ELVL-2020-0045756 Rev A
April 17, 2020

Orbital Debris Assessment for The IT-SPINS CubeSat per NASA-STD 8719.14A

Signature Page

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ELVL-2020-0045756 Rev A

Reply to Attn of: VA-H1

April 17, 2020

TO: Scott Higginbotham, LSP Mission Manager, NASA/KSC/VA-C

FROM: Yusef Johnson, a.i. solutions/KSC/AIS2

SUBJECT: Orbital Debris Assessment Report (ODAR) for the IT-SPINS Mission

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 May 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

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the IT-SPINS CubeSat launching on the NG-14 Antares launch vehicle. IT-SPINS will be deployed from the Cygnus vehicle after departure from the International Space Station. 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 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 2020
A	Corrected editorial errors, new launch date	April 2020

Section 1: Program Management and Mission Overview

IT-SPINS is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is John Guidi. Responsible program/project manager and senior scientific and management personnel are as follows:

Dr. David Klumpar, Principal Investigator, Montana State University

The following table summarizes the compliance status of IT-SPINS mission to be flown on the NG-14 mission to the International Space Station. IT-SPINS 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 ~2.6 yrs
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

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	August 2019
Delivery to Nanoracks	June, 2020
Launch	September 7, 2020

Figure 1: Program Milestone Schedule

IT-SPINS will be launched as a payload on the Northrup Grumman Antares launch vehicle executing the NG-14 mission and will be deployed from the Cygnus spacecraft post-ISS departure. The current launch date is projected to be September 7, 2020.

Section 2: Spacecraft Description

IT-SPINS is flying as part of the ELaNa-31 mission complement. Table 2 outlines its generic attributes.

Table 2: IT-SPINS Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Mass (kg)
IT-SPINS	1	343 x 107.7 x 105.1	3.3

The following pages describe the IT-SPINS CubeSat.

IT-SPINS – Montana State University – 3U

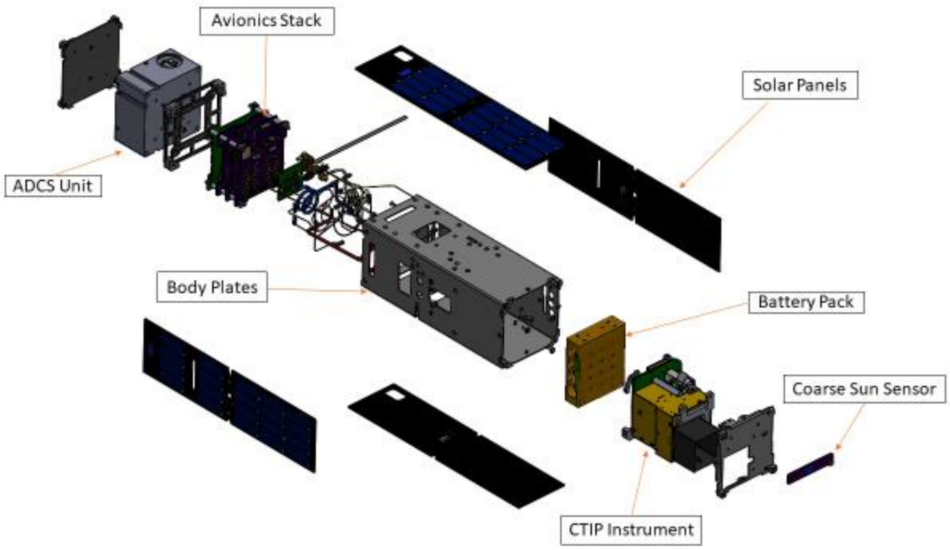

Figure 2: IT-SPINS (exploded view)

Overview

IT-SPINS will use the CTIP (CubeSat Tiny Ionospheric Photometer), a UV photometer that measures atomic oxygen nightglow, and provide 2D tomographic images of the ionosphere.

CONOPS

The satellite has two foot switch inhibits and an RBF inhibit. These are in series, and, when pressed, the satellite electronics are isolated from all power. Immediately after the satellite is released from the dispenser, the foot switches will open and the computer and EPS will activate. Sixty minutes later, the unit will begin transmitting beacons and the manual control of the ADCS system will be initiated. The ADCS unit will cancel the satellite's initial tumbling and begin standard rotating action. The payload will open the light shield covering the instrument, science operations will commence, and the satellite will begin to transmit science data to the ground station.

