ELVL-2016-0044542
August 23, 17

Orbital Debris Assessment for The CubeSats on the CRS OA-9/ELaNa-23 Mission per NASA-STD 8719.14A

Signature Page

Yusef Johnson, Analyst, a.i. solutions, AIS2

Scott Higginbotham, Mission Manager, NASA KSC VA-C

National Aeronautics and
Space Administration

John F. Kennedy Space Center, Florida
Kennedy Space Center, FL 32899

ELVL-XXX-XXXX

Reply to Attn of: VA-H1

August 23, 17

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 ELaNa-23 Mission (DRAFT)

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6A, 5 February 2008
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14A, 25 May 2012
C. International Space Station Reference Trajectory, delivered May 2017
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. 4th ed. Northbrook, IL, Underwriters Laboratories, 2007
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. HQ OSMA Email:6U CubeSat Battery Non Passivation Suzanne Aleman to Justin Treptow, 8 August 2017

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the ELaNa-23 auxiliary mission launching on the CRS OA-9 vehicle. It serves as the final submittal in support of the spacecraft Safety and Mission Success Review (SMSR). Sections 1 through 8 of ref. (b) are addressed in this document; sections 9 through 14 fall under the requirements levied on the primary mission and are not presented here.

The following table summarizes the compliance status of the ELaNa-23 payload mission to be flown using a to-be-determined CRS vehicle. The 8 CubeSats comprising the ELaNa-23 mission are 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 4.3 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 release under ELaNa-23 mission

Section 1: Program Management and Mission Overview

The ELaNa-23 mission is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is Jason Crusan. Responsible program/project manager and senior scientific and management personnel are as follows:

CaNOP: Kevin Crosby, Principal Investigator, Carthage College

CubeRRT: Joel T. Johnson, Principal Investigator, The Ohio State University

EQUISat: Rick Fleeter, Advisor, Brown University

MemSat: Sangho Shin, Principal Investigator, Rowan University

RadSat: Brock LaMeres, Technical POC, Montana State University

RainCube: Eva Peral, Principal Investigator, The Jet Propulsion Laboratory

SORTIE: Geoffrey Crowley, Principal Investigator, University of Colorado

Tempest-D: Steven Reising, Principal Investigator, Colorado State University

Program Milestone Schedule	
Task	Date
CubeSat Selection	August 16, 2016
CubeSat Delivery to NanoRacks	February 1, 2018
Launch	March14, 2018 (U/R)

Figure 1: Program Milestone Schedule

The ELaNa-23 CubeSat complement will be launched as payloads on an upcoming CRS launch vehicle to the International Space Station. The ELaNa-23 mission will deploy 8 pico-satellites (or CubeSats) from the International Space Station, using the NanoRacks CubeSat dispenser. Each CubeSat is identified in Table 2: ELaNa-23 CubeSatsTable 2: ELaNa-23 CubeSats. The ELaNa-23 manifest includes: CaNOP, CubeRRT, EQUISat, MemSat, RadSat, RainCube, SORTIE, and Tempest-D. The current launch date is projected to be no earlier than April 30, 2018.

The CubeSats on this mission range in size from a 10 cm cube to 24 cm x 36 cm x 10 cm, with masses from about .71 kg to 11.4 kg, with a total mass of roughly 49 kg being manifested on this mission. The CubeSats have been designed and universities and government agencies and each have their own mission goals.

Section 2: Spacecraft Description

There are 8 CubeSats flying on the ELaNa-23 Mission. Table 2: ELaNa-23 CubeSats~~Table 2: ELaNa-23 CubeSats~~ outlines their generic attributes.

Table 2: ELaNa-23 CubeSats

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
CaNOP	1	3U (340 x 100 x 100)	2.75
CubeRRT	1	6U (365 x 226.3 x 100)	11.4
EQUISat	1	1U(100 x 113 x100)	1.20
MemSat	1	1U (100 x 113 x 100)	.71
RadSat	1	3U (98.5 x 326.5 x 98.5)	1.6
RainCube	1	6U (116 x 366 x 239)	11.9
SORTIE	1	6U (239.2 x 365 x 115.4)	7.94
Tempest-D	1	6U (226.3 x 365 x 100)	11.09

The following subsections contain descriptions of these 8 CubeSats.

