ELVL-2021-0046129
January 25, 2022

Orbital Debris Assessment for the CatSat CubeSat per NASA-STD 8719.14A

Signature Page

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Reply to Attn of: VA-H1

TO: Liam Cheney, LSP Mission Manager, NASA/KSC/VA-C

FROM: Caley Burke, NASA/KSC/VA-H1

SUBJECT: Orbital Debris Assessment Report (ODAR) for the CatSat CubeSat

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6B, 6 February 2017
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14B, 25 April 2019
C. Reserved
D. McKissock, Barbara, Patricia Loyselle, and Elisa Vogel. *Guidelines on Lithium-ion Battery Use in Space Applications*. Tech. no. RP-08-75. NASA Glenn Research Center Cleveland, Ohio
E. *UL Standard for Safety for Lithium Batteries, UL 1642*. UL Standard. 5th ed. Northbrook, IL, Underwriters Laboratories, 2012
F. Kwas, Robert. Thermal Analysis of ELaNa-4 CubeSat Batteries, ELVL-2012-0043254; Nov 2012
G. Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements, AFSCM 91-710 V3.
H. HQ OSMA Policy Memo/Email to 8719.14: CubeSat Battery Non-Passivation, Suzanne Aleman to Justin Treptow, 10, March 2014
I. ODPO Guidance Email: Fasteners and Screws, John Opiela to Yusef Johnson, 12 February 2020
J. ODPO Guidance Email: 6U CubeSat Battery Concerns, J.C. Liou to Eric Haddox, 18 May 2021
K. Debris Assessment Software User's Guide: Version 3.1, NASA/TP-2019-220300

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the CatSat CubeSat launching on the VCLS Demo-2 Firefly Black mission on the Alpha launch vehicle. It serves as the final submittal in support of the spacecraft Safety and Mission Success Review (SMSR). Sections 1 through 8 of ref. (b) are addressed in this document; sections 9 through 14 fall under the requirements levied on the launch vehicle and are not presented here.

This CubeSat will passively reenter, and therefore this ODAR will also serve as the End of Mission Plan (EOMP) for this CubeSat.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	January 2022

Section 1: Program Management and Mission Overview

CatSat is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is Sam Johnson. Responsible program/project manager and senior scientific and management personnel are as follows:

Christopher K. Walker, Mission PI, University of Arizona
Jekan Thangavelautham, Engineering PI, University of Arizona
Aman Chandra, University of Arizona

The following table summarizes the compliance status of CatSat, which will be flown on the VCLS Demo-2 Firefly Black mission on the Alpha launch vehicle. The current launch date is planned for 16 June 2022. Debris Assessment Software (DAS) version 3.1.2 was used to generate the data provided in this document. CatSat is fully compliant with all applicable requirements.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	Compliance Assessment	Comments
4.3-1a	Not applicable	No planned debris release
4.3-1b	Not applicable	No planned debris release
4.3-2	Not applicable	No planned debris release
4.4-1	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-2	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-3	Not applicable	No planned breakups
4.4-4	Not applicable	No planned breakups
4.5-1	Compliant	
4.5-2	Not applicable	
4.6-1(a)	Compliant	Worst case lifetime 14.2 years
4.6-1(b)	Not applicable	
4.6-1(c)	Not applicable	
4.6-2	Not applicable	
4.6-3	Not applicable	
4.6-4	Not applicable	Passive disposal
4.6-5	Compliant	
4.7-1	Compliant	Non-credible risk of human casualty
4.8-1	Compliant	No planned tether releases

Section 2: Spacecraft Description

Table 2 outlines its generic attributes.

Table 2: CatSat Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm)	CubeSat Mass (kg)
CatSat	1	345 x 245 x 117	8.3

The following pages describe the CatSat CubeSat.

CatSat – University of Arizona– 6U

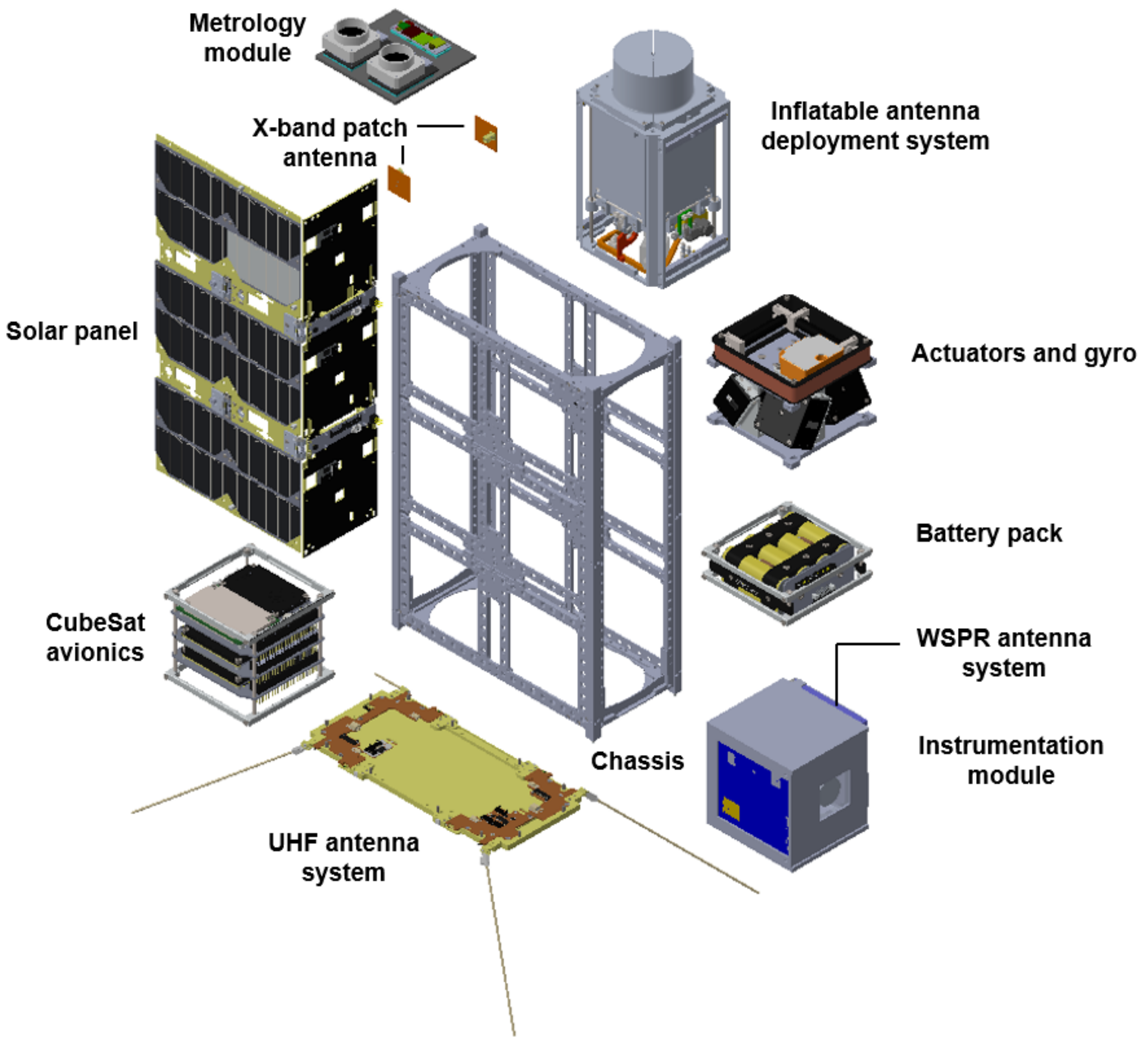


Figure 1: CatSat Expanded View

Overview

CatSat will demonstrate a high-speed communications link using a high gain inflatable antenna system and ionospheric measurements using a low frequency monopole antenna in the low earth orbit space.

Spacecraft components are housed in a 6U bus with an aluminum 6061-T6 chassis. Bus components include an avionics suite, lithium ion batteries, solar panels, electrical power system, reaction wheel and gyro system and payload systems. Payload systems consist of an inflatable antenna deployment module, and instrument module and metrology module. All parts used are commercial off the shelf components to minimize customized designs and minimize orbital debris.

The inflatable antenna deployment module contains a packaged Mylar spherical antenna, a line feed system, associated electrical components, valves, a pressurized gas cylinder and printed circuit boards (PCBs). The instrument module contains a low frequency monopole antenna system, an earth observing camera and associated electronics. The metrology module contains a stereo-camera system configured to verify the inflatable's deployment.

CatSat has four (4) deployable structures:

- 500 mm diameter inflatable membrane antenna that deploys from the +Z face of the spacecraft
- Solar panel spanning 163 mm in width from the +X face of the spacecraft
- Whip antenna spanning 785 mm in length from the –Z face of the spacecraft
- 4-element turn-style UHF (Ultra High Frequency) antenna from the –Z face of the spacecraft

CONOPS

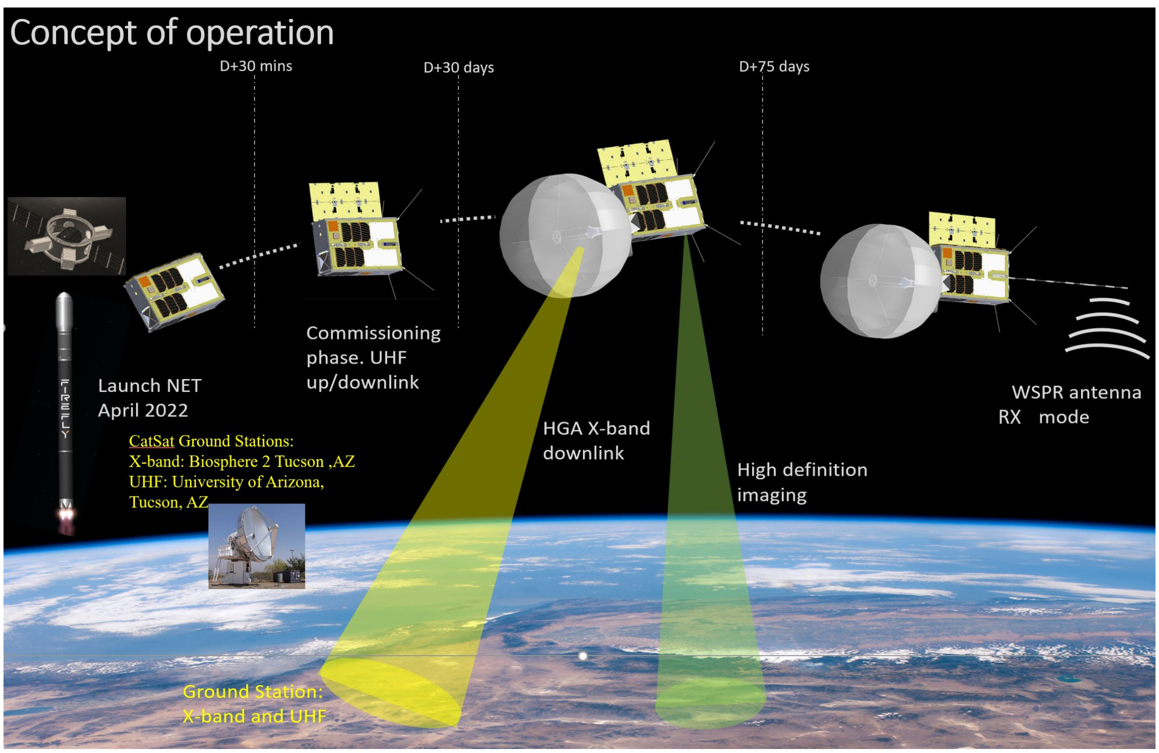


Figure 2: CatSat Concept of Operations

Upon deployment in a sun-synchronous orbit, CatSat will be powered up and countdown timers will be initiated. Thirty minutes into deployment, the UHF antenna will deploy. Starting at 45 minutes into deployment, the UHF transmitter will regularly (e.g., every 20 sec) transmit a short packet with an ASCII call sign and a binary data packet with basic spacecraft housekeeping information (battery voltage, current, temperature, etc.). The CubeSat computer, after performing mandatory system checks, will initiate 3-axis stabilization using on-board reaction wheels to de-tumble the spacecraft. A total period of 5 orbits has been estimated to stabilize the spacecraft to acceptable tolerance.

