Cubesat General Subsystem Performance Specification

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ABSTRACT

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CubeSats are quickly becoming a popular method for everyone from high school and university students to satellite companies to reach space relatively quickly and inexpensively for research and technology demonstration purposes. A standard was created by California Polytechnic State University, San Luis Obispo and Stanford University named the CubeSat architecture. This platform allows many different developers to create unique satellite payloads and buses while maintaining a common launch and deployment form factor. This work provides a performance specification for the general design of a CubeSat satellite. The satellite subsystems are the main focus, including attitude determination and control, data handling, thermal, mechanisms, structures, power, propulsion, telemetry, command and ranging. The purpose of creating this specification is to provide a design starting point to novice satellite developers who may benefit from industry knowledge of requirements, standards and configurations.

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LIST OF ACRONYMS

ADCS – Attitude Determination and Control Subsystem
C&DHS – Command and Data Handling Subsystem
DC – Direct Current
DHS – Data Handling Subsystem
ES – Earth Sensor
FOV – Field of View
GEO – Geosynchronous Earth Orbit
GEVS – General Environmental Verification Standard
ICD – Interface Control Document
ISIS – Innovative Solutions in Space
ISS – International Space Station
Isp – Specific Impulse
ITAR - International Traffic In Arms Regulations
J-SSOD – Japanese Small Satellite Orbital Deployer
LEO – Low-Earth Orbit
Li – Lithium
ME – Mechanisms
NASA – National Aeronautics and Space Administration
P-POD – PolyPicosatellite Orbital Deployer
PR – Propulsion
PW – Power
RBF – Remove Before Flight
RW – Reaction Wheel
SJSU – San Jose State University
ST – Structures
STD – Standard
TC&R – Telemetry, Command and Ranging Subsystem
TH – Thermal
U – Unit

Chapter 1: Introduction

1.1 Background and Motivation

The number of CubeSats that have been designed, built and flown has drastically increased of the past few years. More Universities and even some companies have joined in on the comparatively low cost option to demonstrate new scientific, hardware and concept ideas. The majority of CubeSat developers are novices to the satellite manufacturing industry. The goal of this thesis is to provide a general performance specification document that can be used by new developers to aid their understanding of the unique requirements of satellite subsystems, the space environment and interfaces with deployment systems. Every mission must have a set of requirements in order to keep the goals and milestones in sight and to help ensure mission success. With the provided performance specification future failures and design issues can be minimized to some extent by considering this industry knowledge applied to the CubeSat platform.

1.2 Literature Review

On November 19, 2013, 29 satellites were launched on an Orbital Sciences-built Minotaur 1 rocket [1]. This record breaking CubeSat launch of 28 CubeSats along with an Air Force primary satellite demonstrates the increase in launch availability and the desire and capability of novice developers. Onboard the Minotaur was TJ^3Sat which was designed and built by high school students in conjunction with Orbital Sciences [2]. Previously launch availability has been harder to come by and with fewer CubeSats per launch such as the launch of the SJSU/NASA CubeSat TechEdSat-1 along with F-1 and FITSAT-1 from the International Space Station on October 4, 2012 [1]. Many of the CubeSats are completed by university students working with space experts such as NASA or Orbital Sciences, such programs have the benefit of building off of the knowledge already present within those organizations. However some CubeSats such as FITSAT-1 are built by amateurs who begin with little if any knowledge of how to design or build a satellite [3]. It is those developers which this work aims at providing a guideline for the performance specifications of the CubeSat subsystems, in addition to the existing basic CubeSat specifications [4].

Various hardware companies have begun selling CubeSat components such as power management devices, attitude control actuators and sensors, and main body structures among other units. These micro sized aerospace hardware components allow for more complex CubeSats to be developed. The 3U to 6U size CubeSats allow for additional room and mass to integrate more complex subsystems. ISIS produces a magnetorquer at just 195g produces a magnetic moment of 0.24 Am^2 which provide passive magnetic control [5]. For more complex attitude control there are micro-thrusters in both electric [6] and gas propulsion [7], with I_{sp} of 590s and 100s respectively. There are reaction wheel (RW) assemblies that can be used on the larger CubeSats that require momentum storage. The SSBV Aerospace and Technology Group manufactures a RW system that provides up to 20 mNm and 0.65 Nms [8]. For attitude sensors there are mini sun sensors [9], earth horizon sensors [10], and GPS receivers [11]. Other components including solar panels, and main body structures are also available.

1.3 Overview of Specifications

Depending on the mission requirements, a set of off the shelf components may be available. Mission requirements drive subsystem budgets and unit selections. Once units have been selected or designed they may drive additional subsystem requirements themselves. Requirements in a performance specification are well formed, complete, consistent, individually verifiable and traceable to a higher requirement or goal [12]. In addition to performance requirements there are also functional, interface and operational requirements to be considered, which is outside the scope of this work. For example, interface control documents for J-SSOD or P-POD would drive additional requirements if chosen as the CubeSat deployer. Detailed in Chapter 2 are the general requirements for the Attitude Determination and Control, Data Handling, Power, Thermal, Telemetry, Command and Ranging, Structures and Mechanisms subsystems. These requirements are aimed at a larger CubeSat that has the capacity for such abilities as 3-axis attitude determination and control. Technical requirements performance specification documents in the satellite industry are formatted as shown in Chapter 2, with the entire document as a table. Statements that contain “shall” are requirements and statements that contain “may” are design goals or options.