CaNOP – Carthage College – 3U

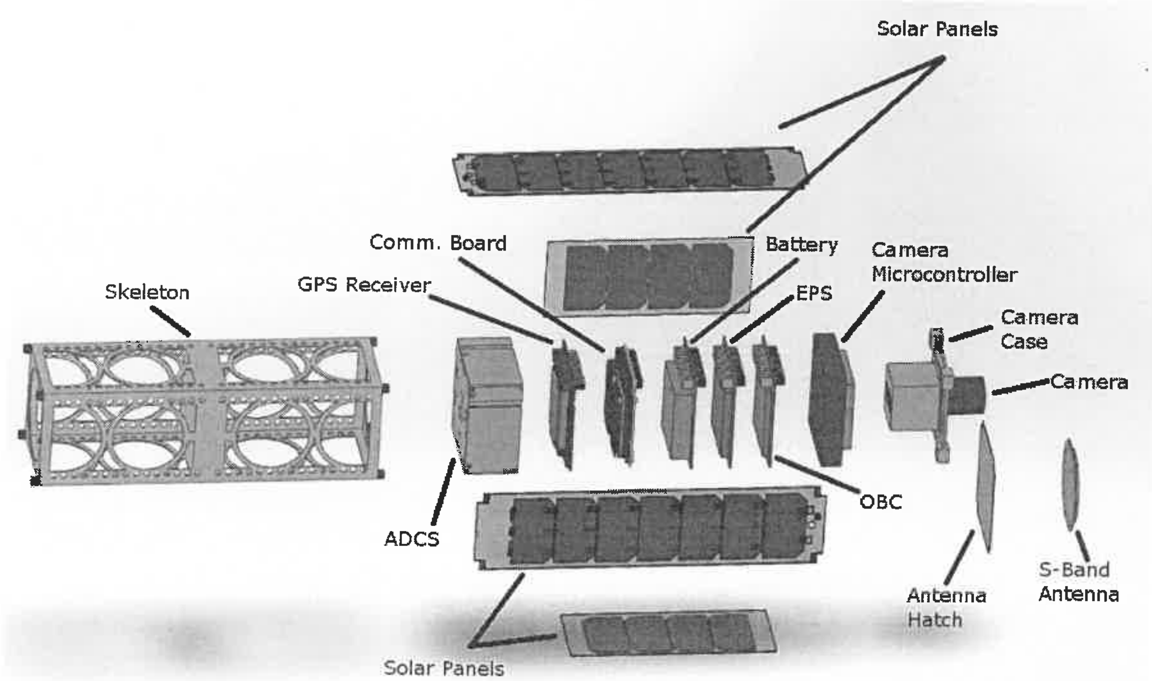

Figure 1: CaNOP Expanded View.

Overview

The CaNOP CubeSat mission objective is to provide an educational experience in aerospace engineering to undergraduate students through designing, building, testing, and operating a 3U CubeSat designed to replicate early Landsat remote sensing capabilities. To achieve this objective, a multispectral linescan imaging sensor and associated optics capable of resolving a ground sample distance of 60 m and a scene size of 120 km will be utilized.

CONOPS

Upon deployment from the ISS, CaNOP will power up and attempt a status test of internal systems. After 45 minutes, the ADCS proceeds to de-tumble CaNOP . When CaNOP is approaching an imaging target, the camera will be activated. The camera will acquire spectrally resolved images along the orbital path. When CaNOP CubeSat is near a Near Earth Network (NEN) ground station with S-band capabilities, the communication system will be activated and begin transmitting handshake signals until downlink is established. Once downlink is established, compressed image data and telemetry will be broadcast to the closest ground station within range. When CaNOP is low on power the EPS will stop powering all unnecessary components and allow CaNOP to orbit until the 30Whr battery has been sufficiently recharged.

Materials

The CaNOP CubeSat components are commercial-off-the-shelf (COTS) materials, electrical components, and solar cells. The primary provider for COTS technology used in CaNOP is ClydeSpace, Inc.. The primary structural component is the 3U frame provided by ClydeSpace, Inc. The ClydeSpace 3U structure is machined from anodized 6061 aluminum.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Power System/Batteries

The electrical power storage system consists of common lithium ion polymer (LiPo) cell batteries with Overcharge, Over-discharge, Overcurrent, Overvoltage, and Under-temperature protection. The LiPo cells are qualified to NASA standards EP-Wi-032.

