ELVL-2022-0046469
May 1, 2023

Orbital Debris Assessment for The M3 CubeSat per NASA-STD 8719.14C

Signature Page

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Reply to Attn of: VA-H1

TO: Norman Phelps, LSP Mission Manager, NASA/KSC/VA-C

FROM: Mike Perotti, NASA/KSC/VA-H1

SUBJECT: Orbital Debris Assessment Report (ODAR) for the M3 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-8719.14C, 05 November 2021
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 M3 CubeSat launching on the SpaceX Transporter-10 mission. 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 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	May 2023

Section 1: Program Management and Mission Overview

M3 is sponsored by the Space Operations Mission Directorate at NASA Headquarters. The Program Executive is Michael Rodelo. Responsible program/project manager and senior scientific and management personnel are as follows:

Dr. Hank Pernicka, PM, Missouri Science & Technology University
Joshua Burch, Chief Engineer

The following table summarizes the compliance status of M3, which will be flown on the SpaceX Transporter-10 mission. The current launch date is planned for no earlier than 01/24/2024. DAS version 3.2.3 was used to generate the data provided in this document. M3 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 13.2 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: M3 Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm)	CubeSat Mass (kg)
M3	1	344 x 108 x 102	3.54

The following pages describe the M3 CubeSat.

M3 – Missouri University of Science and Technology– 6U

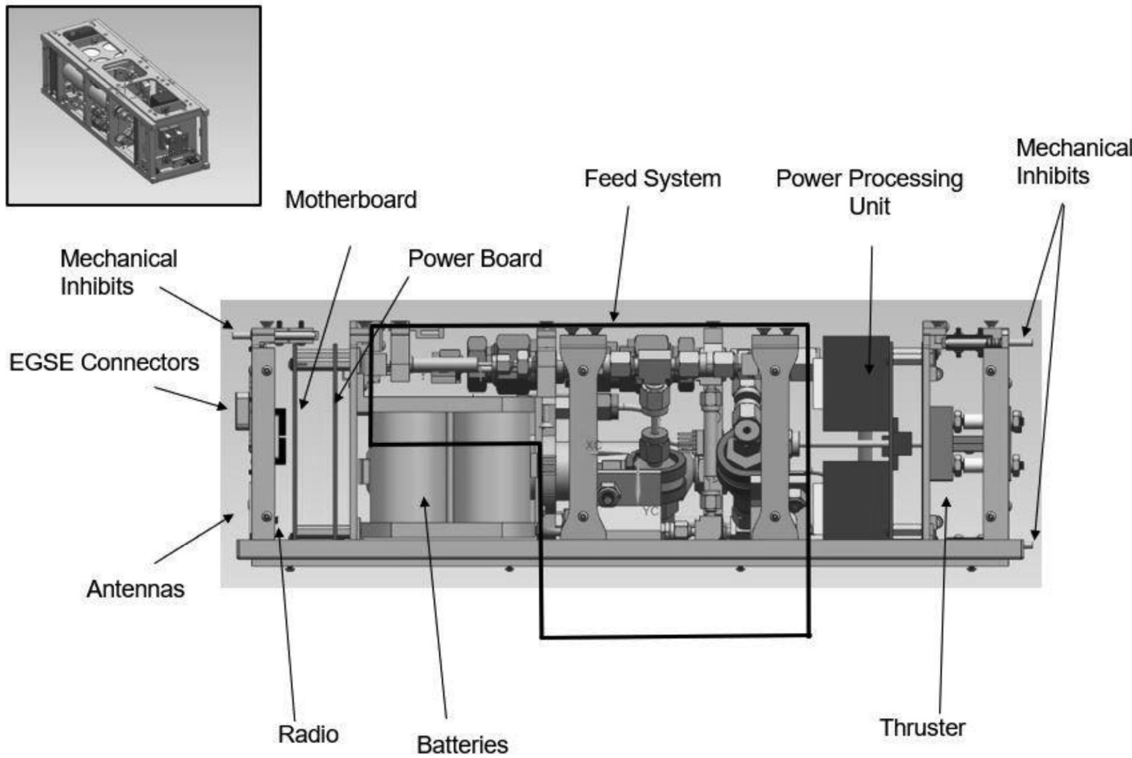

Figure 1: Spacecraft with side panels removed

Overview

The overall goal of the MMM (Multi-Mode Mission or M3) mission is to demonstrate in the space environment a multi-mode-capable thruster operating in electric mode with a student-developed power processing unit (PPU), utilizing an ionic propellant.

