Orbital Debris Assessment for the MakerSat-1 per NASA-STD 8719.14A

Submitted By:

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REVISION LOG

Revision	Effective Date	Author	Description of Changes
DRAFT	9-7-2017	Alicia Johnstone	Draft
1.0	9-22-2017	Alicia Johnstone	Initial Release

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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	Minimal risk to orbital environment, mitigated by orbital lifetime
4.4-2	Compliant	Minimal risk to orbital environment, mitigated by orbital lifetime
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	Lifetime 0.75 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

ODAR Section 1: Program Management and Mission Overview

MakerSat-1 is a technology proof-of-concept mission from Northwest Nazarene University that will demonstrate microgravity additive manufacturing, assembly, and deployment of a CubeSat from the International Space Station (ISS).

MakerSat-1 utilizes four 3D printed frame rails that slide and snap securely together with six solar panel circuit board assemblies and an ISS-approved LiPo battery. Assembly requires no fasteners, tools, glue, or tedious work, which could be difficult, time consuming, and potentially hazardous for the ISS crew. Following MakerSat's 3D print and simple 10 minute snap-together assembly, its battery will be charged and it will be ready for loading into and deployment from the ISS NanoRacks cubesat deployer.

MakerSat-1: Stephen Parke, Program Manager

Launch Vehicle and Launch Site: SpaceX Falcon 9 from Cape Canaveral, FL

Proposed Launch Date: Dec 2017

Mission Duration: Until de-orbit

Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination:

MakerSat-1 will be launched on a SpaceX Falcon 9 vehicle where it will be transported onto the ISS. It will then be deployed from the NanoRacks CubeSat deployment system onboard the ISS.

MakerSat-1 orbital elements are defined as follows:

Perigee: 400 km

Apogee: 400 km

Orbital Inclination: 51.6 degrees

Foreign government or space agency participation:

No foreign agency is participating in this mission. All personnel are United States citizens.

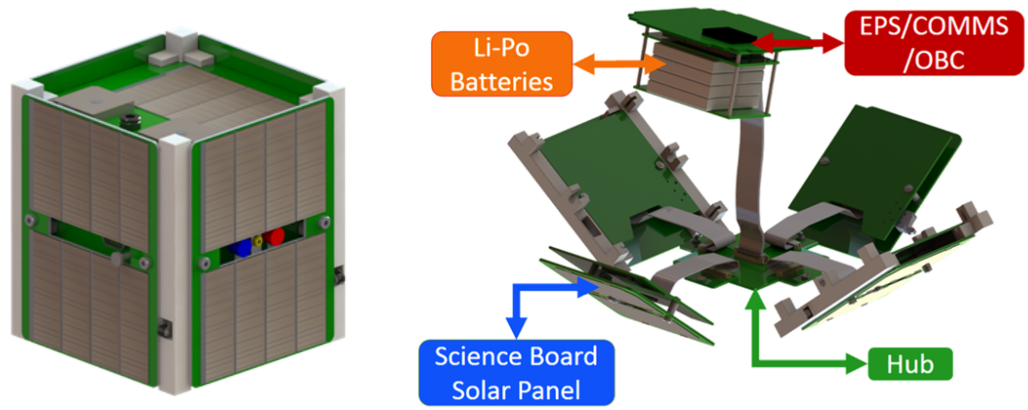
Summary of NASA's responsibility under the governing agreement(s):

Not applicable

Milestone Schedule	
CubeSat Build, Test, and Integration	9/30/2017
MRR	10/10/2017
CubeSat Delivery	10/10/2017
Falcon 9 Launch to ISS	12/10/2017
Assembly on ISS	12/20/2017
Deploy from ISS	12/25/2017
Begin Orbital Operation	12/26/2017

Table 2: MakerSat-1 Milestone Schedule

ODAR Section 2: Spacecraft Description



Physical description of the spacecraft: MakerSat-1 is a 1U CubeSat (10 cm x 10cm x 10 cm), with mass of 0.50 kg total.