CubeRRT – The Ohio State University/Goddard Spaceflight Center/The Jet Propulsion Laboratory/Blue Canyon Technologies – 6U CubeSat

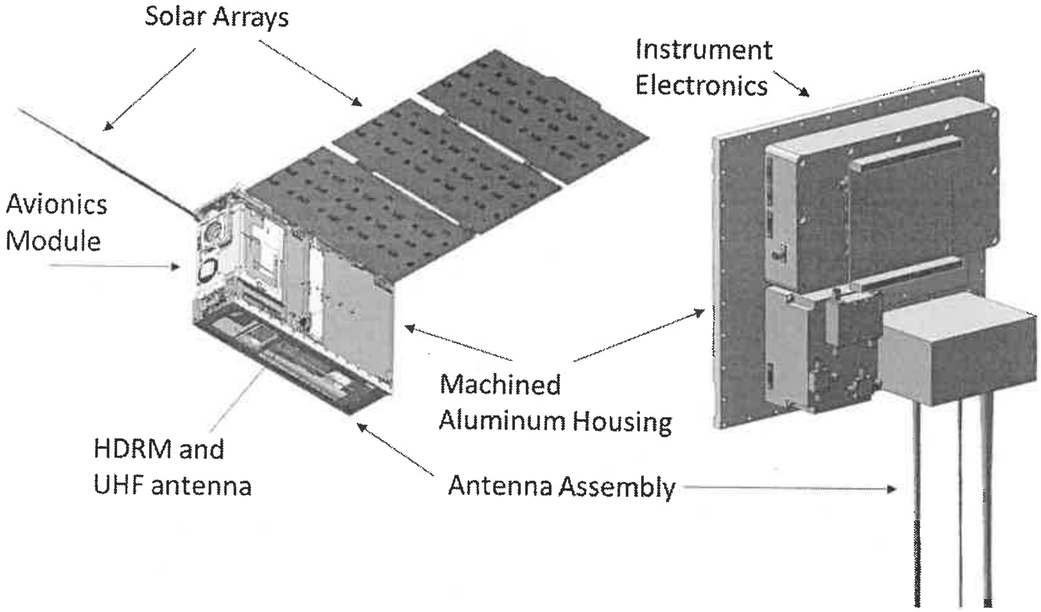

Figure 2: CubeRRT Deployed View/CubeRRT Electronics

Overview

The CubeSat Radiometer Radio Frequency Interference Technology Validation (CubeRRT) mission will observe, detect, and mitigate radio frequency interference (RFI) for microwave radiometers. RFI is a growing concern for Earth science observations due to its negative impact on science measurements with microwave radiometers. CubeRRT is being developed through collaboration between OSU, NASA's Goddard Space Flight Center, and NASA Jet Propulsion Laboratory (JPL). Goddard and JPL will build the front-end instrument and the backend electronics for the spacecraft, respectively, while OSU will implement CubeRRT's antenna subsystem and manage the project. Blue Canyon Technologies (BCT) will integrate the CubeRRT payload with the 6U spacecraft bus and perform environmental testing of the complete spacecraft. The spacecraft will be operated from BCT's Mission Operations Center located in Boulder, Colorado.

CONOPS

Once CubeRRT is ejected from the dispenser and separation is confirmed, the CubeSat begins an autonomous initialization sequence which begins with the CubeSat entering a sun pointing mode and begins recording vehicle state of health (SOH) data. The spacecraft's guidance then puts the vehicle into a Sun Safe attitude. 30 minutes after separation, the solar arrays and UHF antenna are deployed, and the mirror is unlocked. At 45 minutes after separation, the spacecraft begins beaconing of SOH data, using the GlobalStar system. At 55 minutes after separation, GPS beings cycling in order to determine a position solution. Once the ground analyzes the data and finds it satisfactory, calibration of CubeRRT's instruments begins. Once nominal subsystem performance is confirmed, the ground will command deployment of the payload antenna.

Materials

The majority of the bus is machined 6061-T6 aluminum structure, with carbon-fiber composite solar array panels, fused silica star tracker optics, and various commercial electronics parts.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The power system consists of a peak power tracker that charges 6x lithium-ion batteries (2 strings of 3 cells). The battery design incorporates a cell balancing circuit and protection for over-charge, over-discharge and short-circuits. The UL-listing number is BBCV2.MH19896.

