ELVL-2021-0045978
March 19, 2021

Orbital Debris Assessment for
The JAGSAT 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-E2

FROM: Emily D'Elia, NASA/KSC/VA-H1

SUBJECT: Orbital Debris Assessment Report (ODAR) for the JAGSAT 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. International Space Station Reference Trajectory, delivered December 2019
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. 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 JAGSAT CubeSat launching on the SpX-24 Commercial Resupply Mission (CRS) to the International Space Station. 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 primary mission and are not presented here.

This report 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 primary mission 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	March 2021

Section 1: Program Management and Mission Overview

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

Edmund Spencer, Principal Investigator, University of South Alabama

The following table summarizes the compliance status of JAGSAT, which will be flown on the SpX-24 CRS mission to the International Space Station. The current launch date is planned for no earlier than December 5, 2021. JAGSAT 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 1.177 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: JAGSAT Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm)	CubeSat Mass (kg)
JAGSAT	1	227.0 x 100.0 x 100.0	1.73

The following pages describe the JAGSAT CubeSat.

JAGSAT – University of South Alabama – 2U

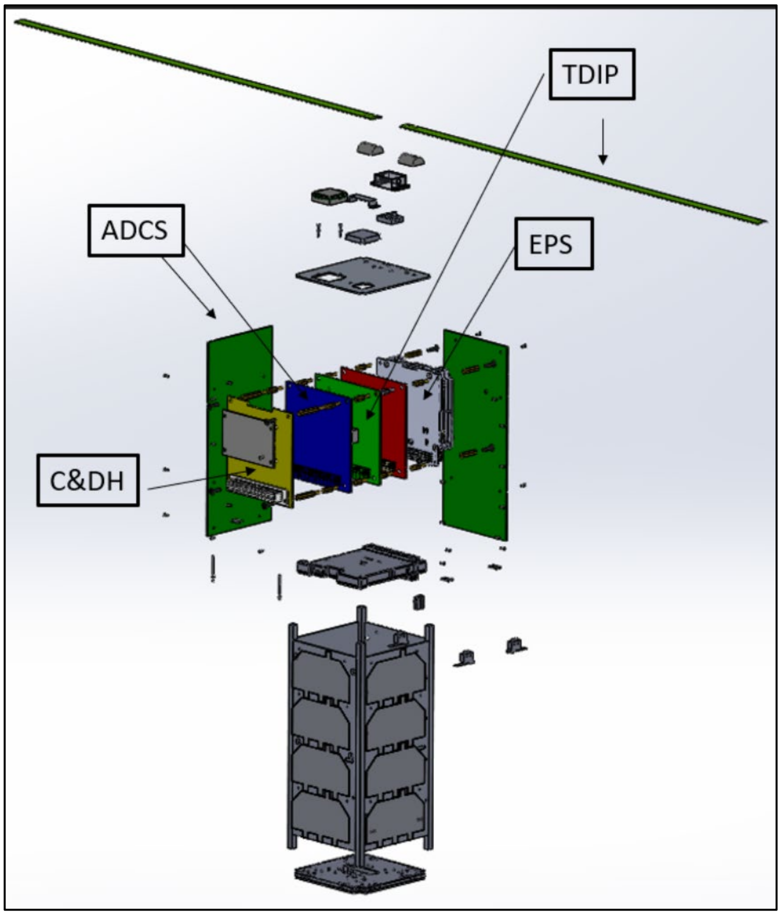

Figure 1: JAGSAT Expanded View

Overview

The JAGSAT 2U CubeSat, designed and built at University of South Alabama (USA), utilizes a mixture of commercially off the shelf (COTS) and in-house fabricated components that will measure plasma electron density in the ionosphere to get a clearer picture of the effect of scintillation on RF signals.