Chapter 2: Subsystem Performance Specifications

Requirement Number	**2.1 General Specification Scope**
	2.1.1 Document Overview
	This specification provides the requirements of a CubeSat for the general performance and design. This document is geared towards larger CubeSats, such as the 3U to 6U form factors.
	2.1.2 Specification Flow down
	This document is derived in part from applicable documents such as the General Environmental Verification Standard (GEVS) NASA (GSFC-STD-7000), Cubesat Design Specification from Cal Poly, ICDs of various deployment platforms such as the NanoRacks CubeSat Deployer and satellite manufacturing industry knowledge.
	Each subsystem must satisfy the environmental, test and design requirements of the applicable documentation for the specific launch provider chosen. Any new revision of the launch provider’s documents supersedes this document so care should be taken to look for new revisions subsequent to the publication date of this material.

	2.1.3 Requirements Scope
	Each CubeSat will have a unique set of design requirements that must be met to ensure mission success, this document outlines the general requirements for 1U to 6U Cubesats. There are internal requirements to the developer of each CubeSat and there are also derived requirements imposed on CubeSats to ensure safety and compatibility with deployers and launch providers.
	In order to show compliance to the requirements set forth in this document various evidence must be produced by each CubeSat developer to demonstrate to the appropriate deployment and launch providers before the CubeSat will be approved for manifest. Such verification methods are industry common and include analysis, inspection, demonstration, or test. Requirements may need to be verified at different levels such as unit, subsystem or systems level.
	2.2 Attitude Determination and Control Subsystem (ADCS) Performance Specification
	2.2.1 Attitude Determination and Control Subsystem (ADCS) Description
	The ADCS includes the actuators, sensors, software and electronics in order to determine the satellites orientation and

	provide corrective motion and orbital control as necessary. Many CubeSats have no means of attitude control or even sensing ability and may simply accept a mission design that is compatible with a possible random tumble or unknown initial injection and mission attitude. However some more complex CubeSats rely on elementary ADCS actuator hardware such as magnetic torque coils, basic reaction wheels and micro thrusters, listed in order of increasing complexity.
	The main functions of the ADCS are to provide delta V to achieve desired orbit, orient and maintain attitude through the missions design life, and to provide means of deorbiting the satellite. Each CubeSat may employ all or only some of these ADCS functions as needed for their mission.
	2.2.2 Reference Frames
	The reference frames may include an inertial, orbital, satellite body, ADCS sensor and launcher body. The orbital reference frame is defined such that the Z axis is located in the instantaneous orbit plane pointing towards the center of the earth. The X axis is located in the orbital plane perpendicular to the instantaneous radius vector and points in the direction of spacecraft motion. The Y axis is perpendicular to the instantaneous orbit plane and points south.

	The CubeSat and NanoRacks deployer reference frame have the +Z direction in the direction of deployment, the access facet is on the +Y direction, and the +X direction follows the right hand rule.
	2.2.3 Definitions of Operational States
ACS101	The ADCS subsystem may support the following operational states: a) Earth Acquisition. An Earth acquisition is normally used when a satellite initially acquires the earth and points the Body Z axis towards the earth. b) Sun Acquisition. This mode may be entered in order to point the solar arrays or panels towards the sun, some satellites may be designed to remain sun synchronous. c) Inertial Pointing. Holds the satellite in an inertially fixed orientation. d) Nominal On-orbit Operation. Attitude is maintained through actuators and determined from sensors. e) Stationkeeping Operation. Maneuvers may be used to maintain the orbital location or provide a transition delta v f) Safe. In the event of a system anomaly the satellite may enter a troubleshooting mode or potentially deactivate or perform safety precautions to itself in order to prevent catastrophic outcomes such as pressure vessel rupture.

	2.2.4 ADCS Configuration
ACS102	The unit configuration for a specific CubeSat will be specific to its mission and design.
ACS103	Possible actuators may include: magnetic torque coils, reaction wheels, or micro-thrusters.
ACS104	Possible sensors may include: earth sensor, gyros, sun sensors, magnetometer or star trackers.
	2.2.5 ADCS General Performance
ACS105	The ADCS shall determine the spacecraft attitude following separation and initial power on until the end of the mission life.
ACS106	Attitude option 1: The ADCS may determine and actively control the spacecraft attitude following separation and initial power on until the end of the mission life.
ACS107	Attitude option 2: The ADCS may passively control the spacecraft attitude following separation and initial power on until the end of the mission life.
ACS108	The ADCS shall provide stable operations with the mission orbital inclination(s).
	2.2.5.1 Sensor Biases
	The earth sensor biases either electrical or mechanical are defined as positive pitch bias in the East direction with the

	satellite body biasing to the West, a positive roll bias in the North direction with the satellite body biasing to the South.
ACS109	The ADCS shall maintain the bias values appropriate for each operational state.
	2.2.6 ADCS Telemetry
ACS110	The telemetry stream shall include the following information: a) Sensor and actuator data b) Operational mode c) Diagnostic, health and status telemetry of processors, sensors, and actuators. d) Micro-thruster data including number of pulses and on-time. e) Critical temperature data f) Deployment mechanism status
	2.2.7 ADCS Command
ACS111	The ADCS units shall be able to receive commands from the data handling subsystem.
ACS112	The command capabilities shall include: Actuator and sensor on/off and configuration commands, actuator control settings e.g. reaction wheel speeds or thruster on times, operational states and modes.