Further system checks take place for a period of 7 days. The monopole antenna is then deployed and 1 day is allowed for the antenna and spacecraft to stabilize. The monopole antenna is then used to receive high frequency weak signal propagation reporter (HF WSPR) beacons from ground based amateur radio stations. The beacon information is then transmitted to Earth at X-band via microstrip patch antennas attached to the spacecraft. Initial data collection will take place for 7 days.

Following this the metrology camera system is activated and the inflation of the high gain antenna initiated. A period of ~2 days is allowed for the spacecraft to stabilize following the inflation sequence. The Earth observation camera is then activated. High speed data transfer of both images and HF WSPR beacon data is then attempted using the inflated antenna system. If the inflatable antenna is inoperative, data will be transferred at a lower rate through the X-band patch antennas.

The experiment will continue for 6 or more months, depending on the health of the spacecraft.

Materials

The CubeSat structure is made of aluminum 6061-T6. It contains commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The electrical power system consists of lithium-ion battery pack and electrical power system.

Hazards

The inflatable antenna deployment system consists of four (4) 80 mL stainless steel cylinders each containing a gas mixture (95/5 Nitrogen/Helium by volume). The cylinders feed into a manifold at an equilibrated gas pressure of 300 psi. Pressurized gas is then fed into the inflatable membrane via two (2) solenoid valves in parallel. A 3rd venting valve is used to relieve excess pressure.

The valve control system uses feedback from two relative pressure sensors designed to maintain the relative pressure inside the inflatable at a 0.012 psi nominally. The control algorithm checks for anomalous pressure increase/ decrease rates. Passivation can be achieved by commanding the venting/ relief valve to leak all gas through a separately provided venting port in the event of an anomaly. The four (4) cylinders are packaged in an aluminum housing which is further packaged within the spacecraft structure.

There are no hazardous or exotic materials. The spacecraft does not contain propulsion systems on board.

The passivation plan after the mission is completed is to release whatever gas remains within the manifold. The pressure will drop over time from its start at 300 psi at launch as the gas is used to inflate (and keep inflated) the balloon. If there is still gas remaining when the mission is complete, the system includes relief valves that will expel the remainder of the gas.

Regarding fragmentation due to a cylinder being hit by a micrometeorite or other potential objects, the cylinders are stainless steel and encapsulated by > 5 mm thick aluminum on all sides except the interface with the manifold. The cylinders are at the back of the inflation deployment system, surrounded by the deployment mount, as well as CatSat's exterior surfaces and chassis. The cylinders are rated for a safety factor of 2.6 times the initial pressure of 1300 psi in the lab. At delivery, during launch, and during flight, the cylinders will be at no more than 300 psi. In the event that the cylinders were punctured, the gas would be released through the new puncture. This would eventually cause the antenna to deflate, and likely cause CatSat to lose its orientation until / unless the ADCS was able to recover.

Additionally, the antenna deployment system will include two software-controlled relief valves; they will be opened in any case where the system is experiencing overpressure. In the event where all the gas was released into the balloon (e.g., a failure of the valves), the balloon will over inflate and fail.

Batteries

The battery module is a NanoPower BPX, a high-capacity lithium ion battery pack with a heater from GomSpace A/S. There are eight (8) tested cells in the pack, which have been tested to meet the requirements in United Nations (UN) Regulations UN38.3 by the manufacturer. Every cell goes through GomSpace's "flight acceptance test (FAT), which is based on the documents 'Flight Acceptance Test Requirements for Lithium-ion Cells and Battery Packs' by NANORACKS, document no.: NR-SRD-139 Rev. C and 'NASA Aerospace Flight Battery Program' by NASA, document no.: RP-08-75 Rev. 1.0. The cells are checked for their physical and electromechanical characteristics, i.e., any occurrence of deformations, open-circuit voltage, capacity and internal resistance." (Appendix C)

The battery protection built into the P60 power supply consists of three parts; over voltage (OV) protection, under voltage (UV) protection and over current (OC) protection. To ensure that the spacecraft subsystems are not allowed to draw more current from the batteries than the batteries are rated, an OC protection function is built into the P60. The OC protection is located in the Parallel Information Processing System (PIPS) directly connected to the batteries. The PIPS are Latch-Up protected.

The OV protection feature of the P60 protects the batteries from an over charge condition. The OV is located in the P60 Dock. If the voltage across the batteries reaches the maximum safe, then the OV protection stops the charging.

The UV protection feature protects the batteries from an under charge condition. The UV is located in the P60 Dock. When the discharge level of the batteries reaches the minimum safe level the UV protection turn off the power supply until the batteries are charged to a safe level plus a hysteresis band.

The flight software will continuously monitor temperatures of all key components. If the temperatures exceed the maximum or minimum allowable limits, CatSat will enter safe mode.

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

The assessment of spacecraft debris requires the identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material.

Section 3 requires rationale/necessity for release of each object, time of release of each object, relative to launch time, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

No releases are planned on the CatSat CubeSat therefore this section is not applicable.

Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

There are no plans for designed spacecraft breakups, explosions, or intentional collisions for CatSat.

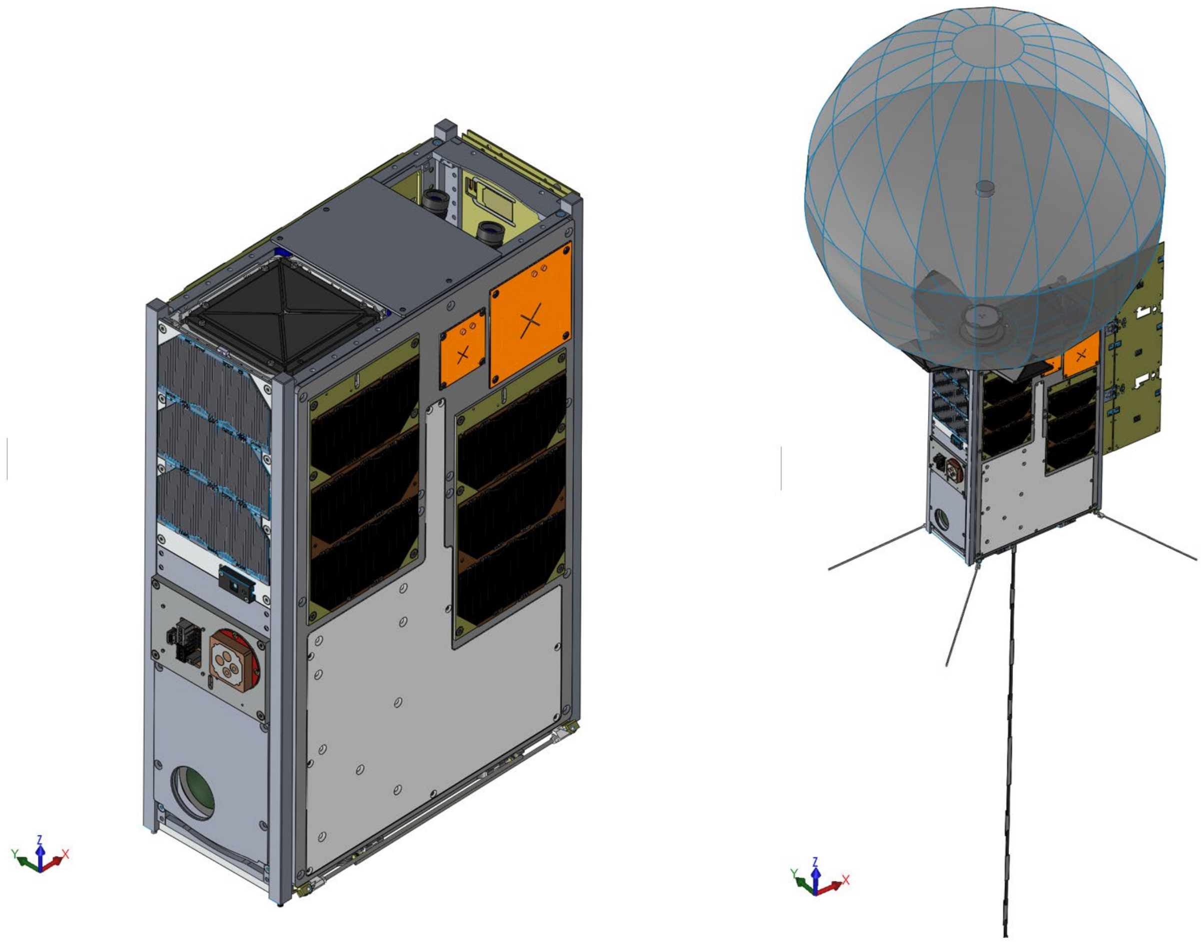
As discussed in Reference H, the probability of battery explosion is very low, and, due to the very small mass of the satellites and their short orbital lifetimes the effect of an explosion on the far-term LEO environment is negligible. The CatSat battery cells are UL certified under UN38.3. testing standards for lithium batteries, which addresses various concerns, including overcharge/overdischarge, temperature cycling, shock, vibration, low pressure, overheating, and other concerns.

Limitations in space and mass prevent the inclusion of the necessary resources to disconnect the battery or the solar arrays at EOM. However, the low charges and small battery cells on the CubeSat's power system prevent a catastrophic failure, so that passivation at EOM is not necessary to prevent an explosion or deflagration large enough to release orbital debris.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum lifetime of 14.2 years maximum, CatSat is compliant.

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

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft takes into account both the mean cross sectional area and orbital lifetime.



As-Ejected Deployed

Figure 3: CatSat As-Ejected and Deployed Views

$$\boldsymbol{Mean\ CSA} = \frac{\sum \boldsymbol{Surface\ Area}}{\mathbf{4}} = \frac{\mathbf{2} * [(\boldsymbol{w} * \boldsymbol{l}) + (\boldsymbol{w} * \boldsymbol{h}) + (\boldsymbol{l} * \boldsymbol{h})]}{\mathbf{4}}$$

Equation 1: Mean Cross Sectional Area for Convex Objects

$$\boldsymbol{Mean\ CSA} = \frac{(\boldsymbol{A_{max}} + \boldsymbol{A_1} + \boldsymbol{A_1})}{\mathbf{2}}$$

Equation 2: Mean Cross Sectional Area for Complex Objects

The CubeSat evaluated for this ODAR is as-ejected in a convex configuration, indicating there are no elements of the CubeSat obscuring another element of the same CubeSat from view. Thus, the mean CSA for the as-ejected CubeSat was calculated using Equation 1. This configuration renders the longest orbital life times for all CubeSats.

