QB50 US04 Columbia
Orbital Debris Assessment Report

Rev. A, November 9, 2016

Prepared by Aaron Ridley

Submitted by:

Aaron Ridley
Principal Investigator, Columbia
University of Michign

Orbital Debris Assessment Report Evaluation: QB50 US04 Columbia

Requirement	Launch Vehicle	Spacecraft	Comments
4.3-1a	Incomplete	Compliant	
4.3-1b	Incomplete	Compliant	
4.3-2	Incomplete	Compliant	
4.4-1	Incomplete	Compliant	
4.4-2	Incomplete	Compliant	
4.4-3	Incomplete	Compliant	
4.4-4	Incomplete	Compliant	
4.5-1	Incomplete	Compliant	
4.5-2	Incomplete	Compliant	
4.6-1a	Incomplete	Compliant	
4.6-1b	Incomplete	N/A	
4.6-1c	Incomplete	N/A	
4.6-2	Incomplete	N/A	
4.6-3	Incomplete	N/A	
4.6-4	Incomplete	Compliant	
4.7-1	Incomplete	Compliant	
4.8-1	Incomplete	N/A	

Note: This ODAR applies to Discovery 2U CubeSat only. An ODAR for the launch vehicle/NanoRacks CubeSat Deployer will be furnished separately.

Section 1: Program Management and Mission Overview

Columbia is a 2U CubeSat, designed, developed and operated by the Space Physics Research Laboratory at the University of Michigan. Funded by the University of Michigan, Columbia is intended to participate in the Von Karman Institute led QB50 project to study Earth's lower thermosphere.

Program Management:

- Aaron Ridley, Principal Investigator, ridley@umich.edu
- Ryan Miller, Lead Engineer, rpmiller@umich.edu

Foreign Government or Space Agency Participation:

- The overall QB50 project is supported through the European Commission's FP7 program.

Summary of NASA Responsibility:

- N/A

Schedule:

- Delivery to Integrator: October 2016 (completed)
- Integration into NanoRacks: December 2016
- Launch to ISS: February 2017
- Release from ISS: April 2017

Mission Overview:
Columbia carries the Flux Probe Experiment (FIPEX), developed by Technical University in Dresden, as its primary payload. Deployed by NanoRacks from the International Space Station, Columbia will orbit in LEO until atmospheric reentry. The nominal mission duration is five months, but actual mission duration is dependent upon rate of orbit decay. Columbia's initial orbit upon release from ISS will have an apogee of 407 km, perigee of 401 km, and inclination of 51.6 degrees. Columbia does not have any propulsive capability and will experience natural orbit decay. No interaction or interference is known or expected between Columbia and any other operational spacecraft.

Section 2: Spacecraft Design

Columbia is a 2U CubeSat consisting of a PC104-type electronics stack housed in a 6061 aluminum chassis. Surface mounted PCBs host sensors and solar cells. Four acrylic deployed panels allow for aerodynamic stability. Aluminum end plates provide rigidity to the chassis and mounting points for FIPEX. A deployed monopole antenna ("tape measure" antenna) deploys from the nadir face of the CubeSat. The mass of Columbia is 1.6 kg. Columbia carries no on-board fluids or propulsion systems, so the dry and total launch mass are identical.