CONOPS

Upon ejection from the dispenser, JAGSAT will boot up and begin the timed start procedure. 30 minutes after deployment the boot up process begins and 1 minute later detumbling begins. At 91 minutes, the time-domain impedance probe (TDIP) deploys and 9 minutes later the UHF antenna deploys. 1 minute later at 101 minutes post-deployment the first attempts at UHF communication begin.

Materials

The JAGSAT structure is constructed from 6061-T6 Aluminum. The majority of boards and components are manufactured in-house, excluding the COTS GPS antenna and receiver, UHF radio and antenna, solar cells, and smaller electrical components.

Hazards

There are no pressure vessels, hazardous materials, or exotic materials.

Batteries

The electrical power system (EPS) converts, maintains, and stores power. It consists of four commercially available solar panels with a total of 16 solar cells, delivering power to the COTS Lithium-Ion 30Whr Varta battery. The battery's UL Listing number is BBCV2.MH13654.

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 JAGSAT 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 JAGSAT.

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 (ref (h)).

The CubeSat batteries still meet Req. 56450 (4.4-2) by virtue of the HQ OSMA policy regarding CubeSat battery disconnect stating;

> “CubeSats as a satellite class need not disconnect their batteries if flown in LEO with orbital lifetimes less than 25 years.” (ref. (h))

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 1.177 years maximum, JAGSAT 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.

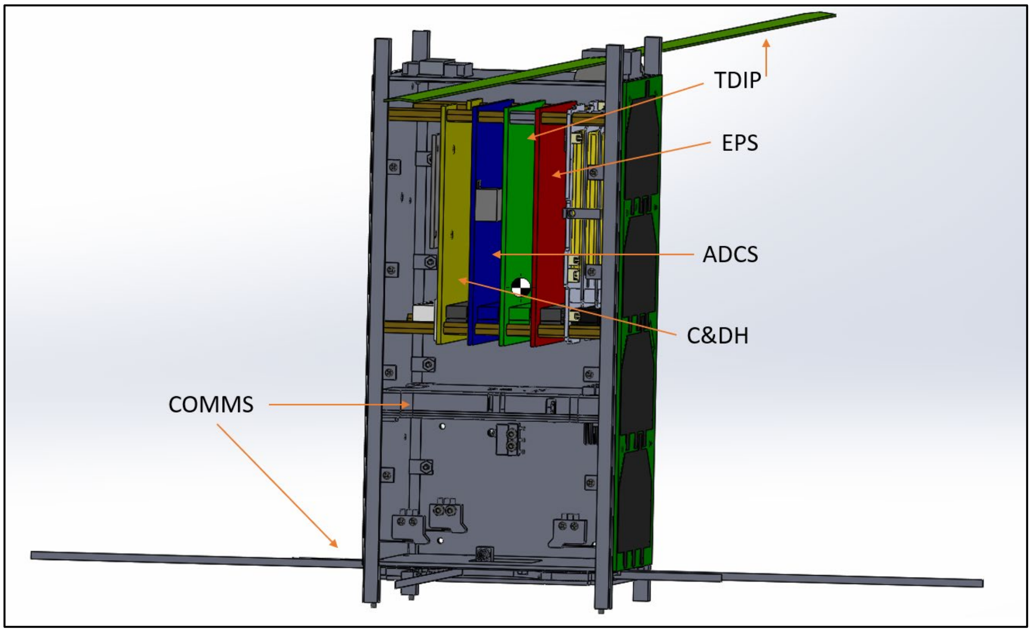

Figure 2: JAGSAT As-Deployed View

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

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 stowed 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 stowed CubeSat was calculated using Equation 1. This configuration renders the longest orbital life times for all CubeSats.

JAGSAT's expected orbit at deployment has a 427.0-km apogee and a 414.2-km perigee at a 51.6° inclination. With an area to mass ratio of 0.0160 m^2/kg, DAS yields 1.177 years for orbit lifetime for its as-deployed state, which in turn is used to obtain the collision probability. JAGSAT is calculated to have a probability of collision of 0.0. Table 3 below provides complete results.