Materials

The CubeSat's main walls are made from 5052-H32 aluminum, while the internal components are made of FR-4, ULTEM, 6061-T6 aluminum, and 316 stainless steel. The fasteners are comprised of 18-8 and 316 stainless steel, with a small number of aluminum and nylon parts. The instrument is made of a variety of components, notably 316 stainless steel, 18-8 stainless steel, 5052-H32 aluminum, copper, and Delrin. It also contains two strontium fluoride crystals, a barium fluoride crystal, and a photomultiplier tube made of fused quartz, magnesium fluoride, beryllium copper, nickel, and cesium iodide. The square mirror on the inside is made of 6061-T6 aluminum and coated with lanthanum trifluoride and magnesium fluoride. The solar cells are standard commercial off-the-shelf (COTS) parts.

Hazards

There are no pressure vessels or hazardous or exotic materials.

Batteries

The electrical power storage system consists of common lithium-ion batteries with over-charge/current protection circuitry. The batteries were removed from their original packaging and repackaged to suit the interior geometry of the satellite. Each battery bears the UL number "MH48285" and the repackaged batteries will undergo flight acceptance testing in accordance with the procedures described in NanoRacks document NR-SRD-139 RevC "Flight Acceptance Test Requirements for Lithium-ion Cells and Battery Packs."

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.

The 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 IT-SPINS 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 IT-SPINS.

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 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))

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 2.86 years, IT-SPINS 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.

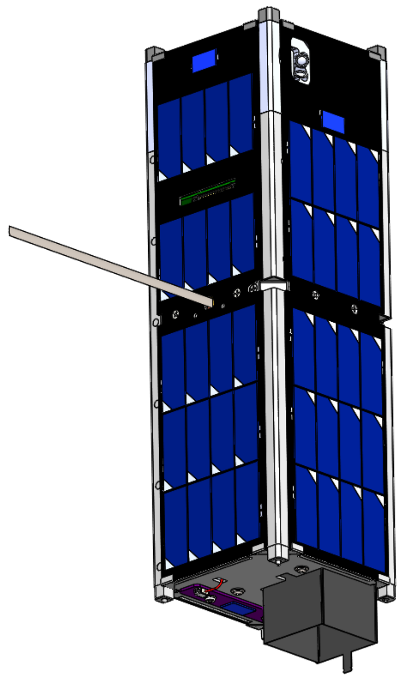

Figure 4: IT-SPINS Deployed View

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

Equation 2: Mean Cross Sectional Area for Complex Objects

The CubeSat evaluated for this ODAR are 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 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 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.

IT-SPINS's expected (~3.3 kg) orbit at deployment will be 500 km circular at 51.6 degree inclination. With an area to mass ratio of ~0.009 m^2/kg, DAS yields 2.66 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. IT-SPINS is calculated to have a probability of collision of 0.0. Table 3 below provides complete results.

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.

CubeSat		IT-SPINS
	Mass (kg)	3.268
Stowed	Mean C/S Area (m^2)	0.0298
	Area-to Mass (m^2/kg)	0.00917
	Orbital Lifetime (yrs)	**2.66**
	Probability of collision (10^X)	**0.0000**
Deployed	Mean C/S Area (m^2)	0.0448
	Area-to Mass (m^2/kg)	0.0137
	Orbital Lifetime (yrs)	**2.23**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated 1/16/2020

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of any IT-SPINS colliding with debris and meteoroids greater than 10 cm in diameter and 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 IT-SPINS to be compliant. Requirement 4.5-2 is not applicable to this mission.

IT-SPINS has no capability or plans for end-of-mission disposal, therefore Requirement 4.5-2 is not applicable. IT-SPINS will passively reenter and therefore this ODAR also serves as the EOMP (End of Mission Plan)

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

IT-SPINS 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 is achieved via passive atmospheric reentry.

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

$$\frac{0.029m^2}{3.26\ kg} = \ 0.009\frac{m^2}{kg}$$

The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS Orbital Lifetime Calculations:</u>
DAS inputs are: 500 km maximum apogee 500 km maximum perigee altitudes with an inclination of 51.6º at deployment no earlier than September 2020. An area to mass ratio of ~0.009 m^2/kg for the IT-SPINS CubeSat was used. DAS yields a 2.66 years orbit lifetime for IT-SPINS in its stowed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference **Table 3: CubeSat Orbital Lifetime & Collision Probability**.

