CUBESPACE

Product Description

CubeWheel - NanoSat & SmallSat Ranges

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1.02	J. Miller	14/02/2025	Update for Larger Wheels. Removed orbital reference frames appendix.
1.03	J. Miller, N Roets	23/02/2025	Updated torque values. Updated reference documents' revisions where applicable. Document structure and content refinements.

Reference Documents

The following documents are referenced in this document.

[RD1] CS-DEV.PD.CA-01 CubeADCS Product Description Ver.1.01 or later

[RD2] CS-DEV.ICD.CW-01 CubeWheel ICD NanoSat Range Ver.1.04 or later

[RD3] CS.DEV.UM.CW-01 CubeWheel User Manual Ver.1.03 or later

[RD4] CS-DEV.ICD.CW-02 CubeWheel ICD SmallSat Range Ver.1.00 or later

List of Acronyms/Abbreviations

ADCS	Attitude Determination and Control System
CAN	Controller Area Network
CW	CubeWheel
EM	Engineering Model
FDIR	Fault Detection, Isolation, and Recovery
HMI	Human Machine Interface
I2C	Inter-Integrated Circuit
ID	Identification
OBC	On-board Computer
RWL	Reaction Wheel
SBC	Satellite Body Coordinate
SPI	Serial Peripheral Interface
TC	Telecommand
TCTLM	Telecommand and Telemetry (protocol)
TLM	Telemetry
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 satellite system. It documents CubeWheel features, characteristics, and capabilities to serve as an introduction to the product. This document is a prelude to the CubeWheel Interface Control Document ([RD2] and [RD4]) and CubeWheel User Manual ([RD3]).

CubeSpace offers a comprehensive array of CubeWheel variants with specific momentum storage capacities, indicated by each product code. These are conveniently grouped into a NanoSat range and a SmallSat range, as shown in Table 1, below.

Table 1: CubeWheel Product Grouping

NanoSat Range		SmallSat Range	
CubeWheel Variant	Momentum Storage [mNms]	CubeWheel Variant	Momentum Storage [mNms]
CW0017	1.77	CW1200	120
CW0057	5.7	CW2500	250
CW0162	16.2	CW5000	500
CW0500	50	CW10K0	1000
--	--	CW40K0	4000

Depending on the application, a client could employ CubeWheel in any of several configurations:

- A single CubeWheel:
  - Stabilise attitude in a single axis
- Three, orthogonal CubeWheels:
- Perform precise 3-axis attitude manoeuvres such as sun or target tracking, and roll- pitch- and yaw-reference following
- A set of 4 CubeWheels, mounted in a pyramid configuration:
  - Provides enhanced 3-axis control and adds redundancy. A pyramid can still provide full 3-axis control even in the event of a single wheel failure.
  - This option can also be fully isolated to minimise any possible transfer of micro-vibrations to the satellite chassis.

CubeWheel's ease of use and robust design, make it the perfect reaction wheel for satellites with strict performance requirements and high reliability demands.

CubeSpace can provide consultation and guidance to make an informed decision on which CubeWheel and configuration to choose to optimally fulfil mission requirements.

2. CubeWheel in the ADCS Context

Subsystems of a CubeSpace attitude determination and control system – itself known as CubeADCS – are termed CubeProducts. An integrated CubeADCS consists of a main ADCS computer, CubeComputer, connected via harnesses to various sensor and actuator subsystems, referred to as nodes. CubeWheel is one such actuator node.

All CubeProducts are designed with modularity in mind to provide flexible CubeADCS system architectures and rapid subsystem integration. Production is also typically standardised and industrialised, resulting in short procurement lead times and increased reliability through repeatability.

For an integrated CubeADCS, the satellite onboard computer (OBC) typically interfaces with a CubeComputer, which in turn interfaces with the other ADCS subsystem nodes. CubeProducts are also available as standalone and can be interfaced with directly according to its specific documentation. A software library is available from CubeSpace for inclusion in client OBC source code to ensure proper communications. Alternatively, API and protocol details can be provided to clients to support the development of independent interfacing code.

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3. Detailed Description

3.1 Design Overview

Integrated into each CubeWheel is a radiation-tolerant electronic drive circuit, speed controller and communications interface. Each flywheel is precision balanced using laser ablation and is mounted on high-load space-grade bearings.

The primary features of CubeWheel include:

- Robust mechanics
- Magnetically shielded
- Integrated custom drive electronics
- Common node electronics design with in-orbit re-programmability
- Multiple mounting options
- Pyramid configuration available
- Vibration isolated pyramid configuration available on request
- No back EMF onto power supply

The standard configurations of CubeWheel are described in Table 2.