CubeSat		JAGSAT
	Mass (kg)	1.73
Stowed**	Mean C/S Area (m^2)	0.0277
	Area-to Mass (m^2/kg)	0.0160
	Orbital Lifetime (yrs)	**1.177**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated 12/16/2020

**** Deployable antenna area is negligible with respect to lifetime and collision calculations**

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of JAGSAT colliding with debris or meteoroids greater than 10 cm in diameter that are capable of preventing post-mission disposal is less than 0.00000, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Assessment of spacecraft compliance with Requirements 4.5-1 shows JAGSAT 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

JAGSAT 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 deorbit device does not deploy.

Calculating the area-to-mass ratio for the worst-case (smallest Area-to-Mass) post-mission disposal finds JAGSAT in its stowed configuration as the worst case. The area-to-mass is calculated as follows:

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

Equation 3: Area to Mass

$$\frac{0.0277\ m^2}{1.726\ kg} = 0.0160\frac{m^2}{kg}$$

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: 427.0-km maximum apogee and 414.2-km maximum perigee altitudes with an inclination of 51.6º at deployment no earlier than December 2021. An area to mass ratio of 0.0160 m^2/kg for the JAGSAT CubeSat was used. DAS yields a 1.177 years orbit lifetime for JAGSAT in its stowed state.

This meets requirement 4.6-1.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on JAGSAT 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)

JAGSAT's construction includes no high melting point components aside from small fasteners/parts (see item 3 above), therefore all components demise upon reentry and JAGSAT 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
JAGSAT	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 JAGSAT has a 1:0 probability, as none of its components have more than 15J of energy.

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

Section 8: Assessment for Tether Missions

JAGSAT 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 CRS provider.

If you have any questions, please contact the undersigned at 321-867-1367.

/original signed by/

Emily S. D'Elia
Flight Design Analyst
NASA/KSC/VA-H1

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-C/Mr. Higginbotham
VA-E2/Mr. Cheney
AIS2/Mrs. Pariso
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. JAGSAT Component List

Item #	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
1	JAGSAT 2U CubeSat		Al 6061-T6	Box	1726.07	100	100	227	No	-	Demise
2	2U Chassis	1	AL 6061-T6	Box	421.3	100	100	227	No	-	Demise
3	EPS Board (Electrical Power System)	1	Encapsulated PCB assembly	Plate	*See 3**				No		Demise
4	TDIP Board (Time Domain impedance Probe)	1	Encapsulated PCB assembly	Plate	*See 4**				No		Demise
5	C&DH Board (Command and Data Handling)	1	Encapsulated PCB assembly	Plate	*See 5**				No		Demise
6	ADCS Board (Attitude Determination and Control System)	1	Encapsulated PCB assembly	Plate	*See 6**				No		Demise
7	TDIP Probe Assembly	1	*See 7**	*See 7**	*See 7**				No		Demise
8	GPS Patch Antenna	1	TBD	Plate	11.46	-	25.1	7.4	No	-	Demise
9	GPS Board	1	FR4 Fiber Glass, 94V0 rated	Plate	31	-	71.1	6.6	No	-	Demise
10	Radio Board (UHF Transciever)	1	Al 6061-T6	Plate	34.57	-	95	23.24	No	-	Demise
11	Radio Antenna	1	FR4 Fiber Glass, SMA, aluminum	Probe	26.07	98	98	12.2	No	-	Demise
12	Solar Panel Assembly	4	PCB Assembly	*See 12**	360	87.8	197	1.8	No	-	Demise
13	Battery Pack	1	Arathane 5750	*See 13**	56.24	90.2	95.9	30.6	No	-	Demise
3*	**EPS**										
3*.1	Circuit Board	1	FR-4 Fiberglass, 94V-0 Rating	Plate	40	90.4	95.9	19.9	No	-	Demise
3*.2	Encapsulant	1	Arathane 5750	Coating	5	90.4	95.9	19.9	No	-	Demise
4*	**TDIP (Payload)**										
4*.1	Circuit Board	1	FR-4 Fiberglass, 94V-0 Rating	Plate	54	90.4	95.93	19.9	No	-	Demise
4*.2	Encapsulant	1	Arathane 5750	Coating	5	90.4	95.93	19.9	No	-	Demise
5*	**C&DH**										
5*.1	Circuit Board	1	FR-4 Fiberglass, 94V-0 Rating	Plate	40	90.4	95.9	22.1	No	-	Demise