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on IT-SPINS 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 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. Fasteners and similar hardware that are composed of stainless steel or a lower melting point material will not be entered into DAS, as suggested by guidance from the Orbital Debris Project Office (Reference I)

2. 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.

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

Table 4: IT-SPINS High Melting Temperature Material Analysis

Name	Material	Total Mass (g)	Demise Alt (km)	Kinetic Energy (J)
Foot Plunger	Alloy Steel	0.89	77.0	-
Pumpkin Base Plate Foot Nut	AISI 4340 Steel, annealed	0.64	77.0	-
Solar Panel Clips	AISI 316 Stainless Steel Sheet	3.84	0.0	0
UHF Antenna	AISI 1045 Steel, cold drawn	1.13	0.0	0
Cherry Microswitch	Nylon 101, Cold-Rolled Ni-Plated Steel	1.38	75.8	-
3G Metalworx Fence	Tin-Plated Steel	1.42	0.0	0
3G Metalworx Top	Tin-Plated Steel	1.54	0.0	0
Bistable Rotary Shutter	18-8 Stainless Steel, Cu Wire, NdFeB Disk	15.02	70.5	-

Bistable Rotary Filter Holder	18-8 Stainless Steel, Cu Wire, NdFeB Disk	17.75	0.0	0
M213 Heraeus PRTD	Encapsulated Platinum	0.54	66.7	-
Instrument Vanes	18-8 Stainless Steel, Copper Oxide Coating	71.82	0.0	0
Light Shield Leaves	18-8 Stainless Steel, Gunmetal Iron Oxide Coating	30.48	0.0	0
180 Degree 0.015" Spring, RH	Heat Treated High Carbon Steel	0.06	77.0	-
180 Degree 0.015" Spring, LH	Heat Treated High Carbon Steel	0.06	77.0	-

The majority of high temperature resistant components demise upon reentry and IT-SPINS 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
IT-SPINS	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 IT-SPINS has a 1:0 probability, as none of its components have more than 15J of energy.

IT-SPINS is shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

IT-SPINS will not be deploying any tethers.

IT-SPINS satisfies Section 8’s requirement 4.8-1.

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 321-867-2098.

/original signed by/

Yusef A. Johnson
Flight Design Analyst
a.i. solutions/KSC/AIS2

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

Appendix Index:

Appendix A. IT-SPINS 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	IT_SPINS, 3U	1	Various	Box	3268.44	105.175	107.695	343.025	-	-	Demise
2	Chassis	1	-	-	-	-	-	-	-	-	Demise
3	Chassis Walls	1	5052-H32 Aluminum Alloy	Box	326.45	100	100	269.09	No	-	Demise
4	Base Plate	1	5052-H32 Aluminum Alloy	Plate	51.91	100	100	1.52	No	-	Demise
5	P-POD Deployment Foot	1	6061 Alloy	Box	1.16	8.5	8.5	8.39	No	2500°	Demise
6	P-POD Foot Plunger	1	Alloy Steel	Cylinder	0.89	3.45		13.27	No	2500°	Demise
7	Pumpkin Base Plate Foot Nut	1	AISI 4340 Steel, annealed	Cylinder	0.64	6.4	7.3	3.2	No	2500°	Demise
8	Solar Panel Clips	4	AISI 316 Stainless Steel Sheet	Triangular Plate	3.84	21.2	21.2	0.5	No	2500°	0 km
9	Plasma Shield	2	ULTEM 1010	Triangular Box	2.28	18.29	18.29	11.18	No	-	Demise
10	MAI Adapter Plate	1	5052-H32 Aluminum Alloy	Plate	42.11	100.0	100.0	2.5	No	-	Demise
11	Plus-Z Cover Plate	1	5052-H32 Aluminum Alloy	Plate	47.08	104.32	104.3	1.52	No	-	Demise
12	Antenna Assembly	1	-	-	-	-	-	-	-	-	Demise
13	Antenna Mount	1	ABS	Box	1.14	22.8	17.0	10.63	No	-	Demise
14	Straight SMA Jack	1	Brass	Cylinder	2.45	6.32		9.52	No	-	Demise
15	UHF Antenna	1	AISI 1045 Steel, cold drawn	Plate	1.13	6.0	187.5	0.1	No	2500°	0 km
16	SMA Plug for Antenna	1	Brass	Box	3.89	7.93	9.2	17.3	No	-	Demise
17	Copper Ground for Antenna	1	Copper	Flange	2.68	25.5	27.0	0.76	No	-	Demise
18	Nylon 2-56 Hex Nut	1	Nylon 6/6	Nut	0.04	4.8	5.5	1.97	No	-	Demise
19	Polycarbonate 2-56 x 0.25" Screw	1	Polycarbonate, High Viscosity	Screw	0.036	4.32 (Head)	2.2 (Threads)	7.95	No	-	Demise
20	RBF Assembly	1	-	-	-	-	-	-	-	-	-