Once a CubeSat has been ejected from the CubeSat dispenser and deployables have been extended, Equation 2 is utilized to determine the mean CSA. A_{max} is identified as the view that yields the maximum cross-sectional area. A_1 and A_2 are the two cross-sectional areas orthogonal to A_{max}. Refer to Appendix A for component dimensions used in these calculations

CatSat's expected orbit at deployment has a 565-km apogee and a 565-km perigee (± 10 km) at a 97.61° inclination. A worst case 575-km circular orbit was assumed. With an area to mass ratio of 0.0090 m^2/kg, DAS yields 14.2 years for orbit lifetime for its as-ejected state, which in turn is used to obtain the collision probability. CatSat is calculated to have a probability of collision of 3.86×10^{-6} for the deployed state. Table 3 below provides complete results.

	CubeSat	**CatSat**
	Mass (kg)	8.3
As-Ejected	**Mean C/S Area (m^2)**	0.0747
	Area-to Mass (m^2/kg)	0.0090
	Orbital Lifetime (yrs)	**14.2**
	Probability of collision (10^X)	**3.06×10^{-6}**
Deployables Extended	**Mean C/S Area (m^2)**	0.3835
	Area-to Mass (m^2/kg)	0.0462
	Orbital Lifetime (yrs)	**3.3**
	Probability of collision (10^X)	**3.86×10^{-6}**

Solar Flux Table Dated 12/29/2021

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of CatSat colliding with debris or meteoroids greater than 10 cm in diameter that are capable of preventing post-mission disposal is less than 0.00001, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Assessment of spacecraft compliance with Requirements 4.5-1 shows CatSat to be compliant.

This ODAR also serves as the EOMP (End of Mission Plan).

Section 6: Assessment of Spacecraft Post-Mission Disposal Plans and Procedures

CatSat will naturally decay from orbit within 25 years after end of the mission, satisfying requirement 4.6-1a detailing the spacecraft disposal option.

Planning for spacecraft maneuvers to accomplish post-mission disposal is not applicable. Disposal will be achieved via passive atmospheric reentry even if the deployables do not deploy.

Calculating the area-to-mass ratio for the worst-case (smallest Area-to-Mass) post-mission disposal finds CatSat in its as-ejected configuration as the worst case. Though the current best estimate (CBE) mass for CatSat is 7.9 kg, the maximum mass of 8.3 kg is used in this document to provide the worst case. The area-to-mass is calculated as follows:

$$\frac{\boldsymbol{Mean}\ {}^{\boldsymbol{C}}/_{\boldsymbol{S}}\,\boldsymbol{Area}\ (\boldsymbol{m^2})}{\boldsymbol{Mass}\ (\boldsymbol{kg})} = \boldsymbol{Area - to - Mass}\ (\frac{\boldsymbol{m^2}}{\boldsymbol{kg}})$$

Equation 3: Area to Mass

$$\frac{0.0747\ m^2}{8.3\ kg} = 0.009\frac{m^2}{kg}$$

The assessment of the spacecraft illustrates it is compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS Orbital Lifetime Calculations:</u>
DAS inputs are: 575-km maximum apogee and 575-km maximum perigee altitudes with an inclination of 97.61° at deployment no earlier than June 2022. An area to mass ratio of ~0.0090 m^2/kg for the CatSat CubeSat was used. DAS yields a 14.2 years orbit lifetime for CatSat in its as-ejected state.

This meets requirement 4.6-1.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on CatSat was performed. The assessment used DAS, 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 they reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a component's 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 it survives reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk of 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 of human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component has a melting temperature between 1000 °C and 1500°C, it can be expected to possess the same negligible risk as a stainless steel component of similar dimensions.

3. Fasteners and similar materials that are composed of stainless steel or a lower melting point material will not be input into DAS, as suggested by guidance from the Orbital Debris Project Office (Reference I)

Table 4: CatSat High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Ceramic Patch	Ceramic	0.050	74.4	0
Top Bracket	Ti6Al4V Grade 25	0.002	0	0.32
Burnwire	Aluminum 6061, PTFE, Kanthal Alloy, Stainless steel	0.007	73.0	0
Burnwire 1	Aluminum 6061, Stainless Steel, PTFE, Kanthal A1	0.0115	72.2	0
Burnwire 2	Aluminum 6061, Stainless Steel, PTFE, Kanthal A1	0.0125	72.0	0

The majority of high melting point components demise upon reentry and CatSat complies with the 1:10,000 probability of Human Casualty Requirement 4.7-1. A breakdown of the determined probabilities follows:

Table 5: Requirement 4.7-1 Compliance by CubeSat

Name	Status	Risk of Human Casualty
CatSat	Compliant	1:0

*Requirement 4.7-1 Probability of Human Casualty ≤ 1:10,000

If a component survives to the ground but has less than 15 Joules of kinetic energy, it is not included in the Debris Casualty Area that inputs into the Probability of Human Casualty calculation. This is why CatSat has a 1:0 probability, as none of its components have more than 15J of energy.

CatSat is compliant with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

CatSat will not be deploying any tethers.

Section 9-14

ODAR sections 9 through 14 pertain to the launch vehicle, and are not covered here. Launch vehicle sections of the ODAR are the responsibility of the launch provider.

If you have any questions, please contact the undersigned at 321-867-5543.

/original signed by/

Caley A. Burke
Flight Design Analyst
NASA/KSC/VA-H1

cc: VA-C/Liam J. Cheney
VA-C/Norman L. Phelps
AIS2/ Jennifer A. Snyder
SA-D1/Kevin R. Villa
SA-D2/Homero Hidalgo

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Appendix A. CatSat Dimensions for Area Calculations
Appendix B. CatSat Component List
Appendix C. Battery Information

Appendix A. CatSat Dimensions for Area Calculations

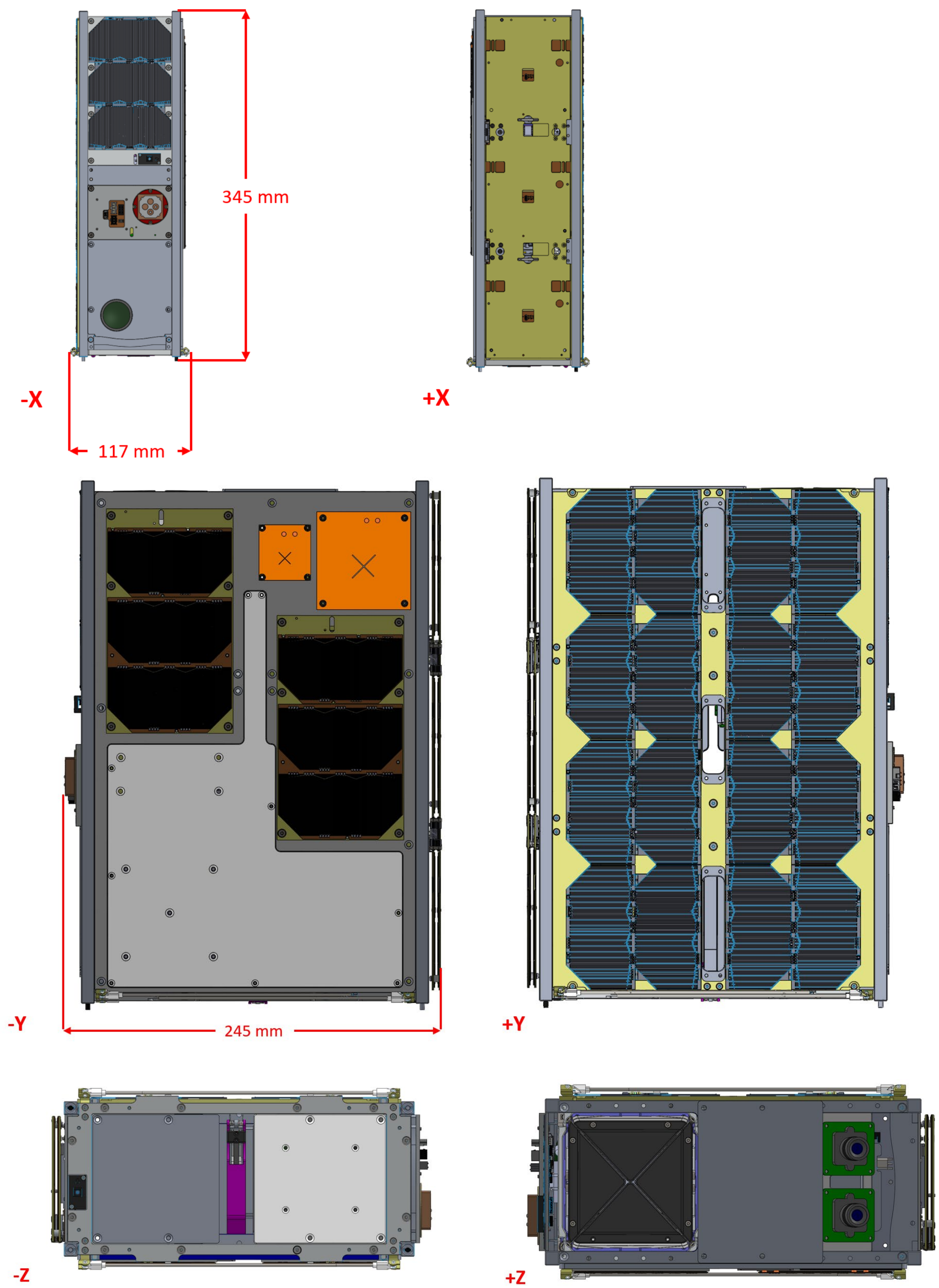


Figure 1: CatSat As-Ejected View (multiple orientations)

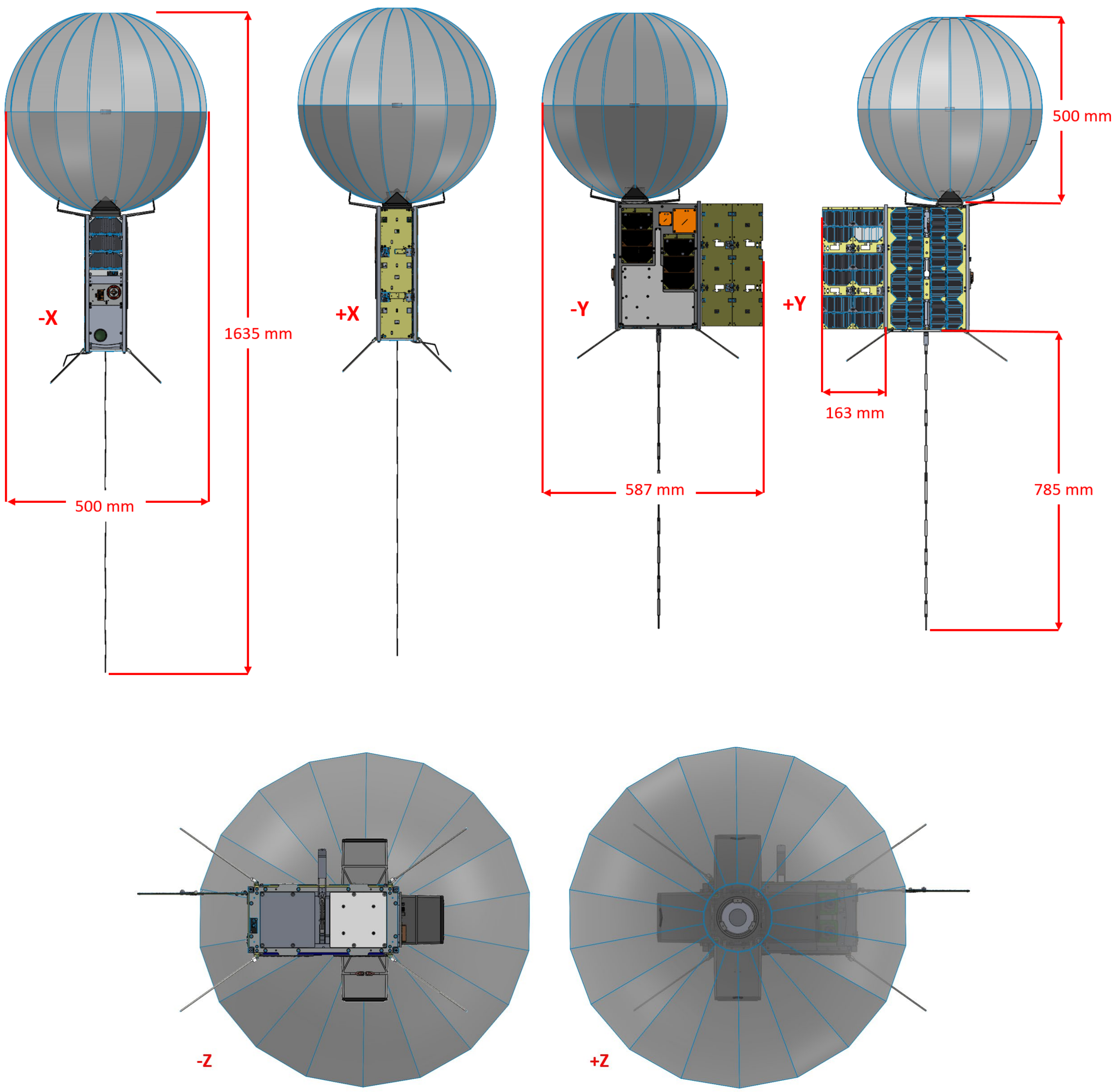


Figure 2: CatSat Deployed View (multiple orientations)