Table 2: CubeWheel & CubeWheel Pyramid Descriptions

Configuration	Details	
CubeWheel 	Description	A single reaction- or momentum wheel.
	Details	Individually precision balanced according to ISO21940 specifications. Excellent zero-crossing behaviour.
	Generic Term	Reaction Wheel (RWL)
	CS Name and acronym	CubeWheel (CW)
CubeWheel Pyramid 	Description	4x wheels mounted in a pyramid configuration.
	Details	Optimised mounting angles for enhanced performance and redundancy: full 3-axis control with any 3 of the 4 wheels.
	Generic Term	N/A
	CS Name and acronym	CubeWheel Pyramid (CW pyramid)
Isolated CubeWheel Pyramid 	Description	CubeWheel Pyramid mounted on vibration isolators
	Details	All advantages of regular CubeWheel Pyramid but includes CubeSpace bespoke isolators to minimise any vibration transfer to the satellite chassis.
	Generic Term	N/A
	CS Name and acronym	Isolated CubeWheel Pyramid

3.2 Subsystem Diagrams

3.2.1 Standard Electronics

The generic CubeWheel control electronics in Figure 1 are consistent across all models in the NanoSat and SmallSat ranges, with the exception that I2C is only available on CW0017, CW0057 and CW0162.

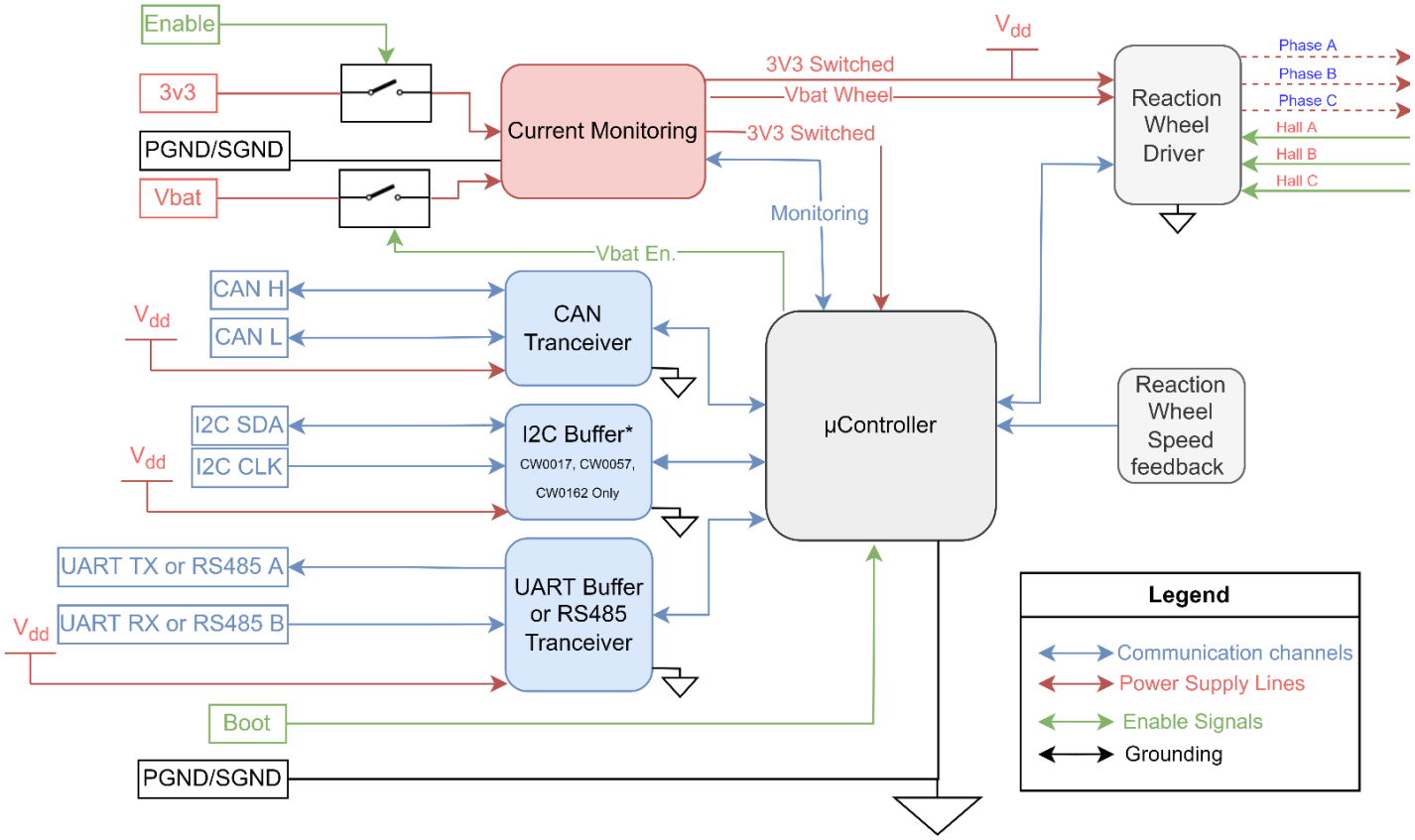

Figure 1: Generic CubeWheel Control Electronics Block Diagram

3.2.2 SmallSat Range Electronic Redundancy

With the exception of the CW1200, the SmallSat range of CubeWheels features full electronic redundancy, depicted in Figure 2. This includes fully redundant control electronics from Figure 1 and rotor driver electronics from **Error! Reference source not found.**.

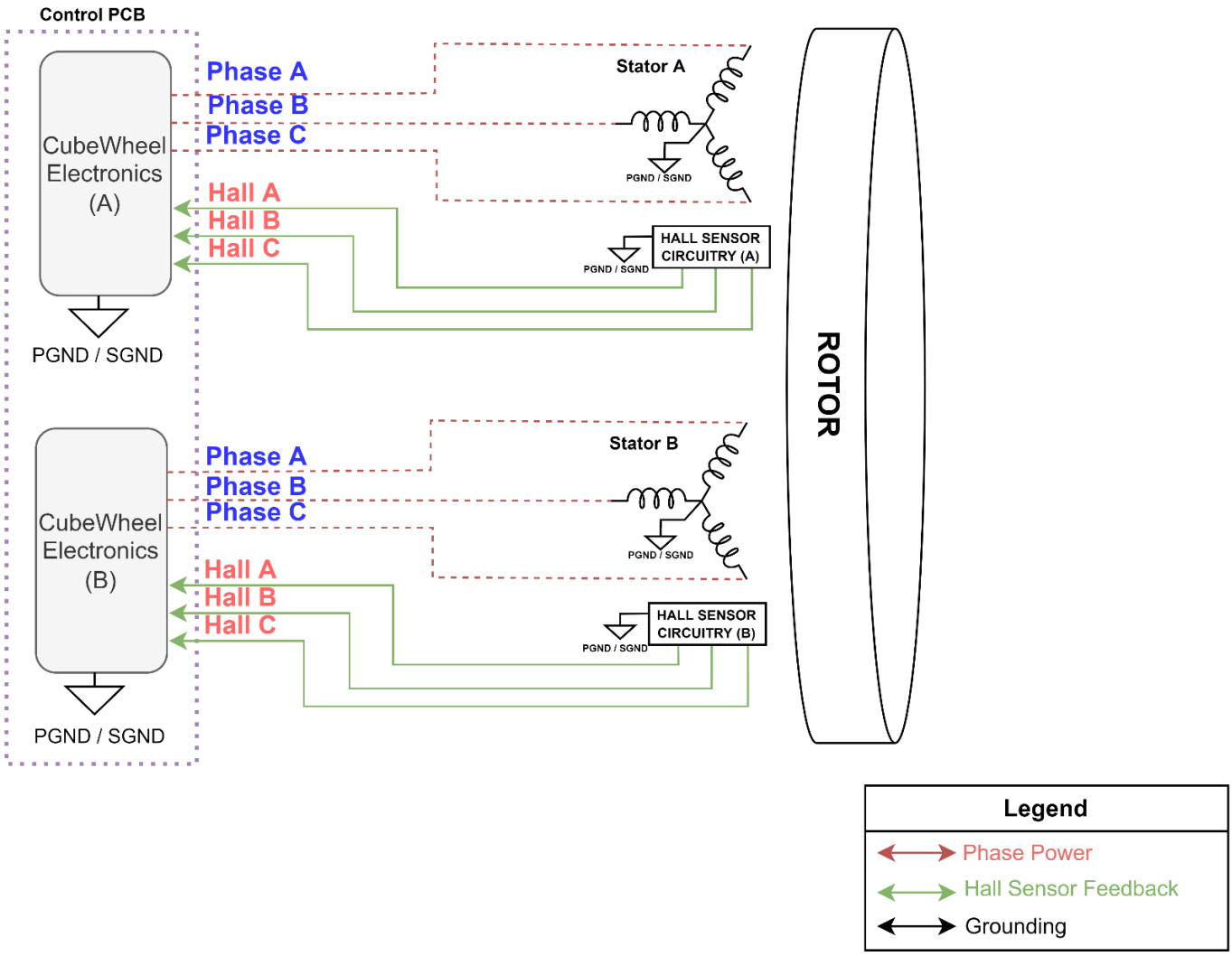

Figure 2: Fully Redundant Electronics Block Diagram – SmallSat Range[1]

[1] Except CW1200 which does not have redundant electronics.