21	RBF Bracket	1	6061-T6 Aluminum Alloy	Flange	9.67	25.0	30.8	2.5	No	-	Demise
22	Cherry Microswitch	1	Nylon 101, Cold-Rolled Ni-Plated Steel	Box	1.38	6.4	19.8	8.95	No	2500°	Demise
23	Instrument	1	-	-	-	-	-	-	-	-	Demise
24	CTIP Foot Bracket	1	7075-T6, Plate (SS)	L-Shaped Plate	19.16	76.7	62.5	5	No	-	Demise
25	CTIP Bracket 3	1	6061-T6 Aluminum Alloy	Box	4.02	15.76	15.8	9	No	-	Demise
26	PCB Level 1 subassembly	1	-	-	-	-	-	-	-	-	Demise
27	PCB Level 0	1	FR-4, Acrylic Coating, Au Flash	Plate	32	86.5	86.5	2.38	No	-	Demise
28	Acrylic Conformal Coat	1	Acrylic	Coating	2				No	-	Demise
29	Ellsworth Adhesives Dow Corning 182	A/R	Silicone	Potting Compound					No	-	Demise
30	3G Metalworx Fence	1	Tin-Plated Steel	Bent Plate	1.42	6	95.91	0.31	No	2500°	0 km
31	3G Metalworx Top	1	Tin-Plated Steel	Plate	1.54	16.0	98.35	0.31	No	2500°	0 km
32	HVM SMHV0510N Power Supply	1	Diallyl Phthalate, High-Performance Epoxy	Box	15	21.6	21.6	15.24	No	-	Demise
33	Airborn MS-262 Connector Receptacle	1	Electroless Nickel, PPS Insulator, Au Contacts, Sn/Pb Alloy Terminations	Box	11.02	27.4	15.2	5.31	No	-	Demise
34	3M 2216 B/A Staking Compound	A/R	Two-Part Elastomeric Epoxy	Staking Compound					No	-	Demise
35	PMT, Shutter, and BaF2 Subassembly	1	-	-	-	-	-	-	-	-	-
36	Photomultiplier Tube	1	Fused Quartz, MgF2, Ni, BeCu, 18-8 Stainless Steel, CsI	Cylinder	7	14.07		35.18	No	-	Demise
37	PMT Holder Base	1	6061 Alloy	Box	9.53	20.2	17.46	26.21	No	2500°	Demise
38	PMT Holder Top	1	6061 Alloy	Box	7.06	20.2	17.46	15.24	No	2500°	Demise
39	1mm x 4mm O-Ring	1	Viton	Cylinder	0.024	6 (OD)	4 (ID)	1	No	-	Demise
40	0.512" x 0.016" O-Ring	1	Viton	Cylinder	0.011	13.82 (OD)	13.004 (ID)	0.41	No	-	Demise
41	PMT Lightshade	1	6061-T6 Aluminum Alloy	Box	1.68	15.24	30.48	3.05	No	-	Demise