The spacecraft is a single unit with the dimensions of three (3) stacked 10 cm x 10 cm x 10 cm CubeSat modules (giving an overall dimension of 10 cm x 10 cm x 30 cm.). The total mass is approximately 3.6 kg.

CONOPS

MMM will be deployed from into 600-km perigee and a 600-km apogee at a 97.61° inclination. Transmission will begin 45 minutes after deployment and cease after complete battery discharge. Once the propellant reaches the desired temperatures, the flight computer will command the propellant feed system solenoid valves to open and the PPU to supply power to the payload, beginning an electrospray burn. The flight computer will then initiate a burn timer and continue the burn until the burn timer expires or the satellite batteries deplete to 65% charge. MMM will perform five electric burns for 30 seconds each while in this mode. During the burns, voltage from the payload's extractor will be measured by voltage dividers located on the flight computer and recorded at a rate of 1 Hz for insertion into a multi-mode thruster performance model.

Once the burn timer has expired, MMM will close its solenoid valves, cease measuring the voltage from the voltage dividers, and cease supplying power to the payload. A full system checkout will be performed by the flight computer to ensure the health of MMM. During this time, MMM will also downlink temperature and pressure measurements from the burn and continue regular system health checks. Upon completion of all five burns in Electric Burn Mode, MMM will enter into its Downlink Mode. If, at any point during Electric Burn Mode, the satellite fails a health check, MMM will enter the Primary Safe Mode. Atmospheric drag will quickly decay the orbit until reentry occurs approximately 24 days after launch. No deployables are used. An Eyestar-S3 simplex transmitter is utilized for downlinking thruster test data. An S band receiver on board the satellite can receive a "kill" command to immediately cease all transmissions.

The total delta-V for the mission duration will be 0.05 m/s. This has a negligible effect to the orbit (~0.17 km worst case).

Materials

The CubeSat structure is composed of aluminum 6061. It contains standard commercial off-the-shelf (COTS) materials, electrical components, and PCBs with the exception of the in-house developed thruster/propellant feed system (which largely consists of stainless-steel components).

Hazards

The propulsion system uses an ionic propellant (1-Ethyl-3-methylimidazolium ethyl sulfate ($C_8H_{16}N_2O_4S$)) classified as "not a hazardous substance or mixture" by its MSDS. The propellant is fed into the thruster by N2 gas loaded at 30 psia. Inhibits are used to prevent premature pressurant and propellent flow prior to orbit deployment. The electric thruster releases small propellent droplets as part of its nominal operation; at the low orbital altitude and ballistic coefficient of each droplet they are expected to harmlessly disperse very quickly with no chance of presenting a debris hazard (in addition to only having a few ounces of propellant on board). MMM will complete five electric thruster burns lasting 30 seconds. The cubesat will undergo environmental testing with propellant loaded and verify that there are no leaks.