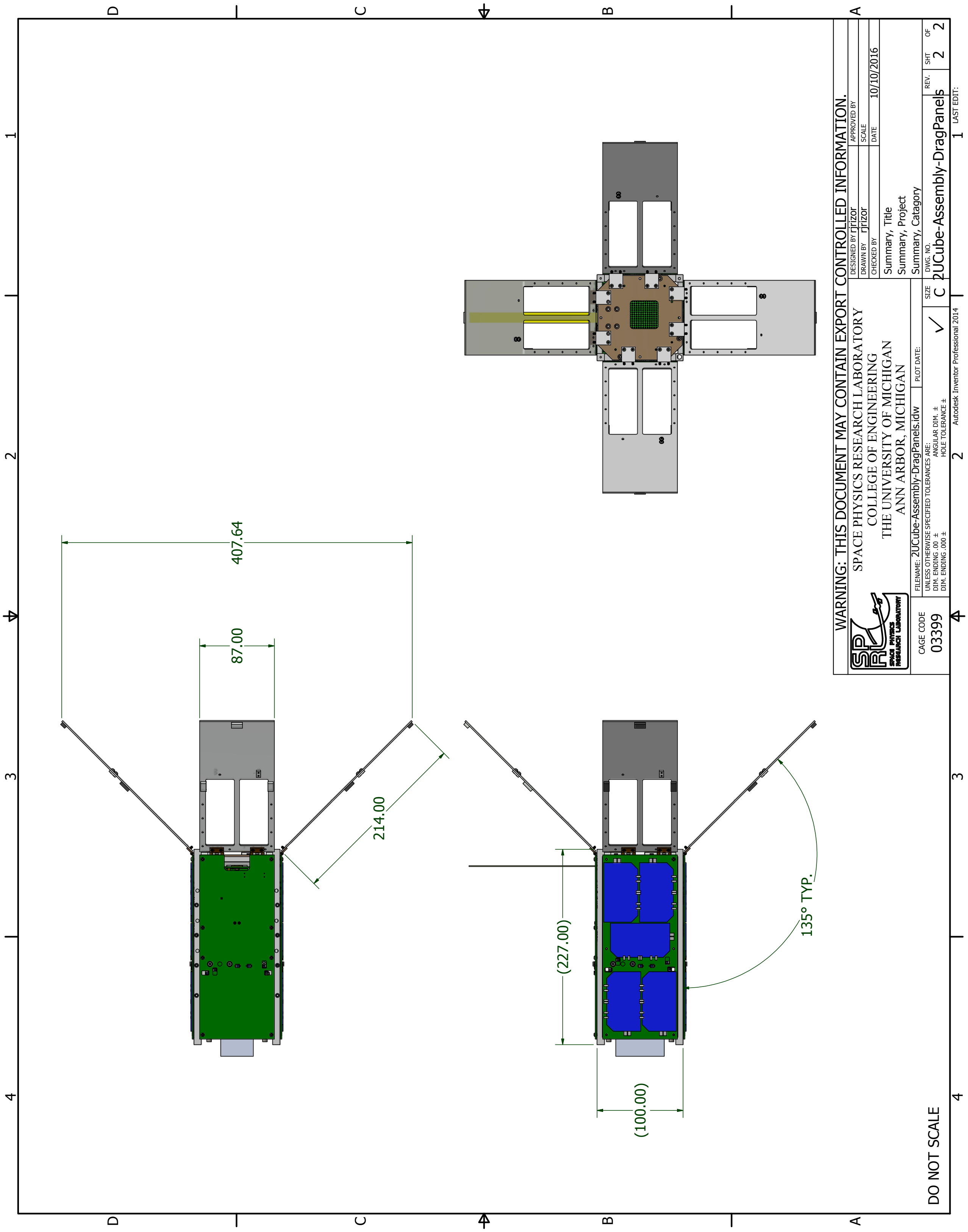
Attitude control for Columbia is actively provided by an attitude determination and control system (ADCS) manufactured by the Space Physics Research Laboratory. The ADCS includes three magnetic torque rods, deployed panels for stability, magnetometers, course sun sensors, and a rate gyro. The main flight computer is used to control the ADCS.