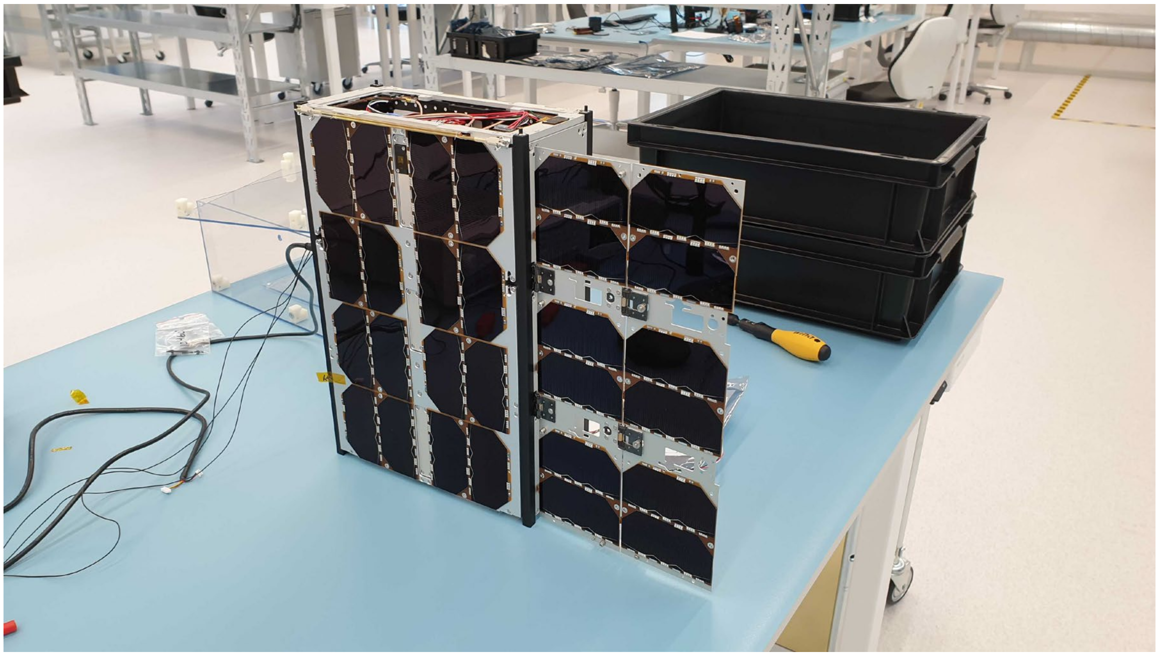


Figure 3: CatSat with Solar Panel Deployed

Appendix B. CatSat Component List

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
1	Wall	2	Aluminum 7075	Flat rectangle	660	226.3	340.5	14.6	No	-	Demise
2	Corner Bracket	4	Aluminum 6082	Extruded L-shape	56	20	20	95	No	-	Demise
3	Ring A/B	4	Aluminum 6082	Hollow Square	60	95	95	4	No	-	Demise
4	M3 Threaded rods - Battery	4	Stainless Steel	Cylinder	2.36	3	30	N/A	No	-	Demise
5	M3 Threaded rods - Avionics	4	Stainless Steel	Cylinder	2.36	3	94	N/A	No	-	Demise
6	Screws	140	Stainless Steel		49				No	-	Demise
8	NegativeY_Panel	1	Aluminum 6061		185				No	-	Demise
9	NegativeY_Radiator	1	Aluminum 6061		189				No	-	Demise
11	NegativeX_Panel_1	1	Aluminum 6061		58				No	-	Demise
14	NegativeZ_Panel	1	Aluminum 6061		27				No	-	Demise
15	NegativeZ_Radiator	1	Aluminum 6061		81				No	-	Demise
17	PositiveZ_Panel	1	Aluminum 6061		29.5				No	-	Demise
0	Housing	1	Aluminum 6082		150				No	-	Demise
0	Panel	2	Aluminum 6082		140				No	-	Demise
19	Brackets	2	Aluminum 6082	Brackets	100	85.9	40.6	92	No	-	Demise
20	PCB	1	Arlon 85 + Cu	Plate	13	85.9	40.6	2	No	-	Demise
21	Li-Ion 18650 Cell	8	Lithium Ion, Graphite Silicon Monoxide	Cylinder	352	18	65	N/A	No	-	Demise
22	Screws, nuts and washers	18	Stainless Steel		19.8				No	-	Demise
24	Structural back plate	1	Aluminum 5005	Plate	251	209	326.5	2.5	No	-	Demise
25	Solar Cell	16	GaInP/GaAs/Ge on Ge substrate	Plate	38.4	44.9	81	0.5	No	-	Demise
26	Solar Cell cover glass	16	CMG 100 cover glass	Plate	17.6	44.9	81	0.2	No	-	Demise

27	PCB	12	Arlon 85 + Cu	Plate	75.6	44.9	81	1	No	-	Demise
28	Screws, nuts and washers	20	Stainless Steel		4				No	-	Demise
29	Kovar Tabs	48	Kovar		4.8	10	5	0.1	No	-	Demise
31	Structural back plate	3	Aluminum 5005	Plate	225	83	326.5	2.5	No	-	Demise
32	Solar Cell	12	GaInP/GaAs/Ge on Ge substrate	Plate	38.4	44.9	81	0.5	No	-	Demise
33	Solar Cell cover glass	12	CMG 100 cover glass	Plate	13.2	44.9	81	0.2	No	-	Demise
34	PCB	12	Arlon 85 + Cu	Plate	75.6	44.9	81	1	No	-	Demise
35	Screws, nuts and washers	20	Stainless Steel		6				No	-	Demise
36	Kovar Tabs	12	Kovar		1.2	10	5	0.1	No	-	Demise
38	Lid	1	Aluminum 6082	Box	23	40	65	8.77	No	-	Demise
39	PCB	1	Arlon 85 + Cu	Plate	10	40	65	2.66	No	-	Demise
40	Therm a Gap	1	Therm-A-Gap	Plate	21	35	30	2	No	-	Demise
42	Lid	1	Aluminum 6082	Box	24	40	65	8.77	No	-	Demise
43	PCB	1	Arlon 85 + Cu	Plate	10	40	65	2.66	No	-	Demise
44	Therm a Gap	1	Therm-A-Gap	Plate	16	35	30	2	No	-	Demise
46	PCB	1	Arlon 85 + Cu	Plate	60	88.9	92	2	No	-	Demise
47	Stack connector	2	Vectra E-130	Box	10	2	10	8	No	-	Demise
48	Standoff	1	Brass	Cylinder	4.9				No	-	Demise
50	PCB	1	Arlon 85 + Cu	plate	10	40	65	1.5	No	-	Demise
51	Shield	1	Aluminum 6082	box	10	40	65	5.5	No	-	Demise
52	Screws	4	Stainless Steel		0.8				No	-	Demise
54	Plate	1	Aluminum 6082	plate	18.9	82.6	53.2	5.5	No	-	Demise
55	PCB	1	Arlon 85 + Cu	plate	6	35.1	35.1	1.5	No	-	Demise
56	Standoff	4	Brass	cylinder	5.6	6	2	N/A	No	-	Demise
57	Screws	8	Stainless Steel		2.4				No	-	Demise
58	Frame	1	Aluminum 6082	Plate	79	107	221.7	5.35	No	-	Demise
59	PCB	2	Arlon 85 + Cu	Plate	10.2	100	50	1.5	No	-	Demise

60	Screws	44	Stainless Steel		8.8				No	-	Demise
61	Rods	4	Aluminum 6061-T6	Rod/cylinder	2	2	160	N/A	No	-	Demise
62	RF Connectors	6	Brass		3.6				No	-	Demise
63	PCB	1	Arlon 85 + Cu	plate	10	40	65	1.5	No	-	Demise
64	Shield	1	Aluminum 6082	box	10	40	65	5.5	No	-	Demise
65	Screws	3	Stainless Steel		0.6				No	-	Demise
66	RF Connectors	1	Brass		0.6				No	-	Demise
67	PCB	1	Arlon 85 + Cu	Plate	47	89.5	92.6	1.6	No	-	Demise
68	Stack Connector	2	Vectra E-130	Box	10				No	-	Demise
69	Standoff	1	Brass	Cylinder	4.9				No	-	Demise
70	PCB	1	Arlon 85 + Cu	Plate	32	89.5	92.6	1.6	No	-	Demise
71	Stack connector	2	Vectra E-130	Box	10				No	-	Demise
72	Standoff	1	Brass	Cylinder	6.1				No	-	Demise
73	PCB	1	Arlon 85 + Cu	plate	0.3	8	10	1	No	-	Demise
74	Housing	1	Aluminum 6082	box	1.5	11	22	5	No	-	Demise
75	PCB	1	Arlon 85 + Cu	Plate	5.4	20	23	8	No	-	Demise
77	PCB	1	Arlon 85 + Cu	Plate	30	40	65	7.1	No	-	Demise
78	RF Connectors	1	Brass		1				No	-	Demise
79	Ceramic Patch	1	Ceramic, PCB	Plate	50	25	25	2	No	2552	Demise
80	Housing	1	Aluminum 6082	box	52				No	-	Demise
81	Screws	1	Stainless Steel		3.2				No	-	Demise
82	PCB	1	Arlon 85 + Cu	Plate	2				No	-	Demise
83	Coils	1	Copper	Wound wire	85	90.5	96.9	17	No	-	Demise
84	PCB	1	Arlon 85 + Cu	Plate	4				No	-	Demise
85	Frame	1	Aluminum 6082	Square	47	90.5	96.9	17	No	-	Demise
86	Screws	1	Stainless Steel		2				No	-	Demise
87	MagneTorquer Iron	1	Supra 50	rod/cylinder	19	5	70	N/A	No	-	Demise