The CubeSat structure is made of PEI ULTEM. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells.
The GlobalStar radio uses ceramic patch antennas. There are no pressure vessels, hazardous or exotic materials.

The electrical power storage system consists of common lithium-polymer batteries with over-charge/current protection circuitry. The lithium polymer batteries and circuitry are from Tenergy 3.7V 2200mAh (925050) Battery - UL Listed.

Table 3: MakerSat-1 Summary

CubeSat Quantity	CubeSat size	CubeSat Name	CubeSat Masses (kg)
1	1U (10cm X 10cm X 10cm)	MakerSat-1	0.50

Description of all propulsion systems (cold gas, monopropellant, bipropellant, electric, nuclear): None

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes: None

Fluids in Pressurized Batteries: None

ODAR Section 3: Assessment of Spacecraft Debris Released during Normal Operations

Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material: There are no intentional releases.

Rationale/necessity for release of each object: N/A.

Time of release of each object, relative to launch time: N/A.

Release velocity of each object with respect to spacecraft: N/A.

Expected orbital parameters (apogee, perigee, and inclination) of each object after release: N/A.

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO): N/A.

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS v2.1.1)
4.3-1, Mission Related Debris Passing Through LEO: NOT APPLICABLE
4.3-2, Mission Related Debris Passing Near GEO: NOT APPLICABLE

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

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the MakerSat-1 mission.

The probability of battery explosion is very low, and, due to the very small mass of the satellite and its short orbital lifetime, the effect of an explosion on the far-term LEO environment is negligible (ref (H)).

The CubeSats 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)).

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum possible lifetime of 9 months the MakerSat-1 CubeSat is compliant.

ODAR 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.

MakerSat-1 has no deployables. The mean cross sectional area (CSA) is:

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

The MakerSat-1 orbit at deployment is 400 km apogee altitude by 400 km perigee altitude, with an inclination of 51.6 degrees. With an area to mass (0.50 kg) ratio of 0.030 m^2/kg. In the stowed configuration, DAS yields 0.75 years for orbit lifetime, which in turn is used to obtain the collision probability. MakerSat-1 will see a probability of collision with large objects of 0.00000. **Table 4** below provides complete results.

Table 4: CubeSat Orbital Lifetime & Collision Probability

	Configuration	Stowed/Deployed
	Mass (kg)	0.50
MakerSat-1	**C/S Area (m^2)**	0.015
MakerSat-1	**Area-to Mass (m^2/kg)**	0.030
MakerSat-1	**Orbital Lifetime (years)**	0.75
MakerSat-1	**Probability of collision**	0.00000

There will be no post-mission disposal operation. As such the identification of all systems and components required to accomplish post-mission disposal operation, including passivation and maneuvering, is not applicable.

The probability of a MakerSat-1 collision with debris and meteoroids greater than 10 cm in diameter was calculated with DAS to be less than 0.00000. This satisfies the 0.001 maximum probability requirement 4.5-1.

Since the CubeSats have no capability or plan for end-of-mission disposal, requirement 4.5-2 is not applicable

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

6.1: Description of Spacecraft Disposal Option Selected:
MakerSat-1 will de-orbit naturally by atmospheric re-entry. There is no propulsion system.

6.2: Plan for Any Spacecraft Maneuvers Required to Accomplish Post-Mission Disposal:
No maneuvers are required.

6.3: Calculation of Area-to-Mass Ratio After Post-Mission Disposal, if the Controlled Re-entry Option is Not Selected:

Spacecraft Mass: 0.50 kg
Cross-Sectional Area: 0.015 m^2
Area-to-Mass Ratio: 0.015 m^2 / 0.05 kg = 0.030 m^2/kg

6.4: Assessment of Spacecraft Compliance with Requirements 4.6-1 Through 4.6-5 (per DAS v. 2.1.1 and NASA-STD-8719.14 Section):

Requirement 4.6-1: Disposal for Space Structures Passing Through LEO: A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods (Requirement 56557):

a. Atmospheric Re-Entry Option:
   - Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission by no more than 30 years after launch.
   - Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.\

b. Storage Orbit Option:
   - Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.

c. Direct Retrieval:
   - Retrieve the space structure and remove it from orbit within 10 years after completion of mission.