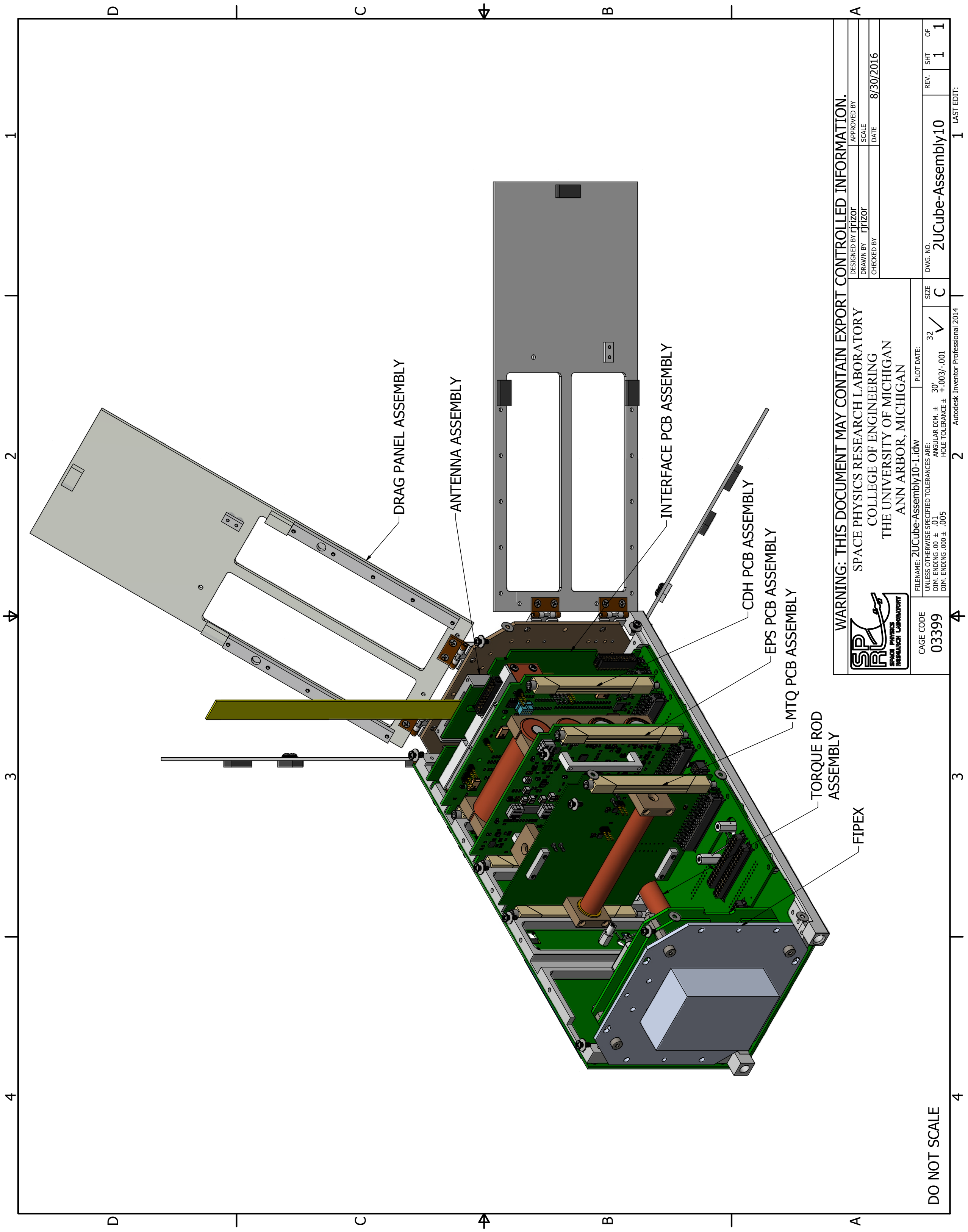
Electrical power is provided by 15 SpectoLab UTJ CIC solar cells charging battery pack composed of four Panasonic 18650b lithium-ion cells. A peak power tracker and low voltage power supply manages the electricity on the CubeSat. Safeguards are in place to prevent overcharging and excessive discharge.