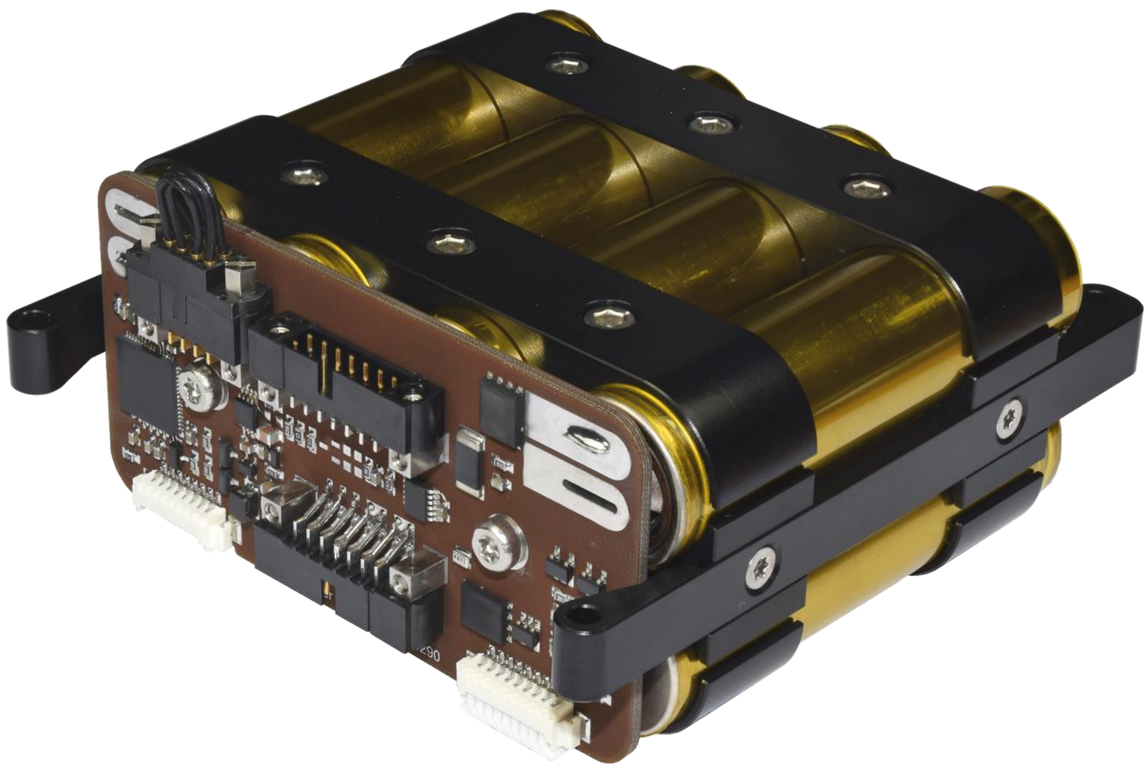
88	Base and Lid	4	Aluminum 6082	Box	208	44	44	27	No	-	Demise
89	Swingmass	4	CuSn7Zn4Pb7	Cylinder	420	25	40	N/A	No	-	Demise
90	Shaft	4	Stainless Steel	cylinder	9.2				No	-	Demise
91	Bearing	4	Stainless Steel	Circle	20				No	-	Demise
92	PCB	4	Arlon 85 + Cu	plate	20				No	-	Demise
93	Stators	4	Copper	cylinder	8				No	-	Demise
94	Fasteners	40	Stainless Steel		4				No	-	Demise
95	Top Bracket	1	Ti6Al4V Grade 25	plate	2				Yes	3040	0 km
96	Webbed base	1	Aluminum 6082 - T651	Plate	39				No	-	Demise
97	Conductor	1	Silver plated copper	Wire	80				No	-	Demise
98	Isolator	1	PTFE	Wire	120				No	-	Demise
99	Spacers	80	Brass	Cylinder	152				No	-	Demise
100	Wiring	1	Teflon coated copper		200				No	-	Demise
101	Housing	1	Aluminum 6061		593				No	-	Demise
102	Fasteners	44	Stainless Steel		8.8				No	-	Demise
103	Rincon ASDR	1	FR4, Copper, Brass, Nickel, Gold, Aluminum 7075		95				No	-	Demise
104	Pixelink BL-P771-G	1	FR4, Aluminum 6061, Stainless steel, PTFE		37				No	-	Demise
105	Cinegon 1_8_4_8_0912	1	Aluminum 6061, Stainless Steel, PTFE, Glass		38				No	-	Demise
106	HF upcoverter	1	FR4, Copper, Brass, Nickel, Gold, Aluminum 7075		20				No	-	Demise
107	RF Relay	1	FR4, Copper, Brass, Nickel, Gold, Aluminum 7075		4.8				No	-	Demise
108	DC Amplifier	0	FR4, Copper, Brass, Nickel, Gold, Aluminum 7075		0				No	-	Demise
109	WSPR Housing	1	Aluminum 6061		52				No	-	Demise

110	WSPR Antenna	1	Stainless Steel		26				No	-	Demise
111	RF Connectors	1	Brass		6				No	-	Demise
112	Burnwire	1	Aluminum 6061, PTFE, Kanthal Alloy, Stainless steel		7				Yes	2750	73 km
113	Fasteners	57	Stainless Steel		5.7				No	-	Demise
114	Frame	1	Aluminum 6061		25				No	-	Demise
115	Brackets	2	Aluminum 6061		14.4				No	-	Demise
116	4D UCAM III	2	Aluminum 6061, Stainless Steel, PTFE, Glass		36				No	-	Demise
117	Fasteners	8	Stainless Steel		1.6				No	-	Demise
118	Kuhne 107A	1	FR4, Copper, Brass, Nickel, Gold, Aluminum 7075		310				No	-	Demise
119	Heatsink	1	Aluminum 6061		203				No	-	Demise
120	Frame	1	Aluminum 6061		83				No	-	Demise
121	Fasteners	16	Stainless Steel		3.2				No	-	Demise
122	Burnwire 1	1	Aluminum 6061, Stainless Steel, PTFE, Kanthal A1	Cuboid	11.5	6.3	14.5	19	Yes	2750	72.2 km
123	Chassis	1	Aluminum 6061	Cuboid	90	86	97	145	No	-	Demise
124	THK Linear rails	4	Stainless Steel		68.8				No	-	Demise
125	Fasteners	20	Stainless Steel		4				No	-	Demise
126	Inflation gas control system	1	Stainless Steel, Aluminum 6061		332				No	-	Demise
127	Feed Structure Housing	1	Aluminum 6061		89				No	-	Demise
128	Feed Structure	3	PTFE		9				No	-	Demise
129	Feed elements	5	Aluminum 6061		3				No	-	Demise
130	Vectran ties	1	Vectran		0.3				No	-	Demise
131	Power spliiter board	1	FR4, Copper, Brass		0				No	-	Demise
132	Feed screws	6	PTFE		0.6				No	-	Demise
133	RF Connectors	1	Brass		3				No	-	Demise

134	O-rings	2	Viton		0.7				No	-	Demise
135	Clamping structure	1	Aluminum 6061, Copper		0.5				No	-	Demise
136	Inflatable antena	1	Mylar	Irregular	27				No	-	Demise
137	Burnwire 2	1	Aluminum 6061, Stainless Steel, PTFE, Kanthal A1		12.5				Yes	2750	72.0 km
138	Flap Assembly	4	Aluminum 6061, Stainless Steel	Cuboid	328	80	80	150	No	-	Demise
139	Stowage Structure	1	Aluminum 6061, Stainless Steel		58				No	-	Demise
140	Constant force springs	2	Spring Steel	Cylindrical	64	10	9		No	-	Demise
141	Fasteners	36	Stainless Steel		7.2				No	-	Demise
142	Inflatable control board	1	FR4, Copper, Brass		34				No	-	Demise
143	Delta P sensors	2	PVDF, Teflon, Brass		12				No	-	Demise
144	10.5 GHz Patch	1	FR4, Copper		3.5				No	-	Demise
145	RF Connectors	1	Brass		0.6				No	-	Demise
146	Fasteners	4	Stainless steel		0.8				No	-	Demise
147	5.6 GHz Patch	1	FR4, Copper		9				No	-	Demise
148	RF Connectors	1	Brass		0.6				No	-	Demise
149	Fasteners	4	Stainless steel		0.8				No	-	Demise
150	cabling/ connectors	1	Teflon coated copper		200				No	-	Demise

Appendix C. Battery Information

GOMSpace NanoPower BPX Datasheet
High-capacity battery pack for nano-satellites
8 May 2018
gs-ds-nanopower-bpx-3-1.8



NanoPower
BPX

Datasheet
High-capacity battery pack for nano-satellites

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2 Overview

The NanoPower BPX (BPX) is a high-capacity lithium ion battery pack with a heater for nano-satellites. Several BPX battery packs can be coupled in parallel if greater capacity packs are needed.

2.1 Highlighted Features

- Lithium ion battery back for space applications
- Utilizes 18650 lithium ion cells, 2600 mAh cell (Nominal)
- Can be configured for nominal voltages ranging up to 29.6 V
- Provides telemetry over I^2C
    - Voltage
    - Current
    - Temperature
- Autonomous heater system
- Fits standard PC104
- Weight: 500 g
- PCB material: Glass/Polyimide IPC 6012C cl. 3/A
- IPC-A-610 Class 3 assembly

2.2 Customization Options

As GomSpace realizes that different applications place different requirements to a power system, the NanoPower products present a variety of options for customization. Options are to be agreed upon time of order placement.

Below are the standard configurations. It is possible to connect several BPX in parallel using the loop connector PBAT2 (se chapter 4) to get the required capacity.

To find the nominal voltage of the chosen battery pack use the following equation (Vnom(cell) is found in the battery datasheet):

*Vnom(pack) = Vnom(cell) * Number of series cells*

To find the current capacity of the battery pack use the following equation:

*Icap(pack) = Icap(cell) * Number of parallel cells*

To find the nominal capacity (Wh) of the battery pack use the following equation:

*Pcap(pack) = Vnom(pack) * Icap(pack)*

Configuration	**Number of cells**	**Capacity [Wh]**	**V_{range} [V]**	**$V_{nominel}$ [V]**	**Capacity [Ah]**
2S-4P	8	77	6 - 8.4	7.4 V	10.4
4S-2P	8	77	12 - 16.8	14.8 V	5.2
8S-1P	8	77	24 - 33.6	29.6 V	2.6

2.3 Measurements

The NanoPower BPX provides a number of measurement points that enables monitoring of the condition of the system. These measurements are available as digital readings retrievable through the I^2C interface. Measurements include:

- Current into and out of batteries
- Battery voltage
- Four temperature measurements

2.4 Short Circuit Protection

The battery output on connector PBAT1 (se chapter 4) is short-circuit protected. The protection level of depends on the configuration and subject to activation through the enable pin.

Configuration	Short-circuit protected current level
2S-4P	10 A
4S-2P	10 A
8S-1P	3 A

2.5 Enable Pin

By default, only the raw unprotected battery power is accessible through the PBAT2 all other function of the BPX are powered off.

The enable pin on PBAT1 and PBAT2 (default: active high) is used to activate the battery packs onboard functions: housekeeping, heater control, and toggles the over current protected battery power switch to on. See the block diagram in the following chapter.

2.6 ISS Acceptance Test

GomSpace offers an option to perform an ISS acceptance test to meet NASA and NanoRacks safety requirements for ISS launch. This includes: vibration test, vacuum test, battery testing and a test report.