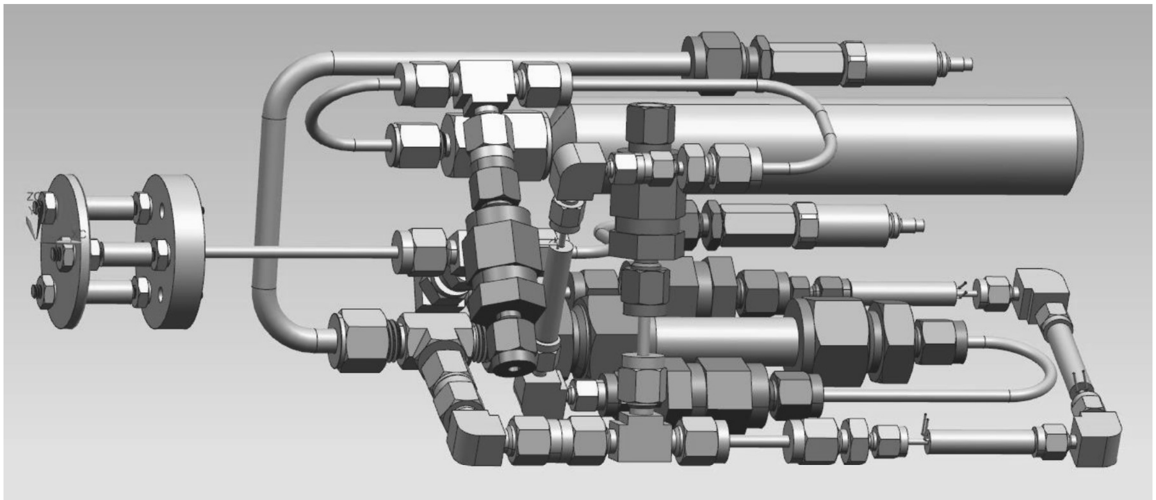

Figure 2: Spacecraft propulsion system CAD

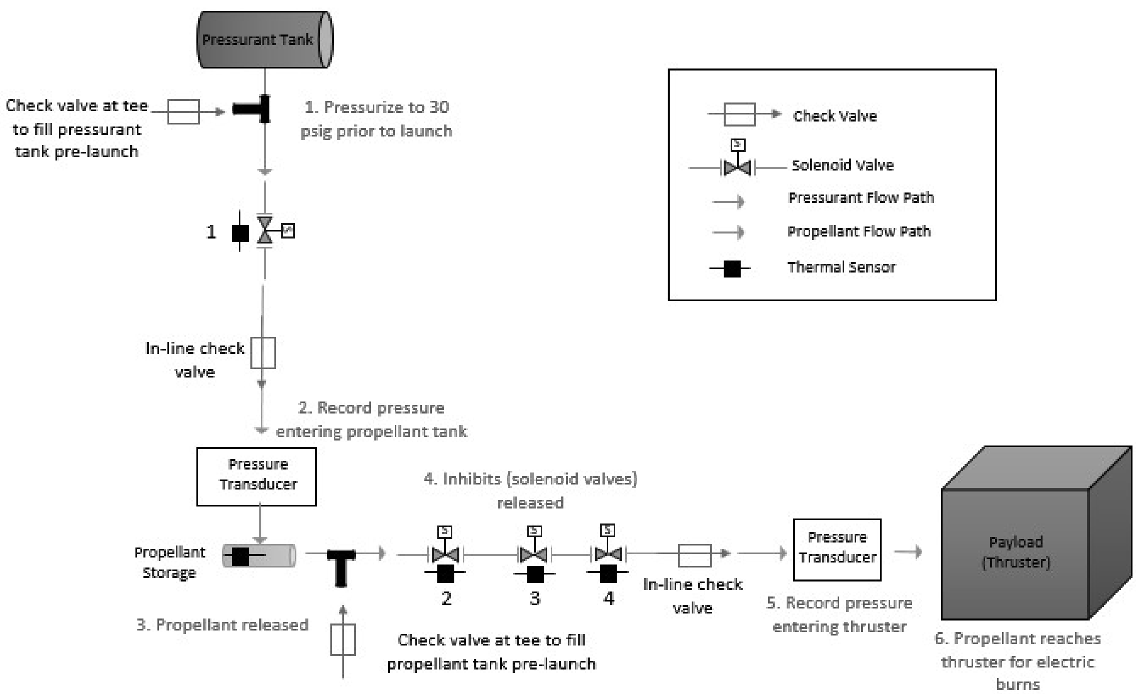

Figure 3: Spacecraft propulsion system schematic

Batteries

The electrical power storage system consists of four common EaglePicher LCF-133 3.0V Primary D Cell (non-rechargeable) lithium metal batteries with current protection circuitry. The nominal voltage and capacity for each battery is 2.6V and 16 Ah, respectively. The batteries have a fully welded hermetically sealed design, pressure relief vent, and shutdown separator. A custom battery pack was developed in conjunction with EaglePicher and is assembled in a 4S1P (4 series/1 parallel) configuration and is protected from reverse current by two active blocking diodes. Each cell is in series with a polymeric positive temperature coefficient (PTC) device. The PTC is thermally coupled to the cell providing both resettable overload and over-temperature protection. The spacecraft does not have any solar cells. A separate Power Processing Unit (PPU) PCB operates as a transformer, converting the 12-volt supply into 3400 volts to energize the thruster.

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 M3 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 M3.

As discussed in Reference H, with respect to 3U and smaller CubeSats, 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 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 13.2 years maximum, M3 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.

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

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 $\boldsymbol{Mean\ CSA} = \frac{\sum \boldsymbol{Surface\ Area}}{\mathbf{4}} = \frac{\mathbf{2}*[(\boldsymbol{w}*\boldsymbol{l})+(\boldsymbol{w}*\boldsymbol{h})+(\boldsymbol{l}*\boldsymbol{h})]}{\mathbf{4}}$ Equation 1. This configuration renders the longest orbital lifetimes 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

M3's assumed orbit at deployment has a 600-km perigee and a 600-km apogee at a 97.61° inclination which is conservative in that it assumes a high orbit insertion. With an area to mass ratio of 0.0118 m^2/kg, DAS yields 13.2 years for orbit lifetime for its as-ejected state, which in turn is used to obtain the collision probability. M3 is calculated to have a maximum probability of collision of 4.4E-6. Table 3 below provides complete results.