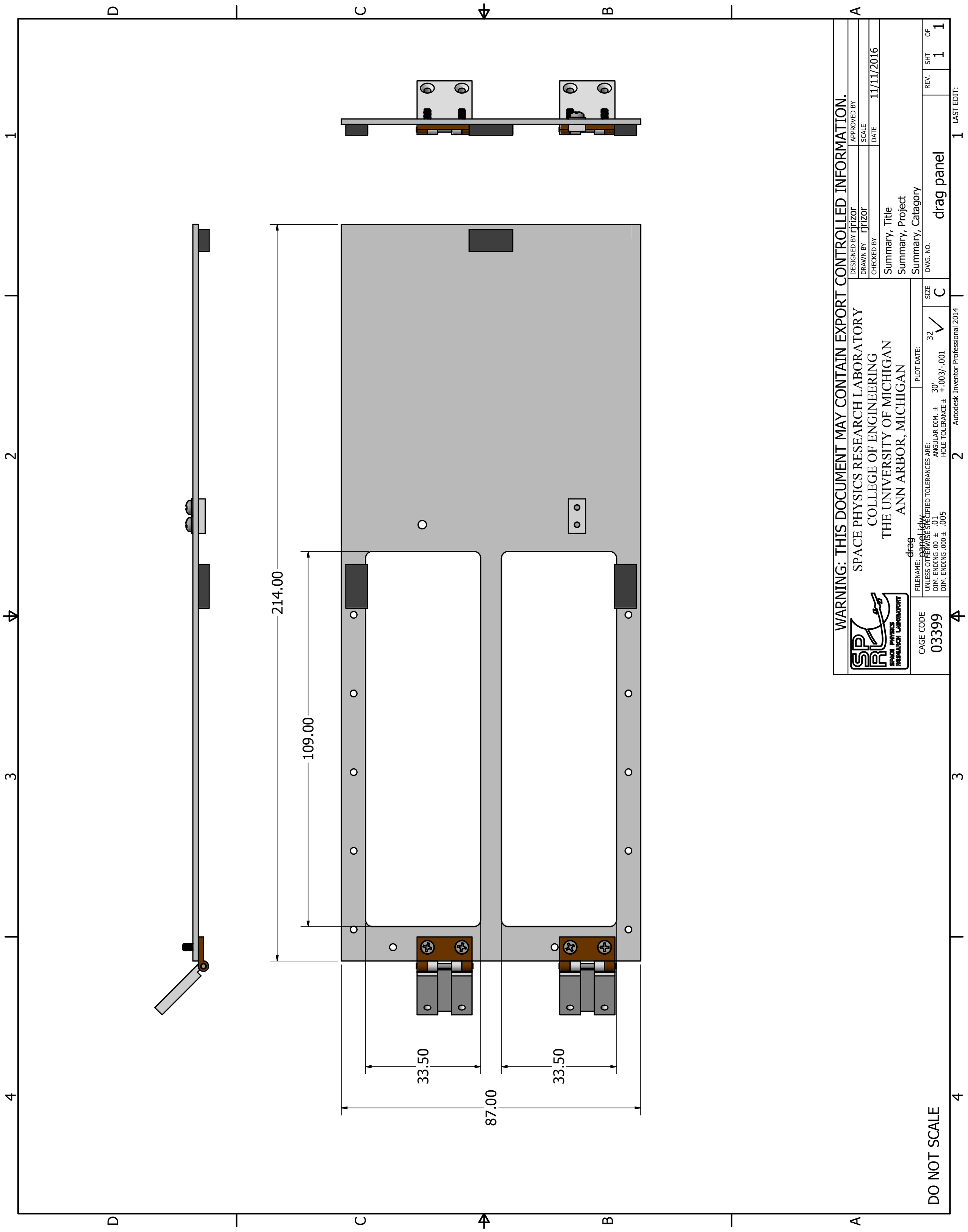
Columbia has no range safety or other pyrotechnic devices. No radioactive materials fly on Columbia. Beyond the batteries mentioned above, there are no other sources of stored energy.