2.7 Block Diagram

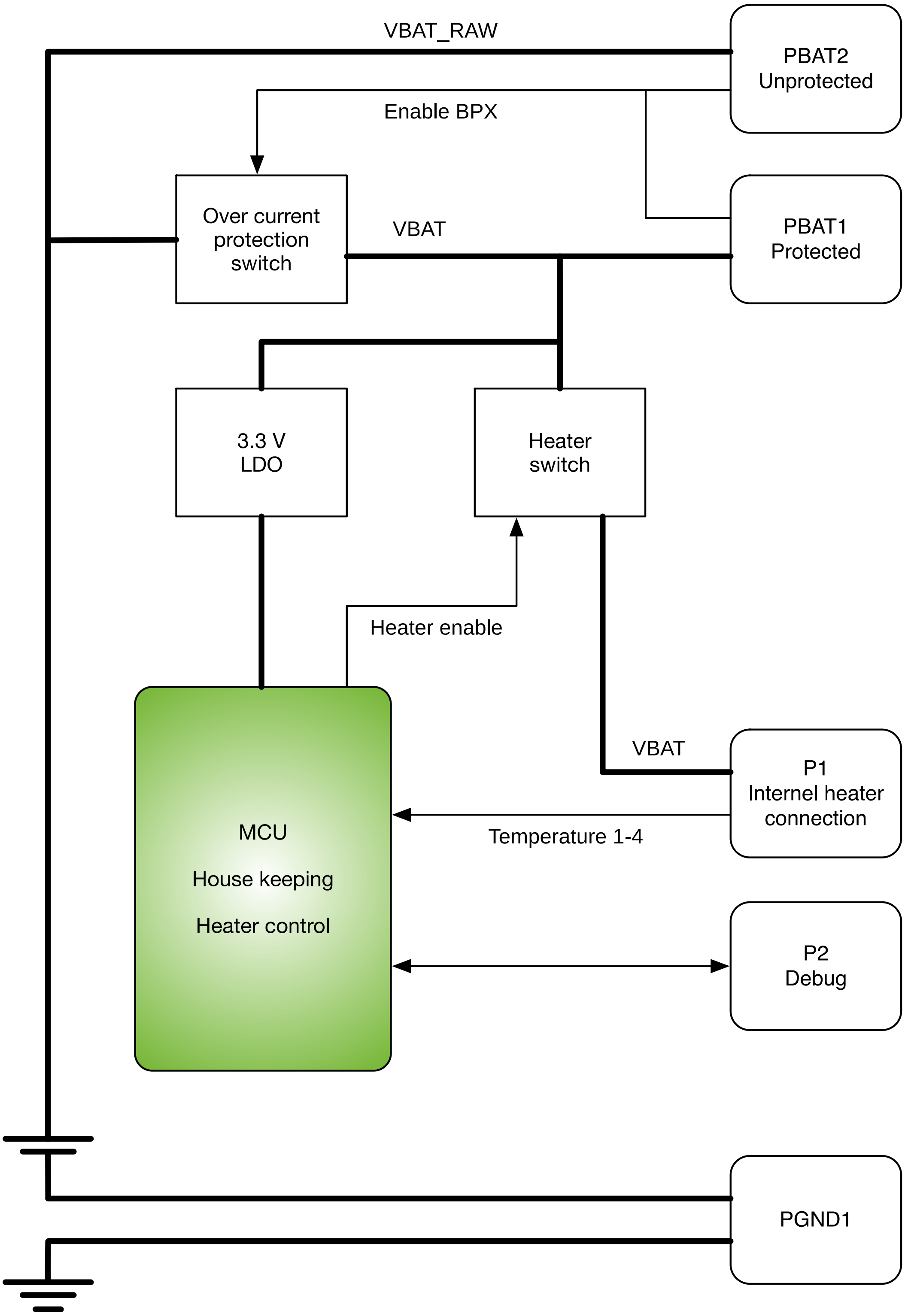
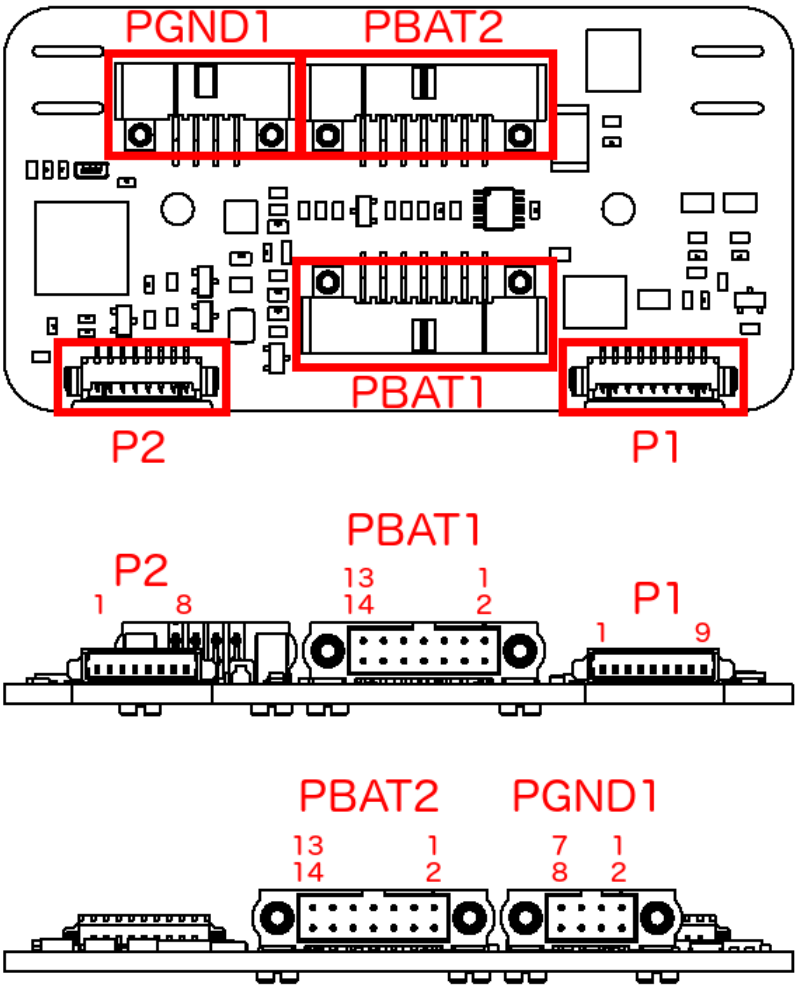


Figure 1 BPX Block diagram

3 Hardware Layout



3.1 P1 - Heater Connector

Picoblade Molex 0532610971

Pin	Description
1	Heater Supply
2	Heater Supply
3	GND
4	GND
5	3.3 V to temperature sensor heater
6	Vtemp 1
7	Vtemp 2
8	Vtemp 3
9	Vtemp 4

3.2 P2 - Debug

Picoblade Molex 0532610871

Used by GomSpace for MCU programming.

Pin	Description
1	GND
2	VCC 3.3 V
3	UART RX
4	UART TX
5	Reset
6	ISP SCK
7	ISP MOSI
8	ISP MISO

3.3 PBAT1 - Battery Connector

Harwin M80-5421442.The connector type is limited to 3 A per pin.

The only difference between PBAT1 and PBAT2 is the VBAT protected and VBAT raw pins. The I^2C, the Enable BPX and Kill switch pins are the same net on the PCB.

Pin	Description	Pin	Description
1	GND	2	GND
3	GND	4	GND
5	VBAT (Protected, se chapter 2.4)	6	VBAT (Protected, se chapter 2.4)
7	VBAT (Protected, se chapter 2.4)	8	VBAT (Protected, se chapter 2.4)
9	I^2C SCK	10	Enable BPX*
11	I^2C Data	12	GND
13	NC	14	Kill switch*

* Se option sheet for enabling BPX

3.4 PBAT2 - Battery Connector

Harwin M80-5421442. The connector type is limited to 3 A per pin.

The only difference between PBAT1 and PBAT2 is the VBAT protected and VBAT raw pins. The I^2C, the Enable BPX and Kill switch pins are the same net on the PCB.

Pin	Description	Pin	Description
1	GND	2	GND
3	GND	4	GND
5	VBAT_RAW Battery Voltage	6	VBAT_RAW Battery Voltage
7	VBAT_RAW Battery Voltage	8	VBAT_RAW Battery Voltage
9	I^2C SCK	10	Enable BPX*
11	I^2C Data	12	GND
13	NC	14	Kill switch*

*Se option sheet for enabling BPX

3.5 PGND1 - Ground Breaker

Harwin M80-5430805

Pin	Description	Pin	Description
1	Battery GND	2	Battery GND
3	Battery GND	4	Battery GND
5	System GND	6	System GND
7	System GND	8	System GND

4 Data Interface

The NanoPowr BPX uses the CubeSat Space Protocol (CSP) to transfer data to and from CSP nodes on-board the main system bus. CSP is a routed network protocol that can be used to transmit data packets between individual subsystems on the satellite bus and between the satellite and ground station. For more information about CSP please read the documentation on http://www.libcsp.org .

4.1 I^{2}C

The standard method to communicate with the BPX is over multi-master I^{2}C. Please note that since the CSP router sends out an I^{2}C message automatically when data is ready for a subsystem residing on the I^{2}C bus, the bus needs to be operated in I^{2}C multi-master mode.

The BPX uses the same I^{2}C address as the CSP network address per default. The BPX's own I^{2}C address is 0x07 per default.

4.2 I^{2}C Slave Mode

Slave mode operation disables the use of the CSP stack, and uses a slave-mode only protocol instead. A limited set of the CSP commands is available in this mode.

5 Debug Interface

The debug interface is a USART that uses the GomSpace Shell (GOSH) to present a console-like interface to the user. GOSH is a general feature present on all GomSpace products. Supported baud rate is 38400 8 bit, no parity and one stop-bit (8N1).

The console can be used during checkout of the BPX to send commands and set parameter. During integration into the satellite, the debug interface can be used to evaluate and see incoming and outgoing traffic through the BPX. Telemetry and housekeeping parameters can also be monitored. Here is a short list of features of the debug interface:

- Inspect CSP traffic (incoming and outgoing)
- Inspect I^{2}C driver (useful during early driver development)
- Inspect runtime performance
- Run tests (ping, etc.)
- Modify routing table
- Modify, save and restore default parameters

6 Heater and Temperature Sensor

Lithium ion batteries cannot charge in low temperatures (see battery datasheet). Using a heater to maintain temperature above charging threshold is a software option. Software default mode is set to manual.

The heater PCB contains four heating elements each placed between two batteries. Each element has its own temperature sensor. Below are two pictures of the PCB with the elements and sensors:

Figure 2 Heater top

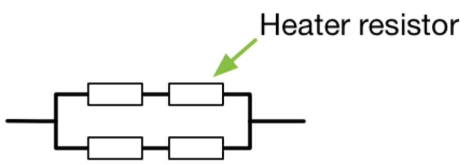
Figure 3 Heater bottom

Red marks = heater
Green marks = Temperature sensor

Heater characteristics:

Parameter	Condition	Min.	Typ.	Max.	Unit
Heater Element					
Heater resistance	8 V 2S-4P		10		Ω
	16 V 4S-2P		40		Ω
	32 V 8S-1P		150		Ω
Heater power	8 V 2S-4P		6		W
	16 V 4S-2P		6		W
	32 V 8S-1P		6		W

Heater resistor circuit setup is shown to the right.



Two temperature sensors with an analog interface are mounted just under each battery-set to provide battery temperatures for housekeeping purposes. A complete thermal control system can be implemented using the two optional heater elements.

For SPI communication details please see the datasheet for the Texas Instruments LM60CIM3.

