2C available for custom solutions

*** Momentum values are given for a 6000-rpm maximum wheel speed at minimum motor supply voltage. Higher momentum can be achieved with higher motor supply voltage

3.4 CubeWheel Actuator sizing

The CubeWheel actuators must be scaled based on the satellite's size, deployable structures, and required manoeuvrability.

The CubeWheel is available in a range of sizes as presented in Table 2 and can be selected based on mission needs. Below are same suggested guidelines:

- For satellite sizes up to 3U, up to 3 CubeWheels of variants CW0017 – CW0057 should be considered.
- For satellite sizes between 3U and 6U, up to 3 reaction wheels of variants CW0057 – CW0162 should be considered.
- For satellite sizes between 6U and 12U, up to 3 reaction wheels of variants CW0057 – CW0162 should be considered.
- For microsatellite sizes, up to 3 reaction wheels of variants CW0500 – CW5000 should be considered, noting however that these variants are currently in prototype phases.
- The number of reaction wheels for use as standalone subsystems within a client satellite is however unlimited.

3.4.1 Wheel configuration

Two configurations of reaction wheels are available, depending on mission needs. Table 3 details both available configurations.

Table 3: Wheel configurations

CONFIGURATION	DESCRIPTION	TYPICAL USE CASE
3-Axis	Three orthogonal reaction wheels are used to acquire full 3-axis control.	Earth-based pointing or target tracking, sun pointing, inertial pointing, satellite tracking
4-Wheel	Four reaction wheels, placed in a pyramid configuration, are used to acquire full 3-axis control. Wheels are biased to an offset speed, thus avoiding zero-crossings. If one of the wheels fail, 3-axis control is still available.	Same as 3-Axis, but with more stability and redundancy.

3.5 Interconnect

The CubeWheel actuator is designed to be connected to the CubeADCS CubeComputer or to the client system by means of harnesses. These harnesses are based on the Molex Micro-Lock Plus family of wire-to-board connectors. These harnesses are made using wires with low-outgassing insulation.

Note that the black wires are available as off-the-shelf cable assemblies from some other vendors are made from PVC and do not have low outgassing properties.

All CubeProduct interface-related information is detailed in the Standard CubeWheel Interface Control Document (ICD). Refer to [2].

3.6 Pre-loaded firmware applications

The CubeWheel is supplied with two pre-loaded applications on the unit. The first is a Bootloader and the other is the Control Program.

3.6.1 Bootloader

The Bootloader is the first application to run when the CubeWheel is powered on. It has the following features:

- Allows for quick identification through communications messages and protocol that is common across all CubeProducts,
- Allows CubeWheel Control Program and configuration to be (remotely) updated,
- Supports FDIR,
- Exposes Bootloader API to Host Device over communication channels.

3.6.2 Control Program

The control program is the main program of the CubeWheel. Some of the main functions are in support of the CubeComputer or client master node:

- Supports FDIR,
- Supports CubeWheel management (e.g. power, status, setup, and configuration),
- Supports/Implements CubeWheel actuator commands,
- Reports CubeWheel measurement telemetry (wheel speed, current, temperature)
- Exposes Control Program API to host device.

3.7 CubeWheel coordinate systems.

The CubeWheel actuator implements its own Local Coordinate Frame (LCF). The CubeWheel LCF is defined in [2].

3.8 CubeWheel actuator placement

In general, all CubeSpace's attitude actuators, and specifically the CubeWheel, must be placed in locations far enough from sensitive payloads or sensors that can be disturbed by their magnetic fields or vibrations caused by the unbalance forces and torques of rotating discs.

Details are discussed in the following sub-section.

3.8.1 CubeWheel - Reaction and Momentum wheels

It is important to mount any wheels for attitude control as far as possible from magnetically sensitive magnetometers, imaging payloads, star tracker sensors and from rate sensors. In the case of imaging sensors and the rate sensors, mechanically induced vibration disturbances due to static unbalance forces, dynamic unbalance torques and bearing noise can cause blurring of images and an increase in rate measured noise.

For a satellite with a very high-resolution and narrow field-of-view imaging payload, the satellite designer should consider the use of vibration-damping fasteners for the wheels. It must also be standard practice to mount an imaging payload and a star tracker on an optical bench to mechanically separate them from the rest of the satellite bus, especially the spinning rotors of wheel actuators.

Reaction wheel jitter due to static unbalance can further be minimized by mounting reaction wheels close to the centre of mass of the satellite.