Item #	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
5*.2	Encapsulant	1	Arathane 5750	Coating	5	90.4	95.9	22.1	No	-	Demise
6*	**ADCS**										
6*.1	Circuit Board	1	FR-4 Fiberglass, 94V-0 Rating	Plate	55	90.4	95.9	10.7	No	-	Demise
6*.2	Encapsulant	1	Arathane 5750	Coating	5	90.4	95.9	10.7	No	-	Demise
7*	**TDIP Probe Assembly**										
7*.1	TDIP Probe	2	Measure Tape Steel	Probe	12	13	500	-	No	-	Demise
7*.2	Burn Wire Housing	1	6061-T6 Aluminum, Type III Hardcoat Anodized	Box	3	20	34	11	No	-	Demise
7*.3	Burn Wire	2	30 gauge NiChrome 80 wire	Wire	0.2	0	90	-	No	-	Demise
7*.4	Probe Antenna Mounting	2	6061-T6 Aluminum, Type III Hardcoat Anodized	Half cylinder	10	16	20	8	No	-	Demise
7*.5	Probe Antenna Tethers	2	Vectran 200 Liquid Crystal Polymer yarn	Wire	0.2	1	260	-	No	-	Demise
7*.6	Burn Wire Mounting	1	6061-T6 Aluminum, Type III Hardcoat Anodized	Box	0	16	20	8	No	-	Demise
8*	**Other hardware**										
8*.1	Deployment switch	4	Plastic pin plunger, fine silver contacts	Box	5.44	5.08	12.7	10.2	No	-	Demise
8*.2	Deployment spring	1	Stainless steel	Spring	0.5	2.6	19	-	No	-	Demise
8*.3	GPS antenna mounting bracket	1	Aluminum	Box	1.5	10	38	6.2	No	-	Demise
8*.4	Hex stand offs (small)	20	Aluminum	Cylinder	15	4.5	19	-	No	-	Demise
8*.5	Hex stand offs (large)	4	Aluminum	Cylinder	4	4.5	31.36	-	No	-	Demise
8*.6	Mounting hardware (M3 screws)	53	Steel	Screw	6.89	5.5	2	-	No	-	Demise
8*.7	Mounting hardware (M2 screws)	26	Steel	Screw	0.52	3	8	-	No	-	Demise
8*.8	Mounting hardware (M2 nuts)	26	Steel	Nut	0.468	4	-	1.6	No	-	Demise
8*.9	Mounting hardware (M3 nuts)	45	Steel	Nut	2.597	5.5	-	2.4	No	-	Demise
12*	**Solar Panel Assembly**										
12*.1	Solar cells	16	GaAs (3G30A)	Box	5.7	53	80	0.3	No	-	Demise
12*.2	Solar Panel Connectors (TFM-107-01-L-S-WT)	4	Liquid Crystal Polymer, Phosphor Bronze Contact, Gold Finish	Box	0.612	4.45	15.57	7.569	No	-	Demise

Item #	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
12*.3	Solar Cell Attachment Kit	4	Double-sided Kapton Tape, Silver-Saturated Solder (96.5Sn/3.5Ag), Epoxy	Coating	32	-	-	-	No	-	Demise
13*	**Battery Pack**										
13*.1	Battery cells	6	Lithium polymer (2s3p)	Cylinder	59.52	35.6	57.8	0.5	No	-	Demise