Parameter	Min.	Typ.	Max.	Unit
Temperature Sensors - Range - Accuracy	 -40 -2	 1.5	 125 2	 °C °C

7 Absolute Maximum Ratings for the PCB

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the BPX. Exposure to absolute maximum rating conditions for extended periods may affect the reliability.

Symbol	Description	Min.	Max.	Unit
V	Supply Voltage	0	35	V
$\mathbf{T_{op}}$	Electronic Operational Temperature	-40	+85	°C
$\mathbf{T_{bat}}$	Battery Operational Temperature	See battery cell datasheet		

8 Electrical Characteristics

Parameter	Condition	Min.	Typ.	Max.	Unit
Heater output power	Software enable heater		6		W
Enable • **Input low** • **Input high**	Default active high Onboard 300kΩ pull down	 0 2		 0.4 VBAT	 V V
Battery Voltage	Depends on battery configuration, see chapter 2.2	6		33.6	V
Discharge/charge		See battery cell datasheet			
Power Consumption	VBAT = 16 V Enable active BPX booted and idle		4		mA
Off current	Enable not active, BPX switched off.		15		µA

9 Physical Characteristics

Description	Value	Unit
Mass	500	g
Size	Fits in a PC104 stack 93 x 86 x 41	 mm

10 Physical Layout

10.1 PCB Description

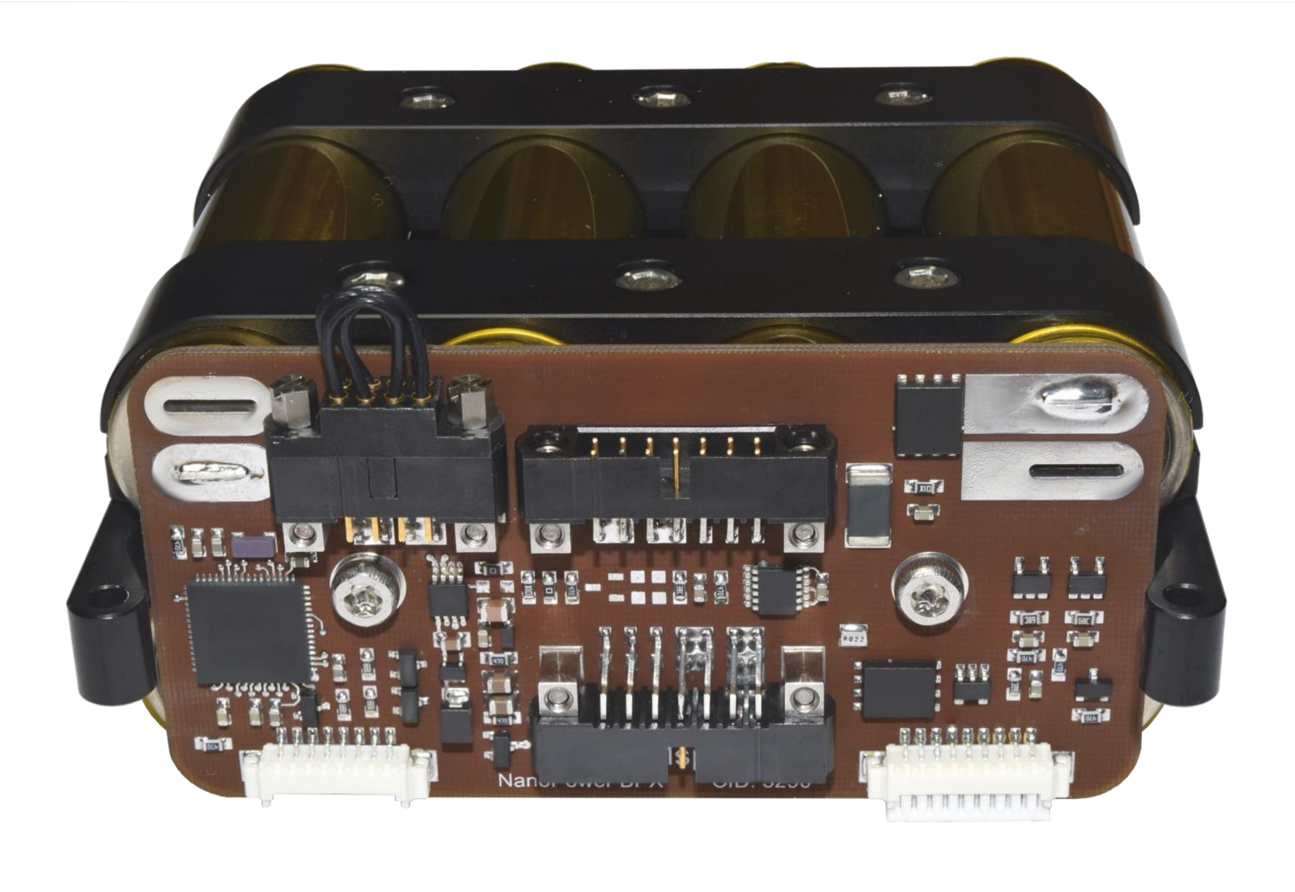


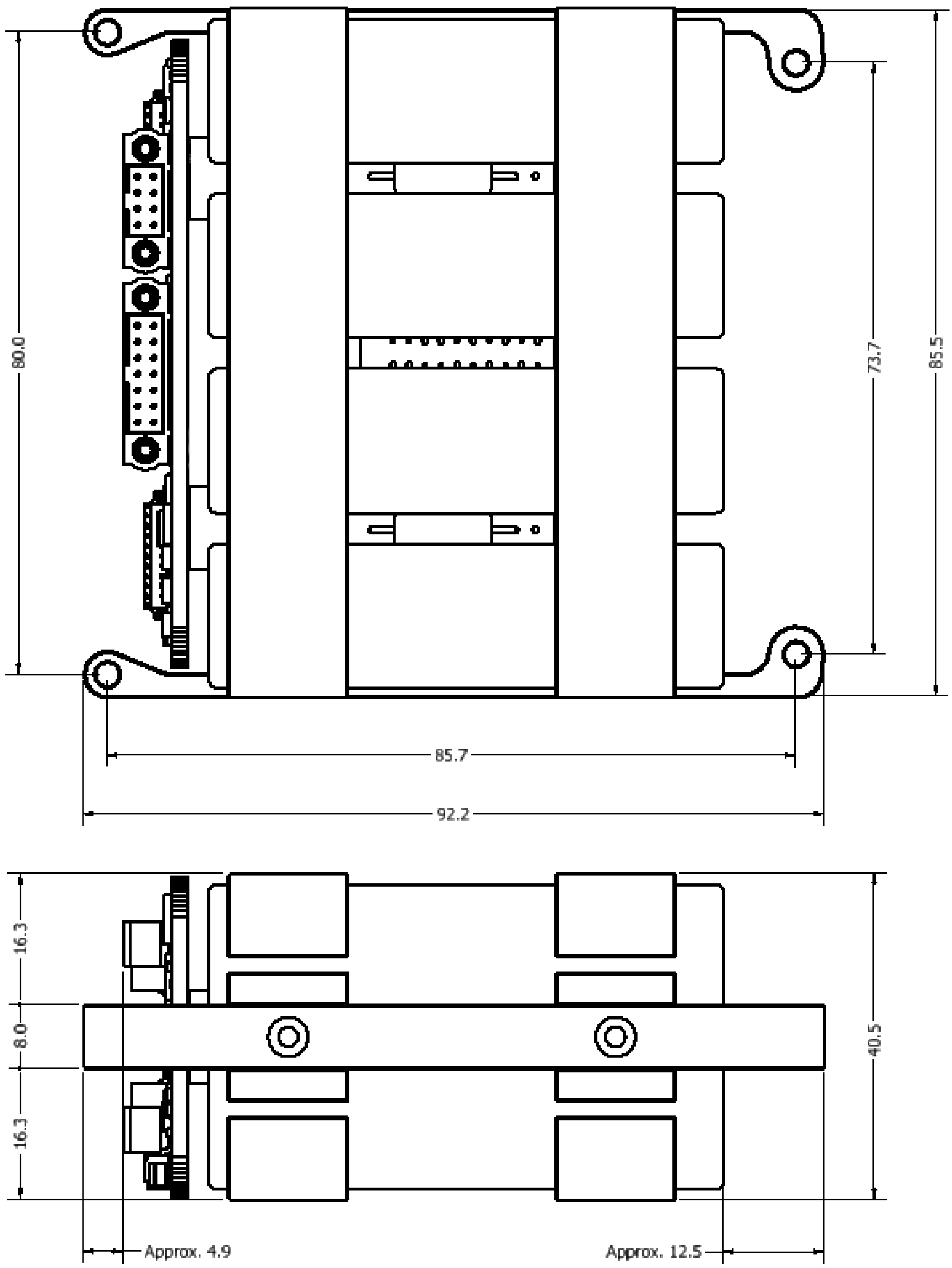
Figure 4 PCB front

All connectors are placed along the upper and lower edge of the PCB. Top left and right corners are the tab connectors from the batteries.

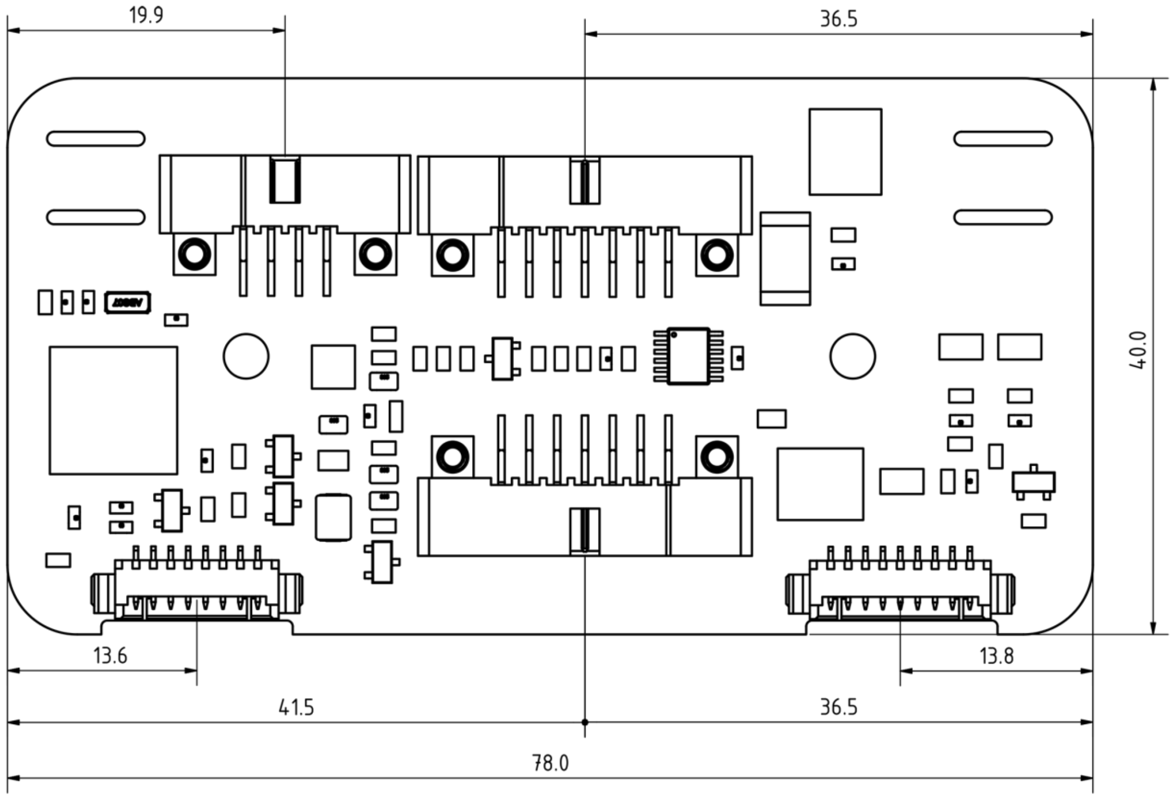
The IC on the middle left is the MCU. To the right of that is the 3.3 V LDO. In the top right corner next to the battery tabs is the VBAT switch and just mid right is the VBAT controller. Lower right is the heater switch.