	CubeSat	**M3**
	Mass (kg)	3.541
As-Ejected	**Mean C/S Area (m^2)**	0.0416
As-Ejected	**Area-to Mass (m^2/kg)**	0.0118
As-Ejected	**Orbital Lifetime (yrs)**	**13.2**
As-Ejected	**Probability of collision (10^{-6})**	**4.4**

Solar Flux Table Dated 12/19/2022

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of M3 colliding with debris or meteoroids greater than 10 cm in diameter that can prevent 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 M3 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

M3 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 M3 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

$$\frac{0.041628\ m^2}{3.541\ kg} = 0.0118\frac{m^2}{kg}$$

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: 600-km maximum perigee and 600-km maximum apogee altitudes with an inclination of 97.61º at deployment no earlier than 01/24/2024. An area to mass ratio of ~0.0118 m^2/kg for the M3 CubeSat was used. DAS yields a 13.2 years orbit lifetime for M3 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 M3 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 considering 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: M3 High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Pressurant Tank	AISI 316 Stainless Steel	0.1450	74.8	-
Battery D-Cell	Stainless Steel/Lithium	0.3415	73.3	-
1/2" to 1/8" Union Reducer	Stainless Steel	0.0780	72.3	-
1/8" Check Valve	Stainless Steel 316	0.2978	73.6	-
1/2" to 1/4" Stem Reducer	AISI 316 Stainless Steel	0.0659	74.0	-
1/4", 1/8" Tee Fitting	AISI 316 Stainless Steel	0.0599	76.9	-
3/8" to 1/8" Union Reducer	AISI 316 Stainless Steel	0.0419	74.6	-
1/8" Tee Fitting	Stainless Steel 316	0.1254	75.6	-
Pressure Transducer	Stainless Steel 316	0.0720	74	-
Thruster Heatsink	AISI 316 Stainless Steel	0.0300	75.7	-
1/8" Elbow	Stainless Steel 316	0.0596	75.5	-

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
1/4" Tube	AISI 316 Stainless Steel	0.0270	75.8	-
1/2" diam Propellant Tank	Stainless Steel 316	0.0215	76.6	-
1/4" 10-32 Male SAE	AISI 316 Stainless Steel	0.0206	75.5	-
Extractor Grid	AISI 316 Stainless Steel	0.0199	76	-
Union 1/8" to 1/16"	Stainless Steel 316	0.0177	75.4	-
1/8" to 1/16" Union Reducer	Stainless Steel 316	0.0177	75.4	-
1/16" Elbow	Stainless Steel 316	0.0163	75.9	-
1/8" 10-32 Male SAE	AISI 316 Stainless Steel	0.0134	75.9	-
10-32 Female Adapter	AISI 316 Stainless Steel	0.0194	75.6	-
Hysteresis Rod	Nickel	0.0246	76.6	-
1/16" to 1/8" Stem Adapter	AISI 316 Stainless Steel	0.0059	76.8	-
Solenoid Valve	316 Stainless Steel Chrome Core 18	0.0227	77.1	-
1/8" 90deg Connector	AISI 316 Stainless Steel	0.0045	77.1	-
1/8" 180 deg Tube	AISI 316 Stainless Steel	0.0084	77.2	-
1/8" Prop to Thruster Pipe	AISI 316 Stainless Steel	0.0035	77.3	-
1/8" Tube	AISI 316 Stainless Steel	0.0022	77.3	-
1/8" Connector Tube	Stainless Steel 316	0.0019	77.4	-
1/8" Tube	AISI 316 Stainless Steel	0.0018	77.3	-
1/8" Connector Tube	AISI 316 Stainless Steel	0.0015	77.3	-
1/8" Connector Tube	Stainless Steel 316	0.0036	77.3	-
1/8" to 1/16" Port Connector	AISI 316 Stainless Steel	0.0012	77.5	-
1/8" to 1/16" Port Reducing	AISI 316 Stainless Steel	0.0012	77.5	-

All high melting point components demise upon reentry and M3 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
M3	Compliant	1:100,000,000

*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. M3 has a 1:100,000,000 probability, as none of its components survive.

M3 is compliant with Requirement 4.7-1 of NASA-STD-8719.14C.

Section 8: Assessment for Tether Missions

M3 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 321-205-4667.