EquiSat – Brown University – 2U

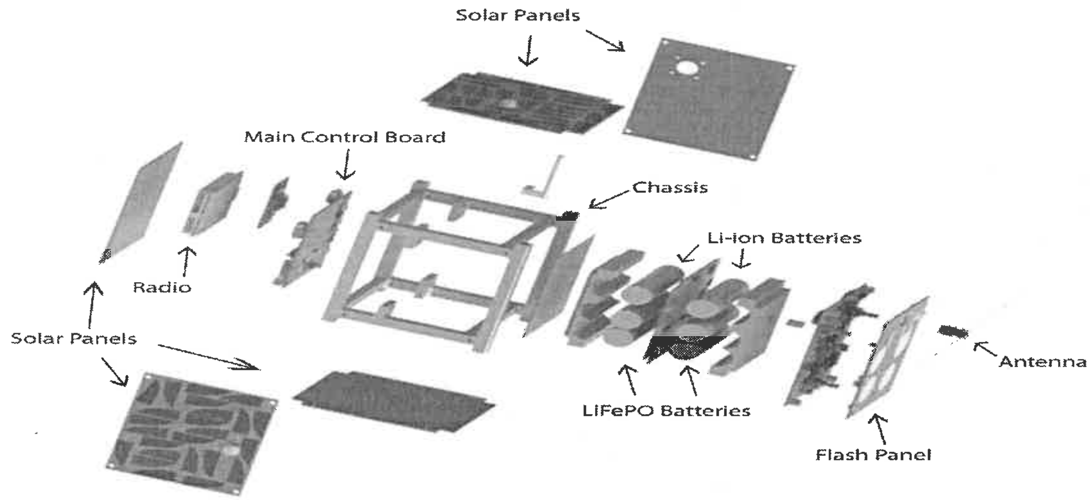

Figure 3: EquiSat Expanded View

Overview

EquiSat will be visible to observers on the ground, within earshot of amateur radio users, and will be testing experimental lithium iron phosphate battery technology. The assembly will prove the feasibility of low cost spaceflight through the use of student designed and manufactured components.

CONOPS

Upon deployment from the ISS, EquiSat will power up and start counting down timers. At 45 minutes, the antenna will be deployed and our radio will start transmitting. Once system checkout has been complete, the spacecraft will progress to its primary operating mode and begin payload tests. Operations will continue until loss of contact with spacecraft.

Materials

The CubeSat structure is milled out of a single block of 6061 Aluminum. It contains standard off the shelf materials, electrical components, PCBs and solar cells.

Hazards

There are no hazardous systems on board. There are no pressure vessels nor thrusters nor any chemical reactants.

Batteries

The electrical power storage system consists of 2 lithium-ion (primary) and 4 lithium iron phosphate batteries (payload) with over-charge/current protection circuitry. The payload batteries carry the UL-listing number MH61931 and the primary batteries are of type 18650.

MemSat –Rowan University – 1U

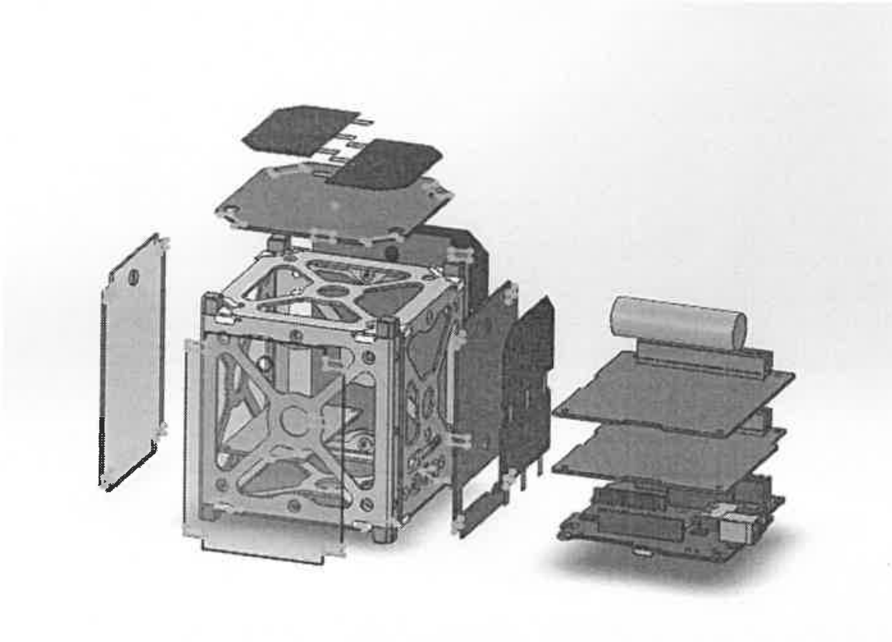

Figure 4: MemSat Expanded View

Overview

MemSat's mission is to evaluate the behavior of novel memristive memory elements against standard, silicon-based memory technologies to determine potential advantages—and/or disadvantages—of memristors for space applications. The key figure of merit to be quantified between technologies for this mission experiment is comparison of single event upset (SEU) rate.