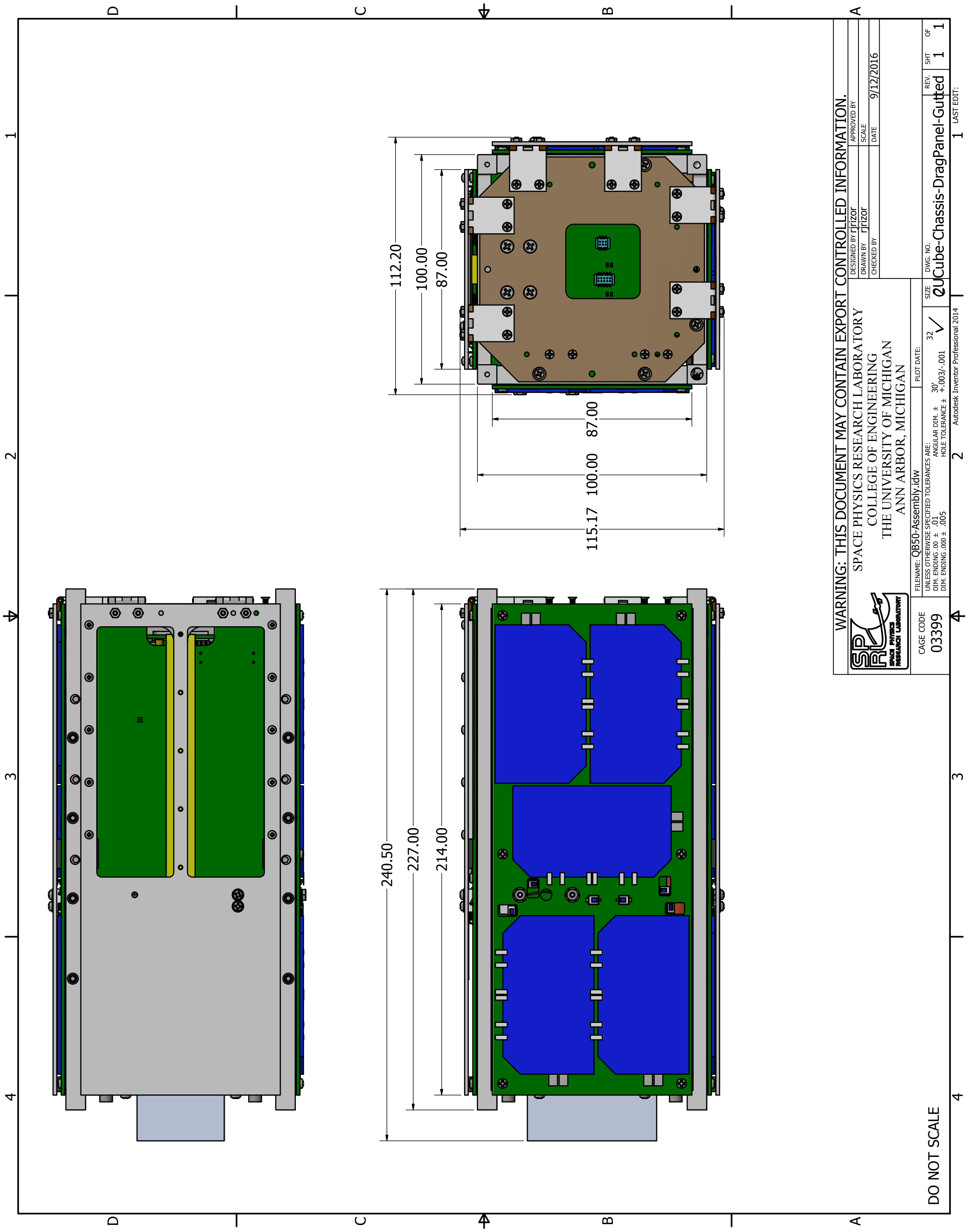
Columbia conforms to constraints imposed by the NanoRacks CubeSat Deployer.