Analysis: The MakerSat-1 satellite re-entry is COMPLIANT using method "a". MakerSat-1 will re-enter approximately 0.75 years after launch with orbit history as shown in **Figure 1**. Analysis assumes an approximate random tumbling behavior.

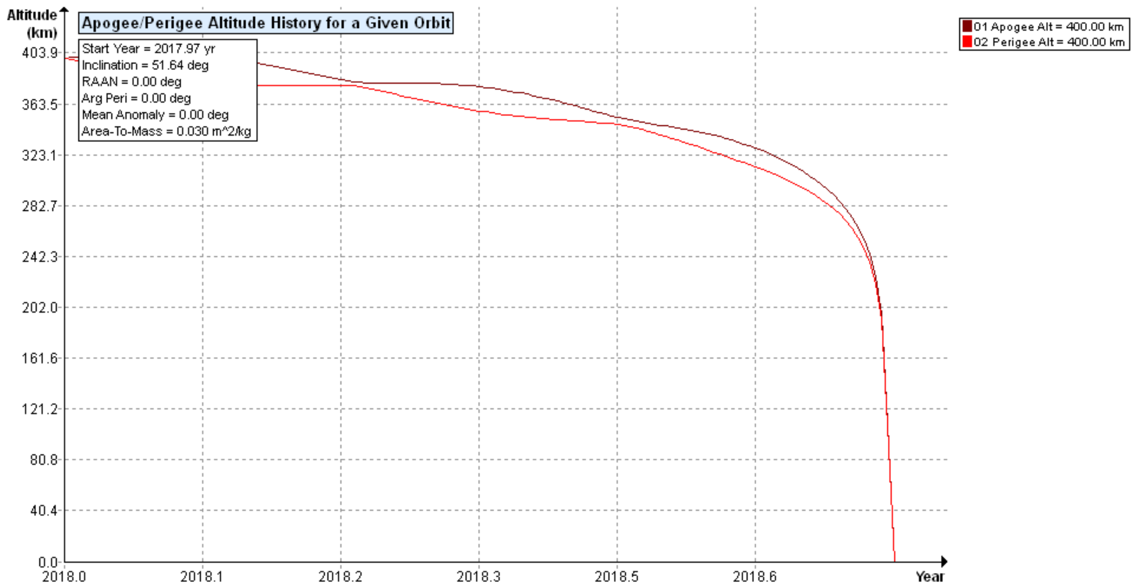


Figure 1: MakerSat-1 Orbit History: Orbital Radius vs Elapsed Days

Requirement 4.6-2: Disposal for Space Structures Near GEO:
Analysis: Not Applicable. MakerSat-1 orbit is LEO.

Requirement 4.6-3: Disposal for Space Structures Between LEO and GEO:
Analysis: Not Applicable. MakerSat-1 orbit is LEO.

Requirement 4.6-4: Reliability of Post-Mission Disposal Operations:

Analysis: MakerSat-1 de-orbiting does not rely on de-orbiting devices. Release from the ISS with downward, retrograde vector will result in de-orbiting in approximately 0.75 years with no disposal or de-orbiting actions required.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

Assessment of spacecraft compliance with Requirement 4.7-1:

> ***Requirement 4.7-1***: *Limit the risk of human casualty:* The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:
> a) For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).
>
> **Summary Analysis Results**: DAS v2.1.1 reports that MakerSat-1 is compliant with the requirement. There will be no risk of human casualty during reentry because it will completely burn up in the atmosphere.

A detailed assessment of the components to be flown on MakerSat-1 was performed. The assessment used DAS 2.1.1, 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 posses the same negligible risk as stainless steel components. See **Table 5**.