CONOPS

Once MemSat has been deployed and the mandated 45 minute radio silence period has passed, the antenna will be deployed and begin to run satellite diagnostics. Once the satellite is operational, it will attempt to communicate with its ground station. After a preliminary status update about the satellite has been sent, the MemSat will begin the Minimum Viable Experiment. The primary experiment will run for 30 days, with upkeep and diagnostics running in the background. After these 30 days, the mission operations team will begin to upload new experimental profiles to the MemSat to be performed.

Material

The CubeSat structure is a Pumpkin 1U Structure made from Al 6061 Stainless Steel. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. Attitude stabilization will be obtained utilizing neodymium magnets.

Hazards

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

Power Systems/Hazards

The electrical power storage system consists of common lithium-ion batteries with over-charge/current protection circuitry. The lithium batteries carry the UL-listing number ICR18650.

RadSat-g – Montana State University – 3U

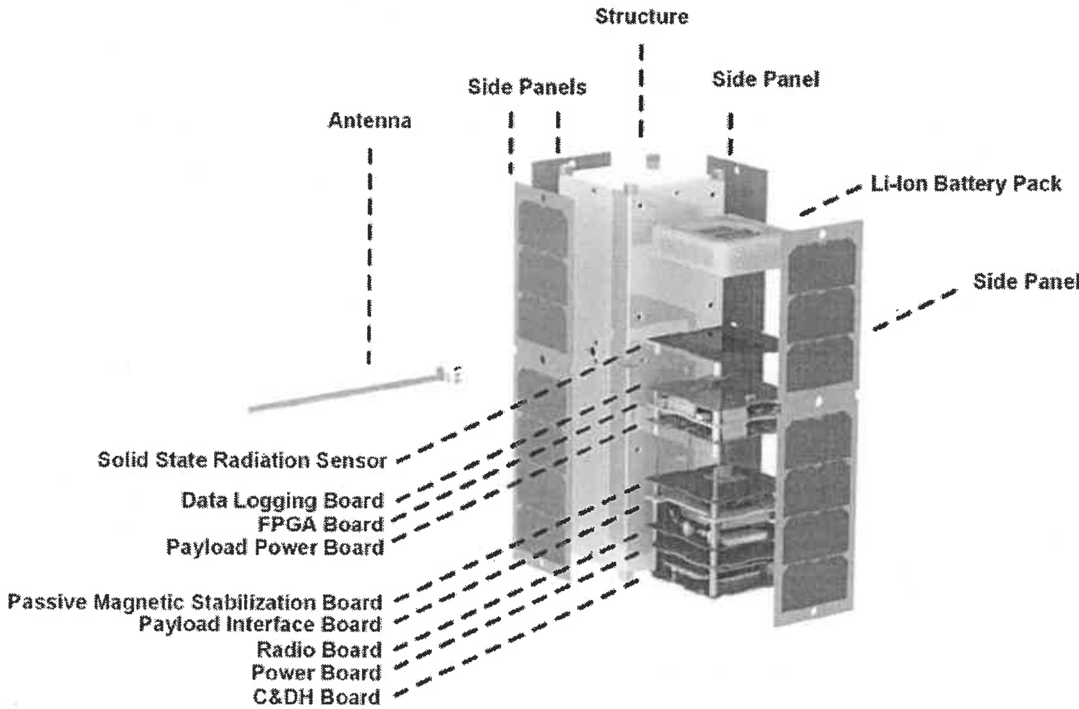

Figure 5: RadSat-g Expanded View

Overview

RadSat-g will demonstrate a radiation tolerant computer technology in Low Earth Orbit. The technology is based on commercial off the shelf (COTS), Field Programmable Gate Arrays. RadSat-g deploys a novel single event effect (SEE) mitigation strategy based on spatial avoidance of faults using an array of redundant processors with selective activation and background repair through partial reconfiguration.