42	Bistable Rotary Shutter	1	18-8 Stainless Steel, Cu Wire, NdFeB Disk	Cylinder	15.02	11.1		22.89	No	2500°	70.5
43	Bistable Rotary Filter Holder	1	18-8 Stainless Steel, Cu Wire, NdFeB Disk	Cylinder	17.75	11.14		23.03	No	2500°	0 km
44	6mm x 0.5mm BaF2 Crystal	1	BaF2	Plate	0.07	6		0.5	No	-	Demise
45	Summers Optical Milbond Type II	1	Two-Part Optical Epoxy	Optical Cement	0.4				No	-	Demise
46	3M 2216 B/A Staking Compound	A/R	Two-Part Elastomeric Epoxy	Staking Compound					No	-	Demise
47	Loctite 271		Saccharin, Cumene Hydroperoxide, Cumene, Methyl Methacrylate	Locking Compound	0				No	-	Demise
48	SrF2 Heated Filter Subassembly	1	-	-	-	-	-	-	-	-	-
49	13mm x 2mm SrF2 Crystal	2	SrF2	Plate	2.24	13		2	No	-	Demise
50	Tensioning Plug	1	Fluorosilicone	Cylinder	0.001	0.79 (OD)	0.23 (ID)	1	No	-	Demise
51	Solid/Stranded Wire Adapter	1	Copper	Cylinder	0.01	1 (OD)	0.71 (ID)	1.52	No	-	Demise
52	M213 Heraeus PRTD Class A 1.7 x 1.2 x 0.9	2	Encapsulated Platinum	Box	0.54	1.24	1.59	0.65	Yes	3215°	Demise
53	Front Thermal Plate	1	Copper, Au Flash	Cylinder	2.32	18 (OD)	14.22 (ID)	2.66	No	-	Demise
54	Rear Thermal Plate	1	Copper, Au Flash	Circular Plate	0.85	18 (OD)	10.31 (ID)	0.34	No	-	Demise
55	Insulator Daughterboard	2	FR-4, Au Flash	Half-Circle Plate	4.42	43.59 (OD)	15.9 (ID)	4.57	No	-	Demise
56	24 AWG Solder Lug	1	Copper	Cylinder	0.02	1.27 (OD)	0.76 (ID)	1.91	No	-	Demise
57	24 AWG Teflon-Coated Hookup Wire	1	Tinned Copper, PTFE Insulated	Wire	2	1.12		25	No	-	Demise
58	Dual Row Right-Angle Connector (10 pins)	1	CuBe Alloy, HDPE Thermoplastic Shell	Box	0.32	6.35	4.978	2.54	No	-	Demise
59	Ellsworth Adhesives Dow Corning 182		Silicone	Potting Compound	0				No	-	Demise
60	16" 30 AWG Insulated Nichrome Wire	1	NiChrome, Acrylic Coating	Wire	0.02	0.25		49.66	No	-	Demise
61	Filter Holder Outer Clamp, Right	1	Delrin 2700 NC010	Box with cutout	4.81	25.4	47.8	7.93	No	-	Demise
62	Filter Holder Outer Clamp, Left	1	Delrin 2700 NC010	Box with cutout	4.82	25.4	47.8	7.93	No	-	Demise

63	Filter Holder Hold-Down Clamp	1	6061-T6 Aluminum Alloy	Flange	0.87	27.08	7.94	2.36	No	-	Demise
64	Loctite 271		Saccharin, Cumene Hydroperoxide, Cumene, Methyl Methacrylate	Locking Compound	0				No	-	Demise
65	Loctite 420		Cyanoacrylate Glue	Instant Glue (Wicking)	0				No	-	Demise
66	Mirror Subassembly	1	-	-	-	-	-	-	-	-	-
67	Square Mirror	1	6061-T6 Aluminum Alloy, LaF3 and MgF2 Coating	Curved Mirror	43.61	45.02	45.02	64	No	-	Demise
68	Heat Shield for WTC3243	1	6061-T6 Aluminum Alloy	Plate	2.48	29.85	29.85	1.01	No	-	Demise
69	Light Tight Frame Subassembly	1	Various	-	-	-	-	-	-	-	-
70	Left Side Box	1	5052-H32 Aluminum, Copper Oxide Coating, Au Coating	Plate	40.51	282.38	79.59	0.83	No	-	Demise
71	Instrument Vanes	9	18-8 Stainless Steel, Copper Oxide Coating	Plate	71.82	69.0	69	0.41	No	2500°	0 km
72	1/32" U-Channel Light-Tight Gasket	?	Fluorosilicone	Plate		2.38	5.56	0.79	No	-	Demise
73	Fold-out Light Shield	1	-	-	-	-	-	-	-	-	Demise
74	Light Shield Leaves	4	18-8 Stainless Steel, Gunmetal Iron Oxide Coating	Plate	30.48	47.22	44.58	0.46	No	2500°	0 km
75	Frame	1	5052-H32 Aluminum	Box	19.22	68.96	68.96	5.08	No	2500°	Demise
76	Frame Pivot Block, Top	1	6061-T6 Aluminum Alloy	Box	0.19	7.11	4.24	3.18	No	-	Demise
77	Frame Pivot Block, Bottom	1	6061-T6 Aluminum Alloy	Box	0.21	4.29	7.79	3.12	No	-	Demise
78	Frame Pivot Block, L-Shape	1	6061-T6 Aluminum Alloy	Box	0.36	7.67	7.16	4.06	No	-	Demise
79	180 Degree 0.015" Spring, RH	2	Heat Treated High Carbon Steel	Wire	0.06	0.38		35.72	No	2500°	Demise
80	180 Degree 0.015" Spring, LH	2	Heat Treated High Carbon Steel	Wire	0.06	0.38		35.72	No	2500°	Demise
81	Light Shield Release Subassembly	1	-	-	-	-	-	-	-	-	-
82	Line Cutter PCB	1	FR-4, Au Flash	Plate	0.22	19.05	9.53	0.81	No	-	Demise