3.9 Harness lengths

Harness lengths are typically not known until a detailed satellite layout has been decided on. CubeSpace will supply a detailed wiring/harness list documenting all aspects of harnesses to the CubeWheel. CubeSpace will request the client to indicate harness lengths based on the final placement of the CubeWheel subsystems within the client satellite/system and the client's harness routing scheme.

3.10 Documentation

The CubeWheel is provided with a set of standard documents which are listed in Table 4:

Table 4: CubeWheel standard documentation

DOCUMENT	DESCRIPTION
Standalone Product Description (PD) - (This Document)	Provides an overview of the standard CubeSpace CubeWheel offering. It is typically supplied to prospective clients to allow a better understanding of the CubeSpace CubeWheel offering.
Standalone Interface Control Document (ICD)	Detailed information about the physical aspects of the standard CubeWheel offering addressing technical aspects of all interfaces. It is typically supplied to prospective clients to allow a better understanding of the CubeSpace CubeWheel offering and how to interface to it; electrically, mechanically and electronically.
API definition	Describes the communication messages that the CubeComputer or client host will use to interface with the CubeWheel in detail. It is typically only supplied to actual clients.
Standalone User Manual	Describes all functions and features in more detail (than provided in the Product Description). It also allows the user to conduct a Health Check to confirm the CubeWheel is “alive and well” after receipt of the shipment at the client. It is typically only supplied to actual clients.
Software Guide	Describes how to make use of provided software packages. It is typically only supplied to actual clients.
CubeProduct Firmware Reference Manual	Provides a complete description of protocols used by communication transport layers. It is typically only supplied to actual clients.
Bootloader Application Note	Describes how to use the Bootloader and make use of all features. It is typically only supplied to actual clients.
Delivery Report	Report to indicate that QA took place on the delivered unit and that a Complete health check was performed at CubeSpace before shipment.

4 Ground Support Equipment

4.1 Support software (CubeSupport application)

The user is provided with ground support software called CubeSupport. This allows the user to directly connect to the CubeWheel and to gain access to all telemetry values and all commands. The CubeSupport application also has convenient HMI elements for uploading- and upgrading firmware, and downloading event, image, and telemetry logs (as applicable for the connected CubeProduct).

4.2 Support hardware (CubeSupport PCB)

CubeSpace provides ground support equipment to allow the user to power and interface with the CubeWheel out of the box. All required cables, interfaces and documentation is provided to allow the user to perform a health check of the CubeWheel upon delivery to the client.

5 Appendix: CubeADCS Coordinates definition

The CubeADCS defines the satellite body coordinate (**SBC**) frame, which is "fixed" to the satellite body. When the satellite has a nominal attitude (zero pitch, -roll and -yaw) the **SBC** will coincide with the orbit reference coordinate system (**ORC**).

5.1 Orbit reference coordinate (ORC)

The **orbit reference coordinate (ORC)** frame, notated as $\mathbf{X}_{\mathrm{ORC}}$, $\mathbf{Y}_{\mathrm{ORC}}$, and $\mathbf{Z}_{\mathrm{ORC}}$, is defined throughout the CubeADCS literature as per Table 5 and Figure 2 below.

Table 5: CubeADCS Orbit reference frame notation

AXIS	POINTING DIRECTION
X_{ORC}	Flight Direction
Y_{ORC}	Orbit anti-normal direction
Z_{ORC}	Nadir direction