CONOPS

Upon deployment from the ISS, RadSat-g will power up and start a timer system. At 45 minutes RadSat-g will turn on and the flight computer will engage the antenna deployment sequence. The system will then begin UHF beacon transmissions at a 30 second cadence. For the first week of operation the ground station operators will attempt communications to perform checkouts of the spacecraft. Approximately 7 days from launch, data from the computer technology will begin to be downloaded and will continue for approximately 1 year.

Materials

The RadSat-g structural components are made of the following aluminum alloys: 5052-H32 and 7075-T6. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The UHF/UHF antennas are made of spring steel.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of common lithium-ion batteries with over-charge/current protection circuitry. The lithium batteries carry the UL-listing number MH48285.

RainCube – The Jet Propulsion Laboratory - 6U

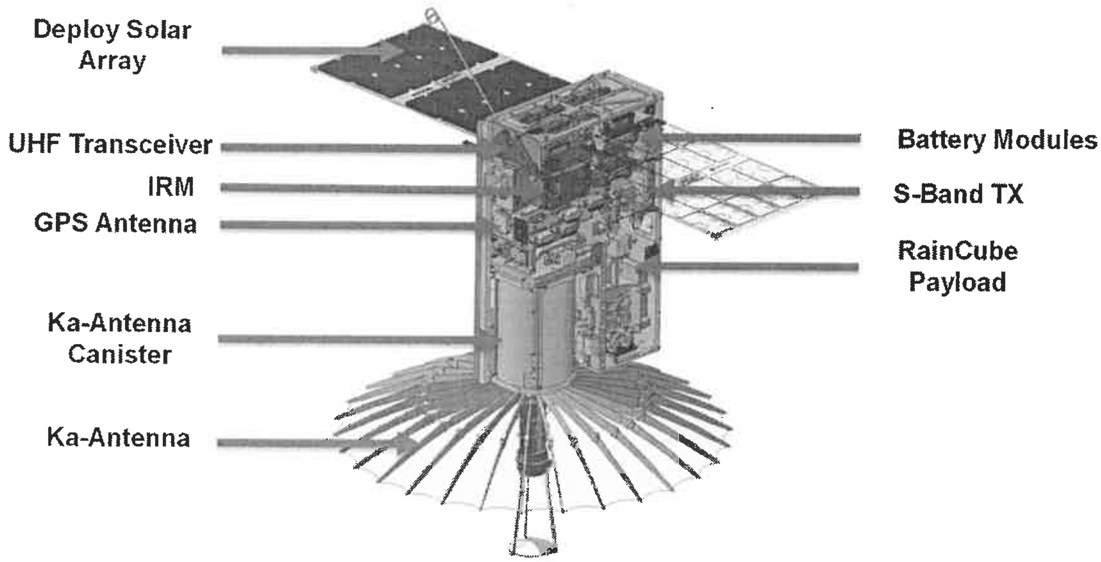

Figure 6: RainCube View

Overview

The RainCube (**Ra**dar **in** a **Cube**sat) mission is a technology demonstration mission to enable Ka-band precipitation radar technologies on a low-cost, quick turnaround platform. RainCube is demonstrating two new technologies: a novel radar architecture called miniKaAR-C (miniature Ka-band Atmospheric Radar for CubeSats) and an ultra compact deployable Ka-band antenna called KaRPDA (Ka-band Radar Parabolic Deployable Antenna). The mission utilizes Tyvak's Endeavor suite architecture for power generation and management, telemetry and commanding (TC), Command and Data Handling (CDH), thermal management, and Guidance Navigation and control (GNC). The Tyvak system utilizes two lithium ion battery modules and deployable solar arrays for power generation and management. The TC consists of a UHF transceiver for bus telemetry downlinks and command uplinks, as well as an S-Band transmitter for payload data downlink. The CDH and GNC are packaged into the Inertial Reference Module (IRM) which consists of a CDH & GNC processor, an IMU, three magnetorquers, and three reaction wheel assemblies, and two star trackers. The payload, comprised of miniKaAR-C and KaRPDA, is designed and manufactured by JPL.

CONOPS

The RainCube vehicle powers on following release from its deployer through the release of three independent enable switches (two high-side, one low-side), and begins operations to de-tumble the vehicle and enter a sun-pointing orientation. Following a 45 minute timer expiration, the UHF antennas are automatically deployed and beacons occur over designated ground stations via UHF. Approximately 90 minutes after deployment, the solar arrays are deployed and the vehicle begins bus commissioning operations, which are anticipated to take several days. Following bus commissioning, the Ka-band antenna is deployed and the vehicle begins payload commissioning operations, which are anticipated to take several days as well. Following payload commissioning, the vehicle being nominal operations to collect science data. Nominal operations will switch between Ka-band measurements with the antenna boresight facing Nadir and sunpointing with the deploy arrays normal to the sun vector.