	2.2.8 ADCS Hardware
ACS113	The ADCS components shall be compliant with the environmental requirements.
ACS114	The ADCS shall meet all requirements for the duration of the mission life.
ACS115	The ADCS units shall have under and over voltage protection.
ACS116	The ADCS hardware shall not harm other hardware if subjected to under or over voltage events.
ACS117	The satellite shall be capable of being stored for up to 6 months with no additional operator attention or maintenance prior to launch. [13]
ACS118	All sensors and actuators shall meet their alignment error requirements.
	2.2.8.1 Earth Sensor (ES)
ACS119	The ES shall provide status telemetry.
ACS120	The ES FOV including any baffles shall meet the mission requirements.
ACS121	The ES shall not be damaged by exposure to the Sun from any angle.
ACS122	The ES temperature shall be controlled within unit specifications.
ACS123	The ES biases shall meet the mission design required values.

	2.2.8.2 Gyro
ACS124	The Gyro shall meet the orientation required by the mission design.
	2.2.8.3 Sun Sensor
ACS125	The sun sensor FOV including any baffles shall meet the mission requirements.
ACS126	The sun sensor biases shall meet the mission design required values.
ACS127	The sun sensor accuracy shall be at least 0.5 degrees.
	2.2.8.4 Reaction Wheels (RWs)
ACS128	The reaction wheels shall not create a resonance that induces ES noise larger than 100% of the nominal ES noise.
ACS129	The reaction wheel lubrication system (if present) shall not lead to performance instabilities.
	2.2.9 ADCS Subsystem Interface
	2.2.9.1 ADCS Configuration
	2.2.9.1.1 Mass Properties
ACS130	The maximum allowable density is 1.3Kg/U. [13]
ACS131	The ballistic number of the satellite shall be equal to or less than 100kg/m^2. [13]
ACS132	The total wet satellite mass corresponding to the form factor shall

	be equal to or less than the mass in Table 1. **Table 1. Satellite Maximum Mass for Deployment with NanoRacks Deployer. [13]**

Form Factor	Maximum Mass (Grams)
1U	2,828
1.5U	4,243
2U	5,657
3U	8,485
4U	11,314
5U	14,142
6U	16,971

	2.2.9.1.2 Center of Gravity Uncertainty
ACS133	The undeployed center of gravity (cg) uncertainty shall be within: X: ±2 cm Y: ±2 cm Z: ±2 cm. [13]
	2.2.9.1.3 Propellant Propulsion
ACS134	Thruster location and pointing shall be optimized to meet station keeping, delta-V and pointing requirements.
ACS135	The AOC thruster throughput and maximum throughput margin shall be compatible with the type of thrusters used.
ACS136	Solar array position and tip deflection shall support the power requirements in this document.

ACS137	The ADCS shall meet all performance and pointing requirements with the deployed frequencies of any reflector or solar array assemblies.
ACS138	The ADCS shall meet all performance and pointing requirements with the structural thermal distortion allocations.
	2.2.10 Control Modes
	2.2.10.1 General Requirements
ACS139	All control modes shall have positive gain and phase margin.
ACS140	Control modes shall be compatible with the actuators selected and be compliant with their operational capability.
ACS141	Propellant slosh shall not cause loss of control of the satellite.
ACS142	There shall be a 2:1 safety margin on the control torque including the reaction wheels and thrusters.
ACS143	The reaction wheels shall support momentum unloading.
ACS144	The momentum unloading shall not cause a loss of control.
ACS145	It shall be possible to calibrate the gyro from ground.
	2.2.10.2 Safe Mode
ACS146	There shall be a safe mode where all actuators are inhibited.
	2.2.10.3 Earth Acquisition Mode
ACS147	There may be a mode that is capable of acquiring the earth and maintain earth pointing with 0.5 degree dead bands.