The following pages contain details of the Columbia design.


407.64
87.00
214.00
(227.00)
(100.00)
135° TYP.
WARNING: THIS DOCUMENT MAY CONTAIN EXPORT CONTROLLED INFORMATION.
SPACE PHYSICS RESEARCH LABORATORY
COLLEGE OF ENGINEERING
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN
DESIGNED BY rjrizor
DRAWN BY rjrizor
DATE 10/10/2016
Summary, Title
Summary, Project
Summary, Catagory
FILENAME: 2UCube-Assembly-DragPanels.idw
CAGE CODE
03399
SIZE C
DWG. NO. 2UCube-Assembly-DragPanels
SHT 2 OF 2
Autodesk Inventor Professional 2014
DO NOT SCALE


DRAG PANEL ASSEMBLY
ANTENNA ASSEMBLY
INTERFACE PCB ASSEMBLY
CDH PCB ASSEMBLY
EPS PCB ASSEMBLY
MTQ PCB ASSEMBLY
TORQUE ROD ASSEMBLY
FIPEX
WARNING: THIS DOCUMENT MAY CONTAIN EXPORT CONTROLLED INFORMATION.
SPACE PHYSICS RESEARCH LABORATORY
COLLEGE OF ENGINEERING
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN
DESIGNED BY rjrizor
DRAWN BY rjrizor
CHECKED BY
APPROVED BY
SCALE
DATE 8/30/2016
FILENAME: 2UCube-Assembly10-1.idw
PLOT DATE:
CAGE CODE 03399
SIZE C
DWG. NO. 2UCube-Assembly10
REV.
SHT 1
OF 1
LAST EDIT:
Autodesk Inventor Professional 2014
DO NOT SCALE


WARNING: THIS DOCUMENT MAY CONTAIN EXPORT CONTROLLED INFORMATION.
SPACE PHYSICS RESEARCH LABORATORY
COLLEGE OF ENGINEERING
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN
DESIGNED BY rjrizor
DRAWN BY rjrizor
CHECKED BY
APPROVED BY
SCALE
DATE 11/11/2016
Summary, Title
Summary, Project
Summary, Catagory
DWG. NO.
drag panel
CAGE CODE 03399
SIZE C
REV.
SHT 1
OF 1
Autodesk Inventor Professional 2014
DO NOT SCALE
214.00
109.00
33.50
33.50
87.00


112.20
100.00
87.00
87.00
100.00
115.17
240.50
227.00
214.00
WARNING: THIS DOCUMENT MAY CONTAIN EXPORT CONTROLLED INFORMATION.
SPACE PHYSICS RESEARCH LABORATORY
COLLEGE OF ENGINEERING
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN
DESIGNED BY rjrizor
DRAWN BY rjrizor
CHECKED BY
APPROVED BY
SCALE
DATE 9/12/2016
FILENAME: QB50-Assembly.idw
CAGE CODE 03399
DWG. NO. 2UCube-Chassis-DragPanel-Gutted
Autodesk Inventor Professional 2014
DO NOT SCALE

Section 3: Assessment of Spacecraft Debris Released During Normal Operations

No objects (>1 mm) are expected to be released from the spacecraft at any time after launch. As such, Columbia is deemed COMPLIANT with requirements 4.3-1 and 4.3-2.

Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosion

Columbia contains four lithium-ion battery cells in a 48 W-hr battery pack. Like all lithium-ion battery cells, there is potential (albeit very limited) for an over-pressure event to cause unplanned venting of the cell. Testing has been performed after manufacturing and before flight (to comply with ISS lithium-ion battery testing), including capacity under vacuum at various temperatures and shock/vibration. The battery pack has an integrated heater to maintain acceptable temperatures. Over-charge, over-discharge, and over-current protection is built in to prevent conditions that could cause the battery to fail. Furthermore, should the battery suffer a failure, it is expected only to vent gases with most debris contained by the chassis. There is no credible failure mode with potential to produce orbital debris. As such, Columbia is deemed COMPLIANT with requirement 4.4-1.