Table 5: MakerSat-1 Stainless Steel DAS Analysis

Stainless Steel Components	Material	Mass (g)	Demise Alt (km)	KE (J)
RBF Pin	Stainless Steel	3	77.4	0
Board Standoffs and Fasteners	Stainless Steel	1	75.4	0
Fasteners / Spacers	Stainless Steel	1	75.4	0
Magnet & Damping	Perm Mag MU-Metal	10	70.3	0

The majority of stainless steel components demise upon reentry. The component that DAS conservatively identifies as reaching the ground have 0 joules of kinetic energy, far below the requirement of 15 joules. No stainless steel component will pose a risk to human casualty as defined by the Range Commander's Council. In fact, any 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 above, **Table 5: MakerSat-1 Stainless Steel DAS Analysis**, MakerSat-1 has been conservatively shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

See the Appendix for a complete accounting of the survivability of all CubeSat components.

ODAR Section 8: Assessment for Tether Missions

Not applicable. There are no tethers in the MakerSat-1 mission.

Appendix:

Appendix A. MakerSat-1 Component List

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Row Number	Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Low Melting	Melting Temp C	Survivability
1	3D printed Frame Rails	External - Major	4	PEI Ultem	Box	4	10	110	10	yes	219	Demise
2	Solar Panels	External - Major	4	Fiberglass + GaAs ALTA cells	Rectangular	24	80	110	3	yes	--	Demise
3	Solar Panel (Hub floor)	External - Major	1	Fiberglass + GaAs ALTA cells	Rectangular	6	100	100	3	yes	--	Demise
4	Antenna Panel (NSL lid)	External - Major	1	Fiberglass	Rectangular	4	100	100	3	yes	--	Demise
5	Transmit Patch Antenna	External - Minor	1	Ceramic	Square	6	25	25	4.5	yes	--	Demise
6	Receive Patch Antenna	External - Minor	1	Ceramic	Square	6	25	25	4.5	yes	--	Demise
7	Rail Deploy Switches	External - Minor	4	Aluminum	Rectangular	4	7	20	10	yes	--	Demise
8	IR Sensor	External - Minor	1	Silicon	Cylinder	2	5	5		yes	--	Demise
9	Board Standoffs & Screws	External - Minor	16	Stainless Steel	Cylinder	16	3	7		no	1400	Demise
10	RBF Pin	External - Minor	1	Stainless Steel	Cylinder	3	2	30		no	1400	Demise
11	Batteries	Internal - Major	2	Lithium Polymer	Rectangular	85	50	50	17	yes	--	Demise
12	PIN Diode Detectors	Internal - Minor	2	Fiberglass / Copper	Rectangular	10	15	25	8	yes	--	Demise
13	EyeStar Radio Transmitter Board	Internal - Minor	1	Fiberglass / Copper	Rectangular	20	40	70	8	yes	--	Demise
14	EyeStar Radio Receiver Board	Internal - Minor	1	Fiberglass / Copper	Rectangular	20	40	70	8	yes	--	Demise
15	NSL EPS Board	Internal - Minor	1	Fiberglass / Copper	Rectangular	30	100	100	8	yes	--	Demise
16	Science Hub Board	Internal - Minor	1	Fiberglass / Copper	Rectangular	30	100	100	8	yes	--	Demise
17	Polymer Science Boards	Internal - Minor	2	Fiberglass / Copper	Rectangular	60	80	80	8	yes	--	Demise
18	Vibration motors	Internal - Minor	2	Aluminum	Cylinder	10	10	20		yes	--	Demise
19	Cantilever polymer samples	Internal - Minor	10	ABS/PLA/Nylon/PEI	Rectangular	10	10	20	10	yes	--	Demise
20	Radiation Science Board	Internal - Minor	1	Fiberglass / Copper	Square	30	100	100	8	yes	--	Demise
21	Fasteners / Spacers	Internal - Minor	20	Stainless Steel	Cylinder	20				no	1400	Demise
22	Cabling & DF13 connectors	Internal - Minor	5	Copper alloy / PTFE	Wire	50				yes	--	Demise
23	Magnet & dampers	Internal - Minor	5	Perm Mag, MU-Metal	Sheet	50	10	10	10	no	1450	Demise