ACS148	An acquisition sequence or timer shall be automatically initiated on board the satellite upon deployment to deploy any antenna, solar array or device no sooner than 30 minutes from deployment. [13]
ACS149	The acquisition sequence shall also be able to be commanded from ground command.
ACS150	The earth horizon sensor shall be used to maintain Earth pointing when Earth presence is detected.
ACS151	The earth horizon sensor and gyro shall be used for rate and attitude data.
ACS152	GPS may be used for orbit data.
	2.2.10.4 Nominal On-Orbit Mode
ACS153	The nominal on-orbit mode shall support the required pointing requirements of the mission.
ACS154	The satellite may be 3-axis stabilized.
ACS155	The satellite may spin about its major axis.
ACS156	The satellite may randomly tumble.
ACS157	Reaction wheels shall be the primary means of attitude control.
ACS158	Thrusters shall provide momentum unloading from reaction wheels either autonomously or by ground command.
ACS159	The reaction wheels shall avoid operating in a speed range that

	causes a resonance in the earth horizon sensor.
ACS160	The reaction wheels shall be operated in a manner that does not cause unexpected behavior.
ACS161	The earth horizon sensor and gyro shall be used for rate and attitude data for roll, pitch and yaw.
	2.2.6 Software Safety Monitors – Attitude Control
ACS162	There shall be a monitor to prevent thrusters from firing while their valves are closed.
ACS163	There shall be a monitor to filter out earth horizon sensor glitches.
ACS164	There shall be a monitor to filter out gyro data glitches.
ACS165	There shall be a monitor to terminate thruster activity if the earth presence is lost until the earth acquisition mode is entered.
ACS166	There shall be a reaction wheel monitor to disable the reaction wheels from the control loop in the event they are not performing as expected.
ACS167	There shall be a gyro monitor to disable the gyro from the control loop in the event it is not performing as expected.
ACS168	There shall be an earth horizon sensor monitor to disable the earth horizon sensor from the control loop in the event it is not performing as expected.

ACS169	There shall be a position angle error monitor to initiate Earth acquisition mode once earth presence is lost.
ACS170	There shall be a monitor to disable thruster control if any thruster fires for longer than 0.5 seconds, or shorter if determined by control design.
ACS171	The thruster duty cycle used shall be compatible with the thruster material used.
ACS172	There shall be a monitor to prevent the reaction wheels from reaching speeds outside of their qualified speed range.
ACS173	Monitors shall be able to be armed, disarmed and reset.
ACS174	Monitors shall set a trip counter stored in memory and transmitted to ground.
ACS175	There shall be a monitor for under and over pressure of the propellant and oxidizer tanks and lines.
ACS176	If there are redundant ADCS units including the gyro, earth horizon sensor, reaction wheels, thrusters or sun sensors there shall be health monitors to swap between units upon failure of the primary unit.
	2.3 Thermal Subsystem Performance Specification
	2.3.1 Thermal Environments
TH101	The thermal subsystem shall maintain the temperature of every

	component of the satellite within its design limits under all of the following conditions:
TH102	During all times from shipment, storage, deployment, and until end of mission under all conditions and environments expected during these periods. a) Under all communications systems configurations including communications system power off. b) All equipment consuming power as expected including worst case margins. c) Including diurnal temperature variations. d) Any orbit inclination specified in the mission design. e) Diurnal or possible seasonal temperature variations. f) Solar Heating. g) Mission specified orbit, e.g. GEO, LEO, polar, etc. h) Any attitude bias or attitude steering. i) Launch on any day of year.
	2.3.2 General Thermal Design
TH103	The main means of thermal control shall be passive however heaters and heat pipes may be used.
	2.3.3 Temperature Margin Prediction
TH104	The satellite thermal design shall be predictable by analysis, test and based on transient analysis.

TH105	The acceptance test conditions of all units shall be at least 5° more than the design limit.
TH106	The qualification and survival test conditions shall be at least 10° more than the design limit.
	2.3.4 Heaters
TH107	Heaters shall be used where necessary to maintain units at least 5° above their thermal design limit.
TH108	Heaters shall include safety switches to prevent stuck on heaters.
TH109	Heaters shall be protected from sharp corners or areas that could damage them.
TH110	Redundant heaters shall be used on all critical or potentially dangerous equipment.
	2.3.5 Thermistors
TH111	Thermistors shall be used as a minimum to report temperatures of the following: a) Battery cells b) Propulsion tanks and lines c) Thruster valves and injectors d) Baseplate temperatures of all units e) Any motor or rotating mechanism
TH112	Thermistors shall be accurate to within 5°.

TH113	Thermistors shall support the entire range of temperatures that a unit may observe.
TH114	Redundant thermistors shall be used on all critical or potentially dangerous equipment.
	2.3.6 Thermal Insulation Blankets
TH115	All blankets shall be grounded with a conductive outer layer.
TH116	All blankets shall be designed and installed to allow venting and mechanical access where required.
TH117	All blankets shall remain in place and not intrude or interfere with any satellite component.
	2.3.7 Thermal On-Orbit Requirements
TH118	The thermal system shall be autonomous and not require any ground intervention for nominal operations.
	2.3.8 Power Subsystem Interface
TH119	The thermal subsystem shall keep the batteries within their design operating limits including during all seasons, eclipses, discharge, and charge periods.
TH120	Thermal design shall keep temperatures of pressurized propellants at least 15° lower than boiling points and 15° above freezing points.
TH121	The thermal subsystem shall maintain the propellant in all areas