As Columbia contains no pressurized fluids or other components needing passivation, there are no plans to passivate components at EOM. There is no danger posed from the battery's reentry, but if desired, the stored energy in the battery could be depleted by commanding the EPS to stop charging. Columbia is deemed COMPLIANT with requirement 4.4-2.

No intentional breakups, explosions, or collisions are planned for Columbia. Therefore, Columbia is deemed COMPLIANT with requirement 4.4-3 and 4.4-4.

Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

In its stowed configuration, Columbia has a convex shape, with no one face obscured by any other. The cross sectional area is given by:

$$A_{CS} = \frac{\Sigma A_S}{4} \quad (1)$$

$$A_{CS} = \frac{118.9 + 118.9 + 233.4 + 233.4 + 233.4 + 233.4}{4} = 292.9cm^2 \quad (2)$$

Where A_{CS} is the cross-sectional area and A_S is the area of the sides of the CubeSat.

In it's deployed configuration, the CubeSat will naturally fly with the dart panels towards the back, since it will be aerodynamically stable in that configuration. Therefore, the cross sectional area will be:

$$A_{CS} = \Sigma A_P + A_F \quad (3)$$

$$A_{CS} = 98.7 \times 4 + 118.9 = 513.9cm^2 \quad (4)$$

where Ap is the area of the four deployed panels projected onto the ram direction.

The collision probability of Columbia with large space objects (>10 cm), computed using NASA DAS 2.0.2 software is 0.00000. Columbia is COMPLIANT with requirement 4.5-1.

Columbia's post-mission disposal plan relies on natural orbital decay. As such, collision with small space objects will not interfere with post-mission disposal. Columbia is deemed COMPLIANT with requirement 4.5-2.

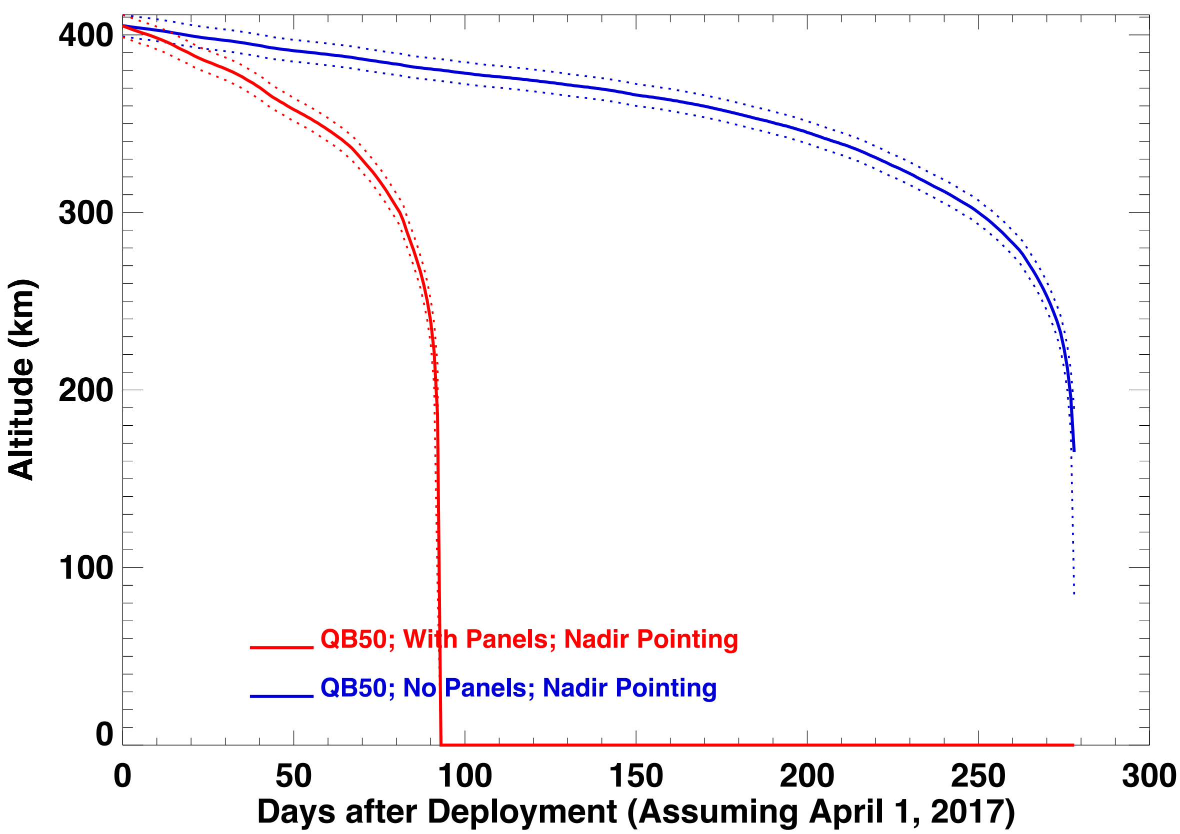
Section 6: Post-Mission Disposal of Space Structures