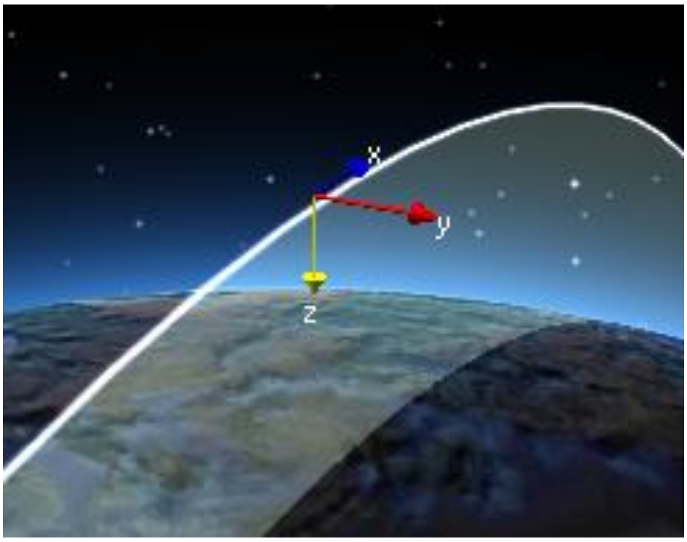

Figure 2: Orbit Reference Coordinate (ORC) frame

5.2 Spacecraft body coordinates (SBC)

The **spacecraft body coordinate (SBC)** frame is notated as $\mathbf{X}_{\mathrm{SBC}}$, $\mathbf{Y}_{\mathrm{SBC}}$, and $\mathbf{Z}_{\mathrm{SBC}}$, and must be "fixed" to the satellite such that when roll-, pitch- and yaw angles are zero, the X_{SBC} axis points along the velocity direction, Y_{SBC} points in the orbit anti-normal direction and Z_{SBC} points towards nadir. For non-zero attitude angles, the **SBC** will rotate with respect to the **ORC**, as depicted in Figure 3.

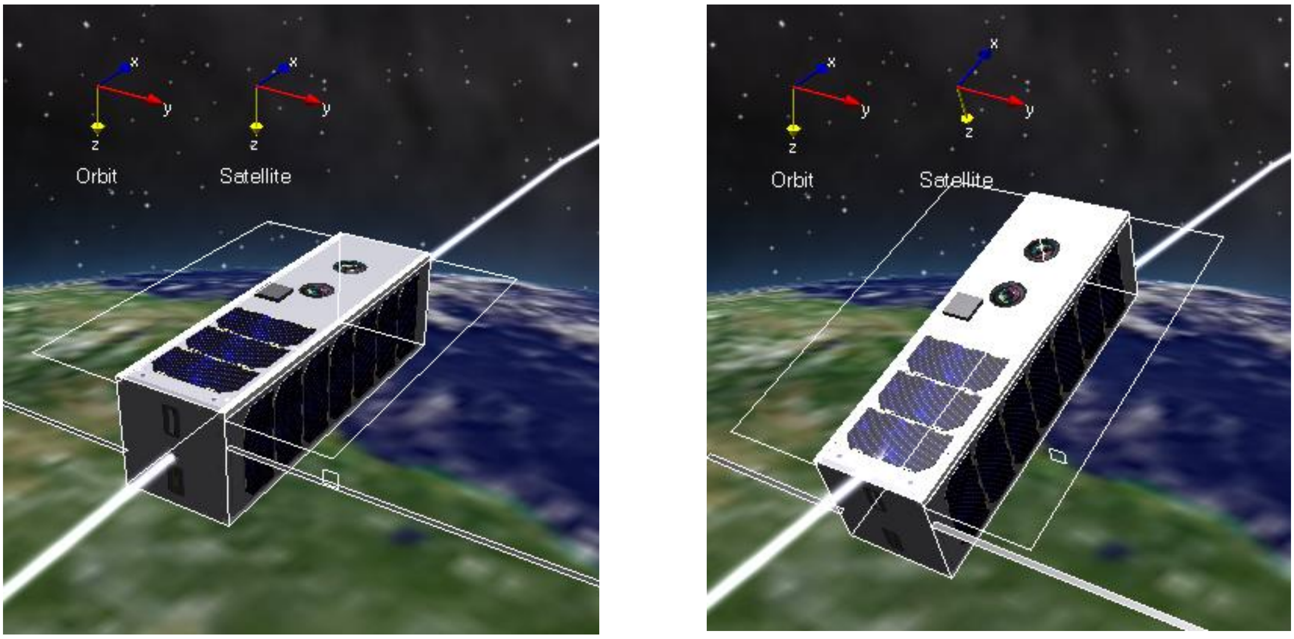

Figure 3: Satellite (spacecraft) Body Coordinate frame, relative to the Orbit Reference Coordinate frame for zero roll, pitch and yaw (left image) and a 20° pitch angle (right image)

5.3 CubeADCS defined SBC versus mechanical and CAD reference frames.

It is often the case that satellite designers use a spacecraft's axes definition for CAD or mechanical ICD purposes that may be different from the CubeADCS defined **SBC**. It is important to note that the ADCS does not attempt to translate or transform between a customer's CAD coordinate frame and the ADCS defined SBC. Instead, the ADCS defined SBC must be the only coordinate frame that is considered when specifying sensor or actuator mounting configurations, and when interpreting attitude angles.

5.4 Attitude angles convention

The CubeADCS follows an Euler 2-1-3 convention for roll, pitch and yaw angles.

5.5 Sensor/actuator mounting configuration

All actuators and sensors each have their own local coordinate systems. Each sensor and actuator mounting must be defined relative to the SBC through a transformation matrix. This means that the transformation matrix for each actuator or sensor should be known.