	to preserve its physical and chemical properties to meet performance requirements.
	2.3.9 Thermal Firmware Requirements
TH122	Heaters shall operate under autonomous control with set points and thermistor inputs.
TH123	Where redundant thermistors are utilized, voting margins shall be used.
TH124	It shall be possible to disable any heater or thermistor by ground intervention.
TH125	The firmware shall support all heaters and thermistors.
TH126	There shall be a minimum thermal protection monitor to reduce heater power consumption in the event of a satellite anomaly where solar power is insufficient to maintain a positive power margin.
	2.4 Command and Data Handling (C&DHS) Performance Specification
DH101	If there are redundant electronics systems they shall be fully cross-strapped.
DH102	Radio communications shall begin no sooner than 30 minutes from deployment. [13]
	Radio communications must adhere to all applicable regulations

	and guidelines.
DH103	C&DHS shall provide telemetry and command capability for all heaters, thermistors, solar array motors, antenna motors, and interface adapters.
DH104	Interface adapters shall be able to handle analog, digital and pulse commands and telemetry.
DH105	Data harnesses shall be unique or keyed to prevent incorrect mating.
DH106	Interface adapter signal types, pulse widths, currents, resolutions, resistances and voltages shall be compatible with both the hardware units, routers and processors.
	2.4.1 Telemetry Requirements
DH107	The telemetry function shall gather, encode, multiplex, format and transmit to ground the unit and satellite data for health, statuses, performance and environments.
DH108	Telemetry shall be functional from subsystem integration until mission end at any time the satellite is powered on.
DH109	Telemetry shall be available in both a normal data rate and a faster dwell data rate where certain data may be needed more frequently for mission required data.
DH110	Dwell telemetry contents shall be configurable to read any

	memory region.
DH111	All telemetry shall be available at the rate required to determine the health, status and performance of each component.
DH112	The satellite telemetry shall provide at a minimum: a) Satellite identification b) Bus voltages and currents c) Cell and battery voltages d) Battery charge/discharge currents e) Solar array current and shunt current f) Unit and critical component temperatures g) Propellant tank and line pressures and temperatures h) Thruster injector and valve temperatures i) Thruster pulse width and on-times j) Actuator and latch valves open/close statuses k) Unit and processor on/off, status, health and performance data l) Actuator and sensor data, voltages and currents
DH113	Critical events such as safety monitor trips shall be stored in a fault log, such that information will be available when telemetry is received by ground station.
DH114	Each telemetry parameter shall have sufficient bit resolution with zero to full scale to meet mission requirements.

DH115	Telemetry shall be continuously transmitted to ground.
DH116	Critical telemetry shall be archived in a data recorder such that all telemetry is available for downlink once communication with ground station is locked, if required by mission design.
	2.4.2 Command Requirements
DH117	Commands shall be able to: a) Control payload units b) Control power subsystem c) Heater control d) Propulsion valve control e) Motor control f) Attitude control unit configuration control g) All unit on/off, configuration and selection h) Memory uploads
DH118	Command decoders shall have unique addresses.
DH119	Command units shall provide phase locking, demodulation, bit synchronization, and decoding of incoming commands.
DH120	Critical commands shall be multiple step commands.
	2.4.3 Data Handling Requirements
DH121	The data handling subsystem shall collect, interpret, and route commands to their intended recipients.

DH122	Commands shall be routed to the actively selected units unless a command is specific to an individual unit.
DH123	There shall be a system clock to provide a time reference since final power on from pre-deployment until at least 200% of mission life.
DH124	The data handling system shall accept ground commands and internal autonomous commands as required.
DH125	Any autonomous feature shall be able to be overridden.
DH126	The data handling system shall accept and process commands as fast as the mission requires.
DH127	The data handling system shall reject invalid commands.
DH128	The data handling system shall be able to ignore signals from any failed unit or component.
DH129	A command echo shall be transmitted to the ground for all executed commands.
DH130	Hazardous command types shall be multiple steps.
DH131	Power shall be provided in 3V, 5V and 9V supplies with total power output sufficient to meet the satellite design.
DH132	The data handling system shall support testing via a test connector while integrated in deployer or launch vehicle.
DH133	A monitor shall indicate when the satellite has been deployed.

DH134	All deployments and mission activity shall not begin sooner than 30 minutes from deployment monitor trip.
	2.4.4 Software Safety Monitors – Data Handling
DH135	On board computers shall have fault monitors that will either correct or reset the processor(s).
DH136	Safety monitors shall be disabled on processor restart.
DH137	Single Event Upsets shall be cleared by a safety monitor.
DH138	Any critical data that is needed to be preserved during a processor reset shall be stored in a safe memory range.
	2.4.5 Interface – Data Handing with Telemetry, Command and Ranging Subsystem (TC&R)
DH139	The TC&R subsystem shall provide the ranging path on/off status in telemetry.
DH140	The TC&R critical components shall be monitored and statuses provided in telemetry.
DH141	Telemetry shall be at least 5% accurate of the full scale value.
DH142	Telemetry shall be calibrated over its full range.
	2.5 Power Subsystem Performance Specification
	2.5.1 Power Subsystem Description
	The power subsystem provides the satellite with power via a power bus in addition to storing, regulating, generating,