/original signed by/

Mike Perotti
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

Appendix Index:

Appendix A. M3 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	M3		Aluminum 6061	Box	3335.65	108.000	344.310	102.000	No	-	Demise
2	NSL RX Board	1	PCB	Plate	29.459	25.500	1.6000	55.000	No	-	Demise
3	EyeStar-S3 Board	1	PCB	Plate	17.230	25.500	14.207	55.000	No	-	Demise
4	Simplex Antenna	2	PCB	Plate	29.400	35.154	1.6764	35.154	No	-	Demise
5	Flight Computer	1	PCB	Plate	29.400	95.884	1.5748	90.168	No	-	Demise
17	EPS Board	1	PCB	Plate	60.000	95.885	1.5748	90.170	No	-	Demise
6	#4-48 x 1/4" Panhead Screw	5	AISI 316 Stainless Steel	Cylinder	2.1540	5.4102	5.4102	7.8586	No	-	Demise
7	Battery Pack Brace	1	Aluminum 6061	Plate	6.5170	15.000	3.0000	54.363	No	-	Demise
8	TC74 Temperature Sensor	2	PTFE/ETFE plastic	Plate	8.3224	10.541	4.6990	30.632	No	-	Demise
9	Battery Top Cap	1	Aluminum 6061	Plate	25.037	73.243	26.500	77.208	No	-	Demise
10	Battery Bottom Cap	1	Aluminum 6061	Plate	32.365	73.243	16.500	77.208	No	-	Demise
11	Battery Bottom insulator	1	PTFE (Teflon)	Plate	11.566	69.600	2.3620	69.600	No	-	Demise
12	Battery D-Cell	4	Stainless Steel/Lithium	Cylinder	341.49	33.300	33.300	55.120	Yes	2550˚	Demise (73.3 km)
13	Battery Insulator	1	PEEK	Box	46.757	49.300	54.880	49.300	No	-	Demise
14	Battery Top Insulator	1	PTFE (Teflon)	Plate	3.7406	69.600	0.3810	69.600	No	-	Demise
15	Magnet Body Cover	1	Aluminum 6061	Plate	0.1462	6.0000	1.0000	11.000	No	-	Demise
16	Magnet Body	1	Neodymium	Cylinder	0.5660	3.1750	3.1750	9.5250	No	-	Demise
18	Switch Screw	6	AISI 316 Stainless Steel	Cylinder	1.8366	4.1656	4.1656	10.698	No	-	Demise
19	Pin	3	Aluminum 6061	Cylinder	2.2500	3.1750	3.1750	36.000	No	-	Demise
20	Retaining Ring	3	Steel 1060	Ring	0.0450	4.1910	0.3810	0.4000	No	-	Demise
21	Switch	3	PTFE Plastic	Box	5.3910	6.4000	14.601	19.812	No	-	Demise
22	Spring	2	Steel 1060	Cylinder	0.1674	0.4581	6.3010	4.5601	No	-	Demise

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
23	PPU Board	1	PCB	Plate	217.80	90.200	42.650	95.800	No	-	Demise
24	Screw Standoffs	6	AISI 316 Stainless Steel	Cylinder	2.9244	5.5626	5.5626	7.6561	No	-	Demise
25	PPU Insulator	1	PTFE (Teflon)	Plate	6.8673	95.799	0.3810	90.198	No	-	Demise
26	Threaded Hex Standoff	4	AISI 316 Stainless Steel	Cylinder	3.6000	5.4993	5.4993	17.521	No	-	Demise
27	#2-64 x 1/4" Screw	63	AISI 316 Stainless Steel	Cylinder	14.276	4.1656	4.1656	7.5243	No	-	Demise
28	Flat Washer	6	AISI 316 Stainless Steel	Plate	2.4000	6.3500	0.4572	6.3500	No	-	Demise
29	Hole Mounted Clamp	4	AISI 316 Stainless Steel	Plate	7.6000	12.700	3.9688	17.502	No	-	Demise
30	SideBar 1A	1	Aluminum 6061	Plate	13.841	20.000	12.000	94.000	No	-	Demise
31	SideBar 2A	1	Aluminum 6061	Plate	12.795	20.000	12.000	94.000	No	-	Demise
32	Side Shield 3A	1	Aluminum 6061	Plate	58.850	83.000	1.0000	330.50	No	-	Demise
33	Side Shield 4A	1	Aluminum 6061	Plate	56.950	83.000	1.0000	330.50	No	-	Demise
34	1/16" Collar	2	Aluminum 6061	Plate	1.3000	16.611	3.0000	17.682	No	-	Demise
35	1/4" Flathead Screw	39	AISI 316 Stainless Steel	Cylinder	13.650	6.4770	6.4770	6.3500	No	-	Demise
36	1/2" Gasket PB2 1A	1	PTFE (Teflon)	Cylinder	2.0473	16.000	3.0000	16.000	No	-	Demise
37	1/8" Collar PB2 1A	2	Aluminum 6061	Plate	4.8730	27.994	3.0000	16.000	No	-	Demise
38	1/8" Collar PB2 2A	1	Aluminum 6061	Plate	2.4375	23.363	3.0000	20.101	No	-	Demise
39	1/8" Gasket PB2 1A	5	PTFE (Teflon)	Cylinder	3.2500	16.000	3.0000	16.000	No	-	Demise
40	Tank Collar	1	Aluminum 6061	Plate	2.3843	12.700	12.700	85.000	No	-	Demise
41	Tank Gasket	1	PTFE (Teflon)	Cylinder	0.5350	27.400	3.0000	27.400	No	-	Demise
42	10-32 Collar PB3 1A	2	Aluminum 6061	Plate	1.3508	17.400	3.0000	23.638	No	-	Demise
43	10-32 Gasket PB3 1A	2	PTFE (Teflon)	Cylinder	0.9722	14.000	3.0000	14.000	No	-	Demise
44	1/8" Collar PB3 1A	1	Aluminum 6061	Plate	2.1012	19.432	3.0000	24.769	No	-	Demise
45	#4-48 x 3/8" FlatScrew	41	AISI 316 Stainless Steel	Cylinder	20.500	6.5000	6.5000	9.5250	No	-	Demise
46	Hysteresis Rod	4	Nickel	Cylinder	24.600	3.3020	3.3020	80.000	Yes	2550°	Demise (76.6 km)