Columbia will be disposed of via passive atmospheric reentry. This does not require a post-mission disposal operation. Spacecraft disposal complies with requirement 4.6-1a, leaving the spacecraft in an orbit in which the natural forces will lead to an atmospheric reentry within 25 years of the completion of the mission and no more than 30 years after launch. Columbia is COMPLIANT with requirement 4.6-1a. Requirements 4.6-1b and 4.6-1c do not apply.

Columbia is not near GEO, therefore requirement 4.6-2 does not apply.

Columbia is in LEO, therefore requirement 4.6-3 does not apply.

Columbia deorbits within 0.5 year if the panels deploy and 1.1 years if the panels fail to open. Both satisfy the 25-year disposal requirement, therefore Columbia is COMPLIANT with requirement 4.6-4.



The figure above shows the altitude of Columbia as a function of days after deployment with and without the deployed panels. With the panels deployed, the mission will most likely last around 3 months, depending on the thermospheric conditions at the time.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on Columbia was performed. The assessment used DAS 2.0.2, a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a CubeSat's component during re-entry. For example, when DAS shows a component surviving reentry it is not taking into account the material ablating away or charring due to oxidative heating. Both physical effects are experienced upon reentry and will decrease the mass and size of the real-life components as the reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a components potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event the survive reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.

2. The remaining high temperature materials are shown to pose negligible risk to human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component is of similar dimensions and has a melting temperature between 1000 °C and 1500°C, it can be expected to possess the same negligible risk as stainless steel components. See Table 1.

Table 1: Columbia Survivability DAS Analysis

High Temp Component	Material	Mass (g)	Length / Diameter (m)	Width (m)	Height (m)	Demise Alt (km)	KE (J)
UHF Whip Antenna	Steel 410	10	0.1	0.013	0.164	0	1
SEP Switch Plunger	Stainless Steel 18-8	2.35	0.0045	0.027	0.005	74.9	0
Mounting Screw	316 Stainless Steel	0.1	0.004	0.007	-	77.6	0

The majority of high temperature components demise upon reentry. The components that DAS conservatively identifies as reaching the ground have less than or equal to 1 joule of kinetic energy, far below the requirement of 15 joules. No high temperature component will pose a risk to human casualty as defined by the Range Commander's Council. In fact, an injury incurred or inflicted by an object with such low energy would be negligible and wouldn't require the individual to seek medical attention.

Through the method described, Columbia is conservatively shown to be COMPLIANT with Requirement 4.7-1.

Section 8: Assessment for Tether Missions

Columbia is not a tether mission; therefore requirement 4.8-1 does not apply.