	monitoring, controlling and conditioning the DC power.
PW101	The power bus is where the regulation characteristics are controlled. It is supplied via the battery and solar arrays and is distributed to the satellite loads. The power bus is regulated and shunted at various power levels.
	2.5.1.1 Solar Array Deployed Frequencies
PW102	The solar arrays could be excited from reaction wheel or thruster activity. The solar array design and attitude control design must be compatible in that the ADCS needs to be capable of handling the solar array response and the operational design should avoid the solar array structural frequency stay out regions.
	2.5.1.2 Battery Mission Operations Profiles
PW103	The following assumptions are made for battery usage and operations. a) Battery must support full mission life from subsystem integration until end of mission life. b) Discharge during eclipse or anomalies will not exceed max discharge rates or depth of discharge that may damage the battery. c) Battery is kept at 100% charge during power positive portions of the orbit. d) Power consumption is minimized during eclipses and

	power negative anomalies.
	2.5.2 Power Subsystem Configuration
PW104	The power subsystem consists of solar cells either on the satellite body or on deployed solar panels, Li-ion batteries, power bus, dischargers, chargers and power conditioning units.
	2.5.3 Power General Requirements
PW105	The power subsystem shall be compatible with operation in a low earth orbit.
PW106	The power subsystem shall provide power to the satellite units, in addition to storing, regulating, generating, monitoring, controlling and conditioning the DC power.
PW107	The power subsystem shall be designed to meet the worst-case power requirements of the satellite design for all mission phases.
PW108	The power subsystem shall provide full time power during sunlight operations and during eclipse operations shall provide sufficient power to maintain the basic satellite bus health.
PW109	The power subsystem shall only have one main power bus.
PW110	The power subsystem shall generate power via photovoltaic solar collectors.
PW111	The power subsystem shall store power in Lithium-Ion batteries.
PW112	Fusing may be used to isolate short circuits or double insulation

	may be used.
PW113	Power conditioning electronics shall be used to regulate the power on the main power bus.
PW114	The power subsystem shall provide at least sufficient telemetry to determine state of health and safety.
PW115	When the battery is fully charged excess power shall be shunted.
PW116	Battery charging shall be automatic once connected to power supply.
PW117	Power shall be internal only before launch.
PW118	Three launch inhibit switches shall be used with no greater force than 3N. [13]
PW119	Launch inhibit switches may be Remove Before Flight (RBF) pins, slide switches, captive jumpers, pusher or roller switches. [13]
	2.5.4 Bus Requirements
PW120	The power system shall provide 3V, 6V and may provide 9V power if required.
PW121	The power subsystem shall use a single point ground.
PW122	The power subsystem shall operate during sunlight, eclipse and during combined array and battery power operations.
PW123	The power subsystem shall regulate power such that no unit is

	under or over voltage under nominal conditions including ripples and transients.
PW124	The power subsystem shall provide sufficient power for all units for the system to meet full performance.
	2.5.5 Solar Array (Panel) Requirements
PW125	The solar array shall be able to support full satellite power load.
PW126	The solar array shall be able to operate in full sun and full eclipse with no damage.
PW127	A short in one photovoltaic cell or string shall not affect the power from any other cell or string.
PW128	The photovoltaic cells shall be designed to be protected from electrostatic buildup.
PW129	Margin shall be added on the power requirements from the solar array to account for degradation or damage from thrusters if it cannot be avoided.
PW130	The solar array shall be grounded to the satellite body.
PW131	Solar array deployment, if required, shall have a 3:1 torque ratio.
PW132	To aid in maintaining desired pointing or rotation, any deployed solar arrays shall be symmetric about the satellite body.
PW133	Solar arrays shall be designed and built to withstand launch, deployment and operational loads and vibrations.

	2.5.6 Battery Requirements
PW134	Charge capability shall be available for all batteries.
PW135	Discharge capability shall be available for all batteries.
PW136	The battery shall be able to be replaced without significant disassembly of the satellite.
PW137	The battery capacity shall be such that the required depth of discharge for the satellite design will not damage the battery.
PW138	The battery shall have a margin of remaining power after every eclipse.
PW139	The battery cycle life shall support the mission design life requirements.
PW140	A failure in one battery shall not propagate to other batteries, if there is more than one battery.
PW141	The battery shall be fully charged before each eclipse.
PW142	Batteries shall be equally discharged, if multiple batteries exist and are operational.
PW143	Batteries shall be maintained within operational temperature limits at all times.
	2.5.7 Power Subsystem Command and Telemetry
PW144	The following commands shall be available to the power subsystem:

	a) Unit on/off b) Battery heater on/off
PW145	The following telemetry shall be available to the power subsystem: a) Unit on/off b) Battery heater on/off c) Battery state of charge d) Battery discharge/charge rate e) Bus voltage f) Bus load g) Solar array current h) Shunt current i) Battery voltage j) Battery temperature k) Battery heater on/off
	2.5.8 Power Subsystem Firmware
PW146	Monitors shall protect the battery from overcharging and under voltage.
	2.6 Mechanism Subsystem Performance Specification
	2.6.1 Mechanism Subsystem Description
ME101	The mechanism subsystem provides the supporting structure for antennas, solar arrays, sensors, actuators and must be compliant