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
47	15mm Standoff	3	Aluminum 6061	Cylinder	0.8838	5.4993	5.4993	10.369	No	-	Demise
48	17mm Standoff	4	Aluminum 6061	Cylinder	3.0976	5.4993	5.4993	20.638	No	-	Demise
49	Wire Shield	1	Aluminum 6061	Plate	0.6271	12.000	1.0000	20.000	No	-	Demise
50	Prop Bracket Component	1	Aluminum_6060	Plate	25.184				No	-	Demise
51	1/8" Hex 1/4" Tube Collar	1	Aluminum 6061	Plate	1.6231	20.702	3.0000	34.493	No	-	Demise
52	1/8" Hex 1/4" Tube Gasket	1	PTFE (Teflon)	Cylinder	1.0289	16.000	3.0000	27.243	No	-	Demise
53	1/4" Collar PB1 1A	1	Aluminum 6061	Plate	0.6951	21.662	3.0000	27.912	No	-	Demise
54	1/4" Gasket PB1 1A	1	PTFE (Teflon)	Cylinder	0.6885	19.000	3.0000	19.000	No	-	Demise
55	1/8" Collar PB 1A	1	Aluminum 6061	Plate	0.7409	16.875	3.0000	26.411	No	-	Demise
56	1/8" Collar PB1 2A	1	Aluminum 6061	Plate	0.6557	18.763	3.0000	21.776	No	-	Demise
57	3/8" Gasket PB1 1A	1	PTFE (Teflon)	Cylinder	1.4628	25.000	3.0000	25.000	No	-	Demise
58	3/8" Collar PB1 1A	1	Aluminum 6061	Plate	1.5226	26.784	3.0000	29.821	No	-	Demise
59	Gasket 4	1	PTFE (Teflon)	Cylinder	0.3222				No	-	Demise
60	Gasket 3	1	PTFE (Teflon)	Cylinder	1.0606				No	-	Demise
61	Gasket 2	3	PTFE (Teflon)	Cylinder	2.8074				No	-	Demise
62	Gasket 1	1	PTFE (Teflon)	Cylinder	2.0669				No	-	Demise
63	Prop Bracket 1-2A	1	Aluminum 6061	Plate	22.405	27.474	8.0000	100.00	No	-	Demise
64	Prop Bracket 1-1A	1	Aluminum 6061	Plate	26.357	32.505	8.0000	100.00	No	-	Demise
65	Thruster Bracket 1A	1	Aluminum 6061	Plate	105.45	34.491	8.0000	91.497	No	-	Demise
66	#10-32 Locknut	2	AISI 316 Stainless Steel	Cylinder	4.3000	11.800	5.9531	11.800	No	-	Demise
67	#10-32 x 5/8" Screw	2	AISI 316 Stainless Steel	Cylinder	4.9000	9.1694	9.1694	18.440	No	-	Demise
68	Prop Bracket 2-2A	1	Aluminum_6060	Plate	32.0699	13.130	8.0000	71.010	No	-	Demise
69	Prop Bracket 2-1A	1	Aluminum 6061	Plate	14.1063	25.503	8.0000	100.00	No	-	Demise
70	Prop Bracket 3-2A	1	Aluminum 6061	Plate	19.1625	17.816	8.0000	71.095	No	-	Demise
71	Prop Bracket 3-1A	1	Aluminum 6061	Plate	15.6275	19.500	8.0000	97.000	No	-	Demise