83	Nylon Monofilament 10-lb Test, UV Sens	1	Nylon 101	Wire	0.14	0.3		20	No	-	Demise
84	24 AWG Pigtail Hookup Wire	2	Tinned Copper, PTFE Insulated	Wire	19.12	1.12		120	No	-	Demise
85	10 Ohm Resistor	1	Metal Film Axial Resistor, Encapsulated	Cylinder	0.25	2.29		6.1	No	-	Demise
86	CTIP Bracket 1 Cut-Corner	1	6061-T6 Aluminum Alloy	L-Shaped Plate	2.73	31.82	24.32	9.81	No	-	Demise
87	CTIP Bracket 2	1	6061-T6 Aluminum Alloy	L-Shaped Plate	1.95	16	22	3	No	-	Demise
88	CTIP Bracket 4	1	6061-T6 Aluminum Alloy	L-Shaped Plate	1.88	23.49	23.37	3	No	-	Demise
89	Battery Assembly	1	-	-	-	-	-	-	-	-	-
90	ULTEM Battery Bracket	1	ULTEM 1010	Box	115.86	95.46	83	26	No	-	Demise
91	Lithium Battery	4	Lithium	Cylinder	200.16	18.2		66	No	-	Demise
92	Battery Protection Circuit	1	FR-4	Plate	0.83	7.5	45.5	1	No	-	Demise
93	Avionics	1	Various	-	-	-	-	-	-	-	Demise
94	Pumpkin Midplane Standoffs	8	7075-T6 (SN)	Box	24	10.55	8.45	5	No	-	Demise
95	SFC Board	1	FR-4, Glass-Filled Polyester, Phosphor Bronze, Ni, with Au or Sn Pin Plating	Plate	56	95.89	90.17	1.58	No	-	Demise
96	SCE Board	1	FR-4, Glass-Filled Polyester, Phosphor Bronze, Ni, with Au or Sn Pin Plating	Plate	45	95.89	90.17	1.58	No	-	Demise
97	EPS Board	1	FR-4, Glass-Filled Polyester, Phosphor Bronze, Ni, with Au or Sn Pin Plating	Plate	100	95.89	90.17	1.58	No	-	Demise
98	COMM Board	1	FR-4, Glass-Filled Polyester, Phosphor Bronze, Ni, with Au or Sn Pin Plating	Plate	68.94	95.89	90.17	1.68	No	-	Demise
99	MAI-400 ADCS Unit	1	Aluminum	Box	694	100	100	55.88	No	-	Demise
100	MAI 400 ACB	1	FR-4	Plate	7.33	43	43	1.58	No	-	Demise
101	X-Face Solar Panels	2	FR-4, InGaP, InGaAs, Ge, Silica Glass	Plate	450	82.5	326	2.69	No	-	Demise

102	Plus-Y Solar Panel	1	FR-4, InGaP, InGaAs, Ge, Silica Glass	Plate	225	82.5	326	2.69	No	-	Demise
103	Minus-Y Solar Panel	1	FR-4, InGaP, InGaAs, Ge, Silica Glass	Plate	225	82.5	326	2.69	No	-	Demise
104	Coarse Sun Sensor	2	FR-4, InGaP, InGaAs, Ge, Silica Glass	Plate	9.96	81.28	15.24	2.58	No	-	Demise
105	Hardware	213	18-8 Stainless Steel, 316 Stainless Steel	Various	85.2				No	-	Demise
106	Wiring	13	Copper, PTFE Insulated	Wire	39				No	-	Demise
107	Nichrome Burn Wire	1	NiChrome, Acrylic Coating	Wire	0.02	0.25		49.66	No	-	Demise
108	Scotch-Weld	A/R	Epoxy	Locking Compound					No	-	Demise
109	Aluminum Spacers	12	Aluminum	Cylinder	10.44	6 (OD)	3.2 (ID)	16	No	-	Demise