3.3 Performance Characteristics

Performance characteristics of the Nanosat range of CubeWheels are presented in Table 3, and the SmallSat range of wheels in Table 4.

Table 3: Performance Characteristics – NanoSat Range

Performance	CW0017	CW0057	CW0162	CW0500
Nominal Motor Supply Voltage [V]	8	12	12	12
Supply Voltage for max speed [V]	6.4	11	11	12
Max Speed [RPM]	10000	10000	10000	10000
Momentum @ 6000 RPM [mNms][2]	1.77	5.7	16.2	50
Torque [mNm][3]	0.23	2	7	10
Balance Quality Grade [G]	1.0	0.3	0.3	0.3
Physical				
Mass [g]	60	115	144	322
Dimensions [WxLxH] [mm]	28x28x26	35x35x24	46x46x24	66x66x26
Power & Data				
Data Bus[4]	CAN/UART/RS-485			
Connector	Molex Micro-Lock Plus			
Digital Supply Voltage [V]	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	7.0-24
Average Power [@2000 rpm] [mW]	180	336	336	800
Peak Power [Nominal Torque] [W] (includes digital power)	0.85	2.7	7.2	15
Qualification Level				
Radiation	24 kRad			
Random Vibration	14.16 gRMS (NASA GEVS)			
Thermal vacuum [°C]	-20 to 80			
Thermal cold and hot start [°C]	-35 to 70			

[2] 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] Higher torques may be achieved by the CubeWheel. However, this will change the power characteristics of the wheel.

[4] I2C available for custom solutions.

Table 4: Performance Characteristics – SmallSat Range

Performance	CW1200[5]	CW2500[5]	CW5000[5]	CW10K0[5]	CW40K0[5]
Nominal Motor Supply Voltage [V]	12	24	24	24	24
Supply Voltage for max speed [V]	12	24	24	24	24
Max Speed [RPM]	10000	8000	8000	TBD	TBD
Rated Momentum [mNms]	120	250	500	1000	4000
Speed @ Rated Momentum [RPM]	5600	5000	5200	TBD	TBD
Torque [mNm]	20	27	37	TBD	TBD
Balance Quality Grade [G]	0.3	0.3	0.3	0.3	0.3
Physical					
Mass [g]	TBD	TBD	TBD	TBD	TBD
Dimensions [WxLxH] [mm]	76x76x31	88x88x40	100x100x38	125x125x48	TBD
Power & Data					
Data Bus	CAN/UART/RS-485				
Connector	Harwin Gecko SL				
Digital Supply Voltage [V]	3.3	3.3	3.3	3.3	3.3
Motor Supply Voltage Range [V]	12 - 24	16 - 36	16 - 36	TBD	TBD
Average Power [@2000 rpm] [mW]	TBD	TBD	TBD	TBD	TBD
Peak Power [Nominal Torque] [W] (includes digital power)	TBD	TBD	TBD	TBD	TBD
Qualification Level					
Radiation	24 kRad				
Random Vibration	14.16 gRMS (NASA GEVS)				
Thermal vacuum [°C]	-20 to 80				
Thermal cold and hot start [°C]	-35 to 70				

[5] Preliminary specification.

3.4 CubeWheel Sizing and Configurations

A satellite's size and inertia, including all deployable structures, and required manoeuvrability must be taken into consideration to select appropriate CubeWheels and their configuration. A sizing selection guideline is provided in Figure 3, it should be used in conjunction with the tabulated performance characteristics in Section 3.3, above, and the configuration descriptions in Table 5, below.

CubeSpace can provide consultation and guidance to make an informed decision on which CubeWheel and configuration to choose to optimally fulfil mission requirements.