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
72	Prop Bracket 4-2A	1	Aluminum 6061	Plate	7.9214	7.5000	8.0000	94.473	No	-	Demise
73	Prop Bracket 4-1A	1	Aluminum 6061	Plate	24.655				No	-	Demise
74	3/4" P-Clamps	2	AISI 316 Stainless Steel	Cylinder	29.200	25.654	15.240	42.954	No	-	Demise
75	Check Valve Bracket 2A	1	Aluminum 6061	Plate	10.883	25.000	4.0000	36.385	No	-	Demise
76	Check Valve Bracket 1A	1	Aluminum 6061	Plate	13.949	30.000	4.0000	40.419	No	-	Demise
77	Side Shield 1A	1	Aluminum 6061	Plate	69.150	83.000	1.0000	330.50	No	-	Demise
78	Side Sheild 2A	1	Aluminum 6061	Plate	70.250	83.000	1.0000	330.50	No	-	Demise
79	Battery Bracket	1	Aluminum 6061	Plate	88.881	98.000	14.000	106.00	No	-	Demise
80	Structural Rib 1A	1	Aluminum 6061	Plate	40.650	100.00	21.000	100.00	No	-	Demise
81	Structural Rib 2A	1	Aluminum 6061	Plate	73.789	100.00	10.000	100.00	No	-	Demise
82	HV -9D D-sub Connector	2	Aluminum 6061	Box	12.700	15.138	15.240	30.988	No	-	Demise
83	Side Panel 1A	1	Aluminum-7075	Plate	180.65	100.00	7.5000	340.50	No	-	Demise
84	Side Panel 2A	1	Aluminum-7075	Plate	186.60	100.00	11.500	340.50	No	-	Demise
85	1/8" Prop to Thruster Pipe	1	AISI 316 Stainless Steel	Cylinder	3.5392	3.1750	3.1750	69.293	Yes	2550˚	Demise (77.3 km)
86	TC74 Temperature Sensor	7	PTFE/ETFE plastic	Plate	29.233	10.541	11.049	23.698	No	-	Demise
87	Swagelock Nut	1	AISI 316 Stainless Steel	Cylinder	8.7074	15.424	15.424	12.405	No	-	Demise
88	#18-8 Screw	4	AISI 316 Stainless Steel	Cylinder	6.7360	7.7978	7.7978	22.225	No	-	Demise
89	Ring Connector	1	AISI 316 Stainless Steel	Plate	0.4098	7.8740	0.9000	12.810	No	-	Demise
90	Copper Tape	1	Copper	Cylinder	0.0023	0.2000	0.2000	12.502	No	-	Demise
91	Needle Lock	1	AISI 316 Stainless Steel	Plate	5.8364	14.500	3.2404	16.450	No	-	Demise
92	Needle	1	AISI 316 Stainless Steel	Cylinder	0.0010	0.1000	0.1000	31.944	No	-	Demise
93	Threaded Rod	4	AISI 316 Stainless Steel	Cylinder	4.7256	3.1552	3.1165	19.194	No	-	Demise
94	Thruster Insulator	4	Ceramic	Cylinder	10.345	6.3000	6.3000	12.900	No	-	Demise
95	Thrust Hex Nut	12	AISI 316 Stainless Steel	Cylinder	12.524	9.3961	9.3961	2.7781	No	-	Demise