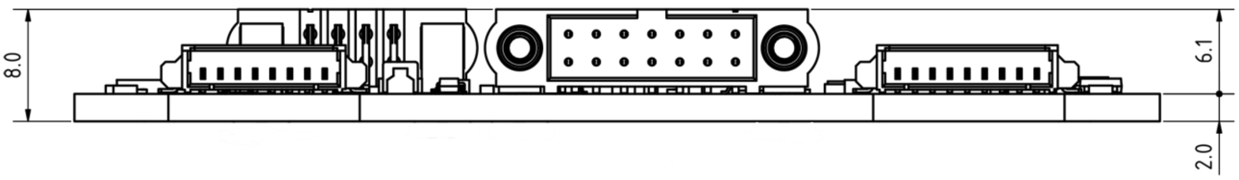
11 Mechanical Drawing

All dimensions in mm.



PCB front.





NanoPower
Battery 2600mAh

Datasheet
Lithium Ion 18650 cells for space flight products – 2600mAh

Product name: NanoPower Battery

Document No.: 1017178

Revision: 2.0

Author: VAKN, LAV

Approved by: BGS

Approval date: 27.09.2019

Confidentiality Notice

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2 Introduction

When choosing batteries for a satellite mission it is important to make sure that they can withstand the hostile environment encountered in space. The GomSpace batteries provide flight heritage and extensive testing and are chosen specifically for their suitability in satellite missions.

3 Characteristics

The battery available from GomSpace are lithium ion and from the rugged and space proven 18650 form factor.

3.1 Electrical and thermal characteristics

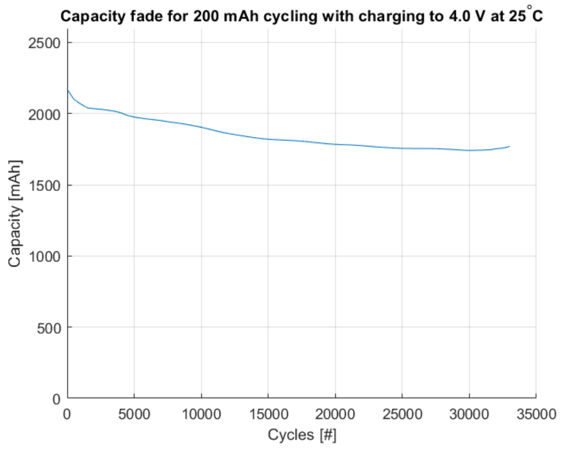
Parameter	Condition	Min.	Typ.	Max	Unit
Nominal Capacity		2500	2600		mAh
Voltage		2.75	3.6	4.2	V
Current - Charge	0 – +45 °C		1250	2500	mA
Current - Discharge	-20 – +5 °C +5 – +60 °C		1250	1250 3750	mA mA
Temperature – Storage (recommended)	3 months 12 months	-20 -20		45 20	°C °C
Temperature - Operating	Charge Discharge	0 -20		45 60	°C °C
Internal impedance				70	mΩ

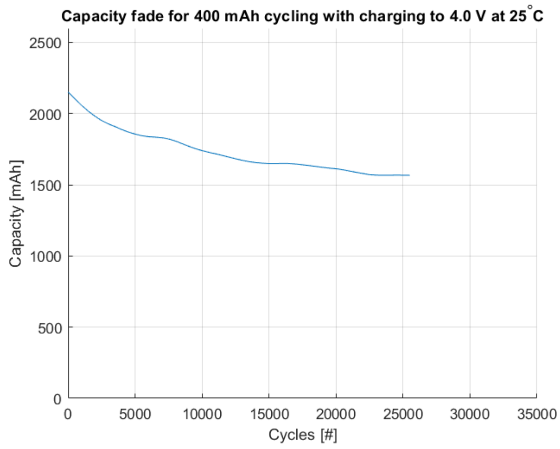
	Current [mA]				
Ambient Temperature	250	500	1250	2500	5000
	Relative Discharge Capacity [%]				
5 °C	93	91	89	89	94
15 °C	98	97	94	94	97
25 °C	100	100	98	98	99
35 °C	102	102	100	100	98
45 °C	102	102	101	101	99

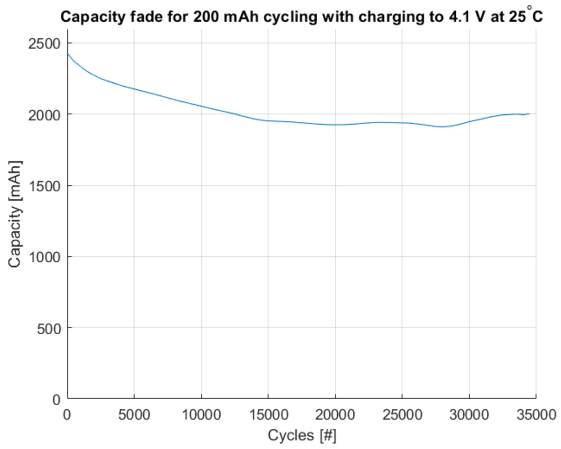
4 Cycle Life

The cycle life of any rechargeable battery depends on a number of factors, but most importantly the Depth-Of-Discharge (DOD) of the cycles, temperature, charge/discharge current and End of Charge Voltage (EOCV). General rules are that:

- The lower the DOD, the better the cycle life.
- The lower the temperature, the better the cycle life (unless too low for charging).
- The lower the charge/discharge current, the better the cycle life.
- The lower the EOCV, the better the cycle life.







Experimentally measured data:

- For aging: the cells were cycled at a specific DOD (200 or 400 mAh) and charged to a specific charging cut-off voltage (4.0 or 4.1 V).
- The presented remaining capacity is related to the respective charging conditions (charging to the charging cut-off voltage of 4.0 or 4.1 V)
- Please note that charging to a lower voltage than the nominal charging cut-off voltage (4.2 V) results in a lower available capacity than the nominal value.

5 Storage

For prolonged storage, it is recommended to charge the batteries to 30 – 60 % SOC and keep temperatures lower than 25°C (preferably 0 - 10°C).

6 Quality control

Samples from every LOT are tested according to “Requirements for flight certification and acceptance of commercial off the shelf (COTS) Lithium-Ion (Li-Ion) batteries,” JSC 66548, for physical characteristics, overcharge and external short.

Every cell goes through the flight acceptance test (FAT), which is based on the documents “Flight Acceptance Test Requirements for Lithium-ion Cells and Battery Packs” by NANORACKS, document no.: NR-SRD-139 Rev. C and “NASA Aerospace Flight Battery Program” by NASA, document no.: RP-08-75 Rev. 1.0. The cells are checked for their physical and electromechanical characteristics, i.e., any occurrence of deformations, open-circuit voltage, capacity and internal resistance.

7 Disclaimer

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MATERIAL SAFETY DATASHEET
GomSpace 18650 2600 Lithium Ion Cell

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Identification of Chemical Product and Company

Product
GomSpace Cylindrical 18650 2600 Lithium Ion cell

Company
GomSpace A/S
Langagervej 6
9220 Aalborg East
Denmark

Composite Information

Hazardous Ingredients	%	CAS Number
Aluminum Foil	2-10	7429-90-5
Nickel compound (proprietary)	10-25	
Manganese compound (proprietary)	6-15	
Cobalt compound (proprietary)	4-10	
Styrene-Butadiene-Rubber	<1	
Polyvinylidene Fluoride (PVDF)	<5	24937-79-9
Copper Foil	2-10	7440-50-8
Carbon (proprietary)	10-30	7440-44-0
Electrolyte (proprietary)	10-20	
Stainless steel and Nickel and inert materials	Remainder	N/A

Cell mass 48g Equivalent Lithium Content: 0.78g

Hazard Identification

Do not short circuit, puncture, incinerate, crush, immerse or expose to temperatures above the declared operating temperature range of the product. Risk of fire or explosion. The rechargeable lithium-ion batteries described in this Product Safety Data Sheet are sealed units which are not hazardous when used according to the recommendations of the datasheet.

Under normal conditions of use, the electrode materials and liquid electrolyte they contain are not exposed to the outside, provided the battery integrity is maintained and seals remain intact. Risk of exposure only in case of abuse (mechanical, thermal, electrical) which leads to the activation of safety valves and/or the rupture of the battery container. Electrolyte leakage, electrode materials reaction with moisture/water or battery vent/explosion/fire may follow, depending upon the circumstances.

Symptoms of exposure

Skin contact	No effect under routine handling and use
Skin absorption	No effect under routine handling and use
Eye contact	No effect under routine handling and use
Inhalation	No effect under routine handling and use
Reported as carcinogen	Not applicable

First Aid Measures

Inhalation	No health hazard
Eye contact	No health hazard
Skin contact	No health hazard
Ingestion	No health hazard

If exposure to internal components of battery happens, the following is recommended:

Inhalation	Leave area immediately and in severe cases seek medical attention
Eye contact	Rinse eyes with water for 15 minutes and seek medical attention
Skin contact	Wash off skin thoroughly with water. In severe cases obtain medical attention
Ingestion	Drink milk/water, induce vomiting, seek medical attention

Fire Fighting Measures

CO2 extinguishers, halon or large quantities of water or water-based foam can be used to cool down burning Li- ion cells and batteries. Do not use sand, dry powder or fire blankets.

Accidental Release Measures

Remove personnel from area until fumes dissipate. If the skin has come into contact with the electrolyte, it should be washed thoroughly with water.

Sand or earth should be used to absorb any exuded material. Seal leaking battery and contaminated absorbent material in plastic bag and dispose of in accordance with local regulations.

Handling and Storage

No special handling precautions are necessary.
Store in a dry and cool place.

Exposure Controls / Personal Protection

Personal Protection

Respiratory protection	In all fire situations, use self-contained breathing apparatus
Hand protection	In the event of leakage wear gloves
Eye protection	Safety glasses are recommended during handling

Physical and Chemical Properties

Appearance	Cylindrical
State	Solid
Odor	NA
pH	NA
Solubility	NA

Stability and Reactivity

Reactivity	None
Incompatibilities	None
Conditions of avoid	Avoid exposure to heat and open flame. Do not puncture, crush or incinerate

Toxicological Information

This product does not elicit toxicological properties during routine handling and use.

Ecological Information

None known if used/disposed of correctly

Disposal Considerations

Dispose of according to regulations.

Transport Information

Lithium Ion cells are considered to be "Rechargeable batteries" and meet the requirements of transportation by the U.S. Department of Transportation (DOT), International Civil Aviation Administration (ICAO).
The cells have been tested to meet the requirements in UN Regulations UN38.3 by the manufacturer. The cells are assembled to a battery pack by GomSpace. The battery is tested to meet the requirements in the UN regulations, Manual of Test and Criteria, subsection 38.3, sixth revision, Amendment 1 (ST/SG/AC.10/11/Rev.6/Amend.1).

Regulatory Information

OSHA hazard communication standard: Non-hazardous