	with thermal, mass, and deployment requirements.
	2.6.2 Mechanism Subsystem Configuration
ME102	The Mechanism subsystem includes the solar array support structure, deployment hinges or springs, and hold down devices.
	2.6.3 Mechanisms General Performance Requirements
ME103	The mechanisms subsystem shall provide the support for any deployment or moving device.
ME104	Mechanisms and deployment devices shall have a 3:1 torque ratio and force margin.
	There may be motor drive for solar arrays or any antenna positioning devices.
ME105	Any motor drive voltage shall have 2:1 margin.
ME106	Any rotating mechanism with bearings shall utilize lubricant.
ME107	Any restraining hold down shall be designed to constrain the object during all phases, including integration, shipping, storage, launch, deployment, and on-orbit until final release of the device or object.
ME108	Mechanisms shall minimize outgassing to within launch providers standards.
ME109	Debris shall not be generated from any mechanism or any deployment event.

ME110	Pyrotechnic devices shall not be used.
ME111	Electro-explosive devices shall not be used.
ME112	Satellites smaller then 6U shall incorporate captive separation springs. [13]
ME113	Separation springs shall be located at opposite corners of the –Z end of the rails. [13]
ME114	Separation springs shall have a minimum clearance of 1mm from the standoff. [13]
ME115	Separation springs shall have a spring force less than or equal to 0.75 lbs each and 1.5 lbs total. [13]
ME116	Any magnet or electromagnet shall not interfere with the launcher or other CubeSats in close proximity.
	2.6.4 Mechanism Subsystem Telemetry and Command
ME117	Telemetry for the mechanism subsystem shall include: a) On/off of all motors b) Motor drive voltages c) Switch states d) Motor temperatures
	2.7 Propulsion Subsystem Performance Specification (if applicable)

	2.7.1 Propulsion Subsystem Description
PR101	The propulsion subsystem is a pressurized propellant based system that provides thrust via micro thrusters. Thrust is for delta-V and attitude control.
	2.7.2 Propulsion General Performance Requirements
PR102	The propulsion system may use monopropellant such as compressed gas.
PR103	The propulsion system may use bipropellant.
PR104	The propulsion system shall have a propellants tank(s), propellant lines and thrusters.
PR105	The number and location of the thrusters shall be optimized for the mission requirements in order to maximize control authority and minimize propellant consumption.
PR106	Thrusters shall use latch valves and actuation valves.
PR107	There shall be a latch valve to isolate the pressurant from the propellant.
PR108	There shall be sufficient propellant loaded in the satellite to complete the duration of the mission.
PR109	Thrusters shall be compatible with the required thrust, I_{sp}, duty cycles and durations required of the control system.
PR110	Thrusters shall be placed so that their plumes do not blind

	sensors or degrade critical components.
PR111	Pulse widths shall be avoided that may damage thrusters.
	2.7.3 Propellant Storage
PR112	The burst pressure of the propellant tanks shall have significant safety margins of the expected worst-case pressure.
PR113	The burst pressure of the propellant lines and fittings have significant safety margins of the expected worst-case pressure.
PR114	Propellant system shall utilize filters and design to minimize debris and eliminate bubbles.
PR115	There shall be propellant fill and drain valves.
	2.7.4 Propulsion Telemetry and Command
PR116	Propulsion telemetry shall include: a) Thruster temperatures b) Thruster on-times and pulse widths c) Propellant tank(s) pressure and temperature d) Propellant line pressure and temperature e) Valve open and close statuses
	2.8 Structures Subsystem Performance Specification
	2.8.1 Structures Subsystem Description
	The structures subsystem includes the supporting body of the satellite, including the main body and any rigid or deployable

	structures. This includes any brackets or hardware holding the satellite together.
	2.8.2 General Structure
ST101	The satellite structure shall provide support for all satellite components, subsystems and as an interface with the deployment device or launch vehicle.
ST102	Any deployable components shall be constrained by the satellite itself. [13]
ST103	The NanoRacks CubeSat Deployer, its guide rails and walls shall not be employed to constrain any deployable items. [13]
ST104	Deployment mechanisms shall hinge towards the +Z direction. [13]
ST105	The satellite shall be able to withstand transportation by air, or ground.
	2.8.3 Testing and Integration
ST106	Access to internal components shall be designed so that minimal disassembly would be required to replace units.
ST107	Access panels or facets shall be incorporated into the satellite design.
ST108	Access facets shall be located on the +Y face of the satellite. [13]

ST109	The access facet shall contain the data plate. [13]
ST110	Any Remove Before Flight (RBF) pins of slide pins shall be located on the access facet.
ST111	Any charging socket, programming socket, fuel loading port, or other access feature shall be located on the access facet. [13]
	2.8.4 Structural Loads
ST112	Each rail of the satellite shall be able to withstand with no damage at least 50 N in compression in the Z direction. [13]
	2.8.5 Satellite Dimensions
ST113	The complete CubeSat structure including all undeployed attachments and components in the stored configuration must be 10 cm L x 10 cm W x 10 cm H, and having a volume of 1 liter if using a form factor of 1U, otherwise acceptable dimensions are shown in Table 2.