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
96	Thrust Washer	12	AISI 316 Stainless Steel	Cylinder	1.6164	6.1000	6.1000	0.8600	No	-	Demise
97	Extractor Grid	1	AISI 316 Stainless Steel	Plate	19.900	31.876	2.5400	31.876	Yes	2550°	Demise (76.0 km)
98	Thruster Heatsink	1	AISI 316 Stainless Steel	Plate	29.950	31.876	9.9060	31.876	Yes	2550°	Demise (75.7 km)
100	1/8" Connector Tube	1	AISI 316 Stainless Steel	Cylinder	1.4976	3.1750	3.1750	29.322	Yes	2550°	Demise (77.4 km)
101	1/8" 90deg Connector	1	AISI 316 Stainless Steel	Cylinder	4.5199	3.1750	3.1750	59.082	Yes	2550°	Demise (77.1 km)
102	Solenoid Valve	4	316 Stainless Steel Chrome Core 18	Cylinder	22.707	6.3500	6.3500	51.950	Yes	2550°	Demise (77.1 km)
103	1/8" 10-32 Male SAE	1	AISI 316 Stainless Steel	Cylinder	13.409	15.127	15.127	24.892	Yes	2550°	Demise (75.9 km)
104	1/4" 10-32 Male SAE	1	AISI 316 Stainless Steel	Cylinder	20.567	18.440	18.440	27.432	Yes	2550°	Demise (75.5 km)
105	1/8" to 1/16" Port Connector	1	AISI 316 Stainless Steel	Cylinder	1.1970	6.0960	6.0960	18.288	Yes	2550°	Demise (77.5 km)
106	10-32 Female Adapter	2	AISI 316 Stainless Steel	Cylinder	19.372	10.999	10.999	19.050	Yes	2550°	Demise (75.6 km)
107	Union 1/8" to 1/16"	1	Stainless Steel 316	Cylinder	17.719	12.905	12.905	30.988	Yes	2550°	Demise (75.4 km)
108	1/8" Connector Tube	1	Stainless Steel 316	Cylinder	1.8791	3.1750	3.1750	39.528	Yes	2550°	Demise (77.4 km)
109	1/8" Connector Tube	3	Stainless Steel 316	Cylinder	3.6342	3.1750	3.1750	25.400	Yes	2550°	Demise (77.3 km)
110	1/8" to 1/16" Port Reducing	1	AISI 316 Stainless Steel	Cylinder	1.1970	6.0960	6.0960	18.288	Yes	2550°	Demise (77.5 km)
111	1/4" Tube	1	AISI 316 Stainless Steel	Cylinder	26.964	6.3500	6.3500	76.750	Yes	2550°	Demise (75.8 km)
112	1/4", 1/8" Tee Fitting	1	AISI 316 Stainless Steel	Box	59.918	53.340	14.288	111.87	Yes	2550°	Demise (76.9 km)
113	1/2" to 1/4" Stem Reducer	1	AISI 316 Stainless Steel	Cylinder	65.852	25.810	25.810	44.958	Yes	2550°	Demise (74.0 km)
114	1/8" Tube	1	AISI 316 Stainless Steel	Cylinder	1.8387	3.1750	3.1750	36.000	Yes	2550°	Demise (77.3 km)
115	1/8" to 1/16" Union Reducer	1	Stainless Steel 316	Cylinder	17.719	12.905	12.905	30.988	Yes	2550°	Demise (75.4 km)
116	1/8" Tube	1	AISI 316 Stainless Steel	Cylinder	2.1707	3.1750	3.1750	42.500	Yes	2550°	Demise (77.3 km)
117	1/8" 180 deg Tube	2	AISI 316 Stainless Steel	Cylinder	8.3648	3.1750	3.1750	31.750	Yes	2550°	Demise (77.2 km)
118	1/8" Tee Fitting	3	Stainless Steel 316	Box	125.43	44.704	11.176	27.115	Yes	2550°	Demise (75.6 km)

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
119	Pressure Transducer	2	Stainless Steel 316	Cylinder	72.007	11.902	11.902	43.810	Yes	2550˚	Demise (74.0 km)
120	3/8" to 1/8" Union Reducer	1	AISI 316 Stainless Steel	Cylinder	41.858	20.164	20.164	40.894	Yes	2550˚	Demise (74.6 km)
121	1/8" Elbow	2	Stainless Steel 316	Box	59.574	28.805	11.176	28.805	Yes	2550˚	Demise (75.5 km)
122	1/16" Elbow	1	Stainless Steel 316	Box	16.336	22.326	22.326	9.5250	Yes	2550˚	Demise (75.9 km)
123	1/16" to 1/8" Stem Adapter	1	AISI 316 Stainless Steel	Cylinder	5.9246	9.1654	9.1654	29.210	Yes	2550˚	Demise (76.8 km)
124	1/8" Check Valve	4	Stainless Steel 316	Cylinder	297.78	20.164	20.164	57.658	Yes	2550˚	Demise (73.6 km)
125	1/2" diam Propellant Tank	1	Stainless Steel 316	Cylinder	21.491	12.700	12.700	85.000	Yes	2550˚	Demise (76.6 km)
126	1/2" to 1/8" Union Reducer	1	Stainless Steel	Cylinder	78.004	25.810	25.810	45.212	Yes	2550˚	Demise (72.3 km)
127	Pressurant Tank	1	AISI 316 Stainless Steel	Cylinder	145.00	25.400	25.400	159.03	Yes	2550˚	Demise (74.8 km)
132	Cable Harness	1	PTFE Cable		23.700				No	-	Demise