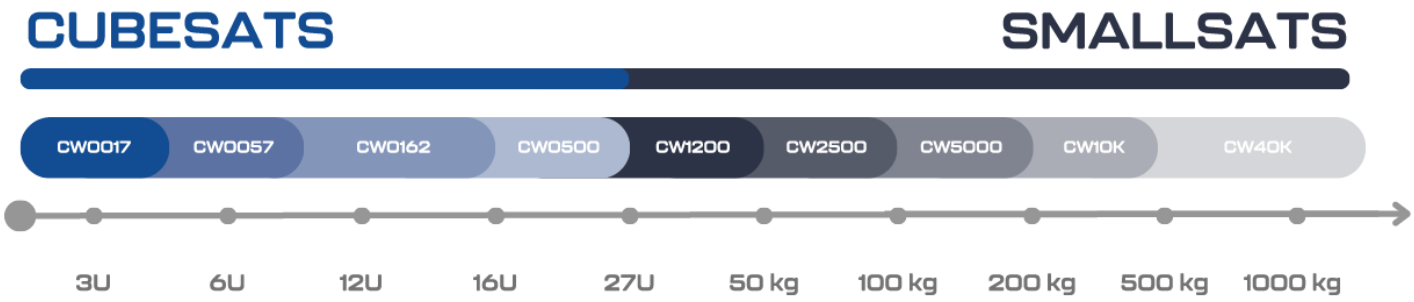

Figure 3: CubeWheel Size Selection Chart

3.4.1 CubeWheel Configurations

An overview of available CubeWheels and pyramids is given in Table 2, and is expanded upon in Table 5, below.

Table 5: CubeWheel Configuration Descriptions & Use Cases

Configuration	Description & Typical Use Case
1x CubeWheel 1-Axis Control	Stabilise attitude against disturbance torques in a single axis.
3x orthogonal CubeWheels Full 3-axis control	Earth-based pointing or target tracking, sun pointing, inertial pointing, satellite tracking.
4x CubeWheels in a pyramid Full 3-axis control Improved performance Redundancy	Use cases the same as above for 3x orthogonal CubeWheels. Wheels are biased to an offset speed, thus avoiding zero-crossings, improving performance. Full 3-axis control is available with any 3 of the 4 wheels.
4x CubeWheels in an isolated pyramid Full 3-axis control Improved performance Redundancy Isolation	Use cases the same as above for 4x CubeWheels in a pyramid. Isolators cut off high-frequency noise and reduce micro-vibrations transferred to the satellite.

3.5 Interconnect

CubeWheel actuators are designed to be connected to the CubeADCS CubeComputer or to the client system by means of harnesses. Harness details for the NanoSat and SmallSat ranges of CubeWheel are specified in the respective interface control documents [RD2] and [RD4]. All FM harnesses are made using wires with low-outgassing insulation. Note, however, that EM harnesses are available as off-the-shelf cable assemblies from other vendors and should not be used for flight models or in a vacuum.

3.5.1 Harness Length

Appropriate harness lengths are typically not known until a detailed satellite layout has been decided on. CubeSpace will require that the client specify harness lengths based on their final placement of CubeWheels within their satellite/system and their harness routing scheme before final production schedules can be committed to.

3.6 Pre-loaded Firmware Applications

Each CubeWheel is pre-loaded with two firmware level applications: the Bootloader and the Control Program.

3.6.1 Bootloader

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

- Allows for quick identification through communications messages and protocol that is common across all CubeProducts,
- Allows the CubeWheel Control Program and configuration to be (remotely) updated,
- Supports FDIR,
- Exposes Bootloader API to a host device.

3.6.2 Control Program

The control program is the main program of the CubeWheel and works 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

CubeWheel implements its own Local Coordinate Frame (LCF), defined in interface control documents, [RD2] and [RD4].

3.8 CubeWheel Actuator Placement Considerations

Great care is taken to balance the wheels and shield the generated magnetic field. However, residual unbalance or residual magnetic fields could disturb sensitive sensors such as magnetometers, optronics and rate sensors. Therefore, it is advised that the CubeWheel must be located far enough from payloads or sensors that are sensitive to magnetic fields or vibrations. Also consider that reaction wheel jitter, due to static unbalance, can be minimized by mounting reaction wheels close to the centre of mass of the satellite.

In the case of imaging and rate sensors: mechanically induced vibration disturbances due to static or dynamic unbalance, or bearing noise, can cause blurring of images and increased rate-measurement noise. For a satellite with a very high-resolution and narrow field-of-view imaging, the isolated CubeWheel Pyramid configuration should be strongly considered. It should 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.

3.9 Standard Documentation

CubeWheel is provided with a standard set of documents, listed in Table 5.

Table 6: CubeWheel Document List

Document	Description
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.
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.
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 clients on order placement.
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 clients upon order placement.
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. This is only delivered for the standalone CubeWheel order. A CubeADCS delivery report will be provided when a bundle is ordered.

4. Ground Support Equipment

4.1 Support Hardware (CubeSupport PCB)

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

4.2 Support Software (CubeSupport Application)

CubeSpace provides ground support software for direct connection to the CubeWheel via the CubeSupport hardware, providing 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.