Table 2. CubeSat Dimensional Requirements [13]

Form Factor	**X dimension (mm)**	**Y dimension (mm)**	**Z payload dimension (mm)**	**Z rail dimension (mm)**
1U	100.00	100.00	100.00	113.50
1.5U	100.00	100.00	156.75	170.25
2U	100.00	100.00	213.50	227.00
3U	100.00	100.00	327.00	340.50

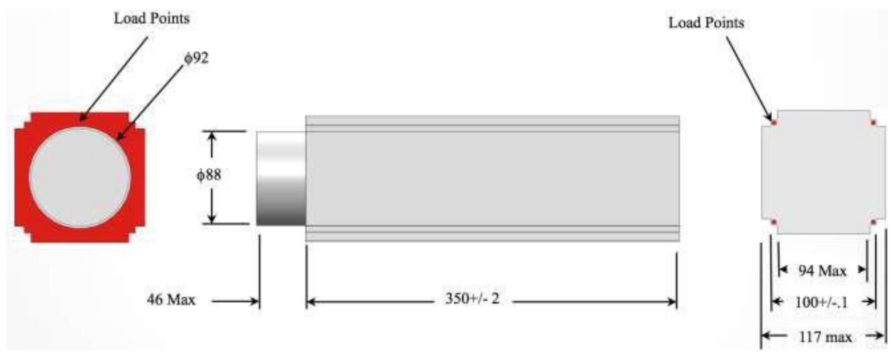
<table>
<tr><td></td><td><table>
<tr><td>4U</td><td>100.00</td><td>100.00</td><td>440.50</td><td>454.00</td></tr>
<tr><td>5U</td><td>100.00</td><td>100.00</td><td>554.00</td><td>567.50</td></tr>
<tr><td>6U</td><td>100.00</td><td>100.00</td><td>667.50</td><td>681.00</td></tr>
</table></td></tr>
<tr><td>ST114</td><td>Tolerance in X, Y and Z shall be ± 0.1mm. [13]</td></tr>
<tr><td>ST115</td><td>There may be additional space outside of the requirements listed in Table 2, as shown in Figure 4. Note that the +Z direction is towards the right.


Figure 1. Additional Space Available in NanoRacks Launcher [13]</td></tr>
<tr><td>ST116</td><td>The main structure of the satellite on the +Z facet shall be recessed a minimum of 7.0mm from the end of the rails. [13]</td></tr>
<tr><td>ST117</td><td>All components on the +Z facet shall be recessed at least 0.5 mm from the outer edges of the rails. [13]</td></tr>
<tr><td>ST118</td><td>The main structure of a CubeSat on the –Z facet shall be recessed more than 6.5mm from the edges of the rails. [13]</td></tr>
</table>

	2.8.6 Satellite Rails
ST119	The satellite shall have 4 rails, one on each edge along the Z direction. [13]
ST120	The satellite rails shall have a minimum width of 8.5mm. [13]
ST121	The edges of the rails shall have a chamfer of at least 1mm. [13]
ST122	The rails shall have a minimum surface area of 6.5mm x 6.5mm for contact with the adjacent satellite or the NanoRacks CubeSat Deployer. [13]
ST123	The rails shall have the following minimum contact ratio: 75% of the length of the satellite shall be in contact with the rails in the Z axis. [13]
ST124	Rail surfaces which contact the NanoRacks CubeSat Deployer rail guides shall be hard anodized aluminum. [13]
	2.8.7 Stiffness and Frequency
ST125	The satellite shall have a minimum fundamental frequency of no less than 100 Hz. [13]
ST126	The satellite shall meet stiffness criteria corresponding to the frequency requirement.
	2.8.8 Alignments
ST127	Units including actuators, sensors, antenna or other position sensitive units shall be aligned such that the mission design

	criteria are met with appropriate interface tolerances in all axes.
ST128	All materials shall be made of materials approved by NASA for space flight and use aboard the ISS according to NASA STD-6016. [12]
ST129	NanoLab CubeSats shall adhere to applicable ISS standards listed in the International Space Station documents. [13]
ST130	The satellite structure, hardware and all components shall be able to withstand the full mission life with at least 50% margin.
ST131	The satellite shall be able to withstand up to 1 year of storage with no maintenance or operations other than battery maintenance and propellant loading.
ST132	Single point failures shall be minimized if feasible.
ST133	Off-gassing materials shall be used according to NASA-STD-(I)-6001A. [12]
ST134	All edges and materials shall be deburred, chamfered or otherwise made safe to handle.

Chapter 3

Recommendations for Future Work

The contents of this work includes the performance specification of the subsystems of a large CubeSat satellite. This information is a necessary step to design and build a quality satellite to complete mission goals and maintain a high mission assurance. There are many other steps in the design and manufacturing of a satellite including but not limited to developing functional, interface, environmental and operational requirements and specification documents. In addition to this work the specific units that are selected or manufactured for a CubeSat program would expand the scope of the presented specification and would be appropriate to be integrated into this document.

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