Materials

The primary structure for RainCube is composed of Aluminum 7075-T7. The spacecraft is largely composed of components manufactured by Tyvak, which consist of electrical components, PCBs or FR4, and solar cells. Both the S-Band transmit antenna and the GPS receive antenna are ceramic patches.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of common lithium-ion batteries with over-charge/current protection circuitry. The lithium batteries used are LG 18650 and have passed IEC/UN38.3. The theoretically peak energy storage is 120Whrs, though circuits limit the peak charge to approximately 109.2 Whrs.

SORTIE– The Astra Corporation – 6U

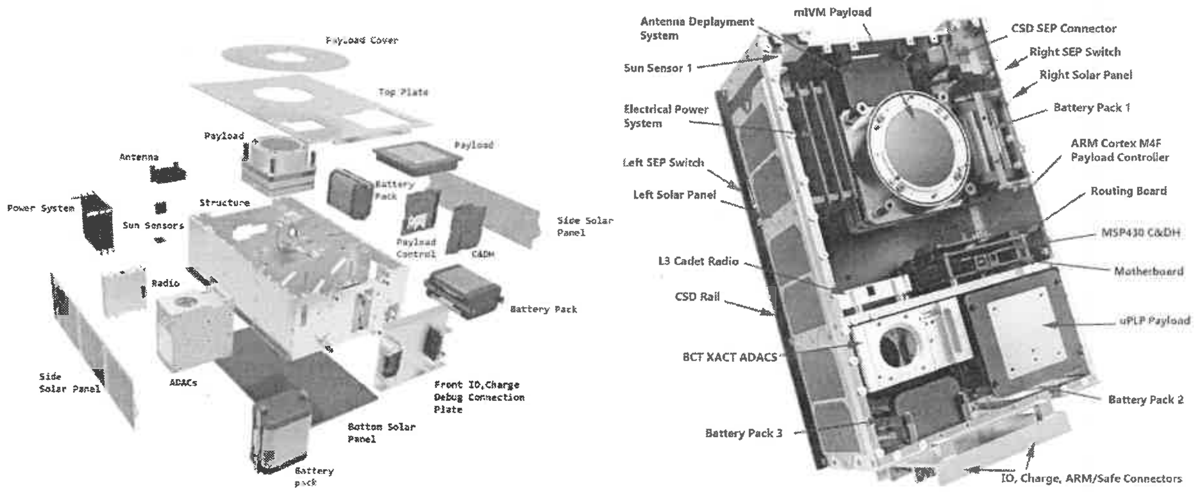

Figure 8: SORTIE Expanded/Deployed View

Overview

Scintillation Observations and Response of The Ionosphere to Electrodynamics (SORTIE)'s mission is to collect data over the course of 6 months, which will allow scientists to describe the distribution of wave-like structures in the plasma density of the ionospheric F-region and to connect these variations to wave sources in the troposphere and in the high latitude thermosphere. SORTIE is a 6U CubeSat that will carry two instruments for determining the structure of equatorial plasma: a miniature Ion Velocity Meter (mini-IVM) built by The University of Texas at Dallas, and a micro Planar Langmuir Probe (μPLP) built by the Air Force Research Laboratory (AFRL) in Albuquerque.

CONOPS

After deployment from the ISS, SORTIE will turn on in a low-power mode. This mode will perform initial system tests, battery tests and start a timer for 45min. After timeout the antenna will be deployed, and SORTIE will wait to hear from the ground station. Upon initial contact with the ground station, SORTIE will download system health telemetry, and payload testing telemetry. This will continue through subsequent orbits until operations team send command to change mode to normal operations. It is expected that a move to normal operations will take more than a week to insure the spacecraft is functioning as expected. After entering normal operations mode, the spacecraft will collect and download payload and system telemetry until the end of life.

Materials

The SORTIE structure is made of Aluminum 6061-T6. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and GaAs solar cells.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The batteries chosen are lithium-ion from Panasonic ACA4000PE3. They have acquired UL1642. The power system has current protection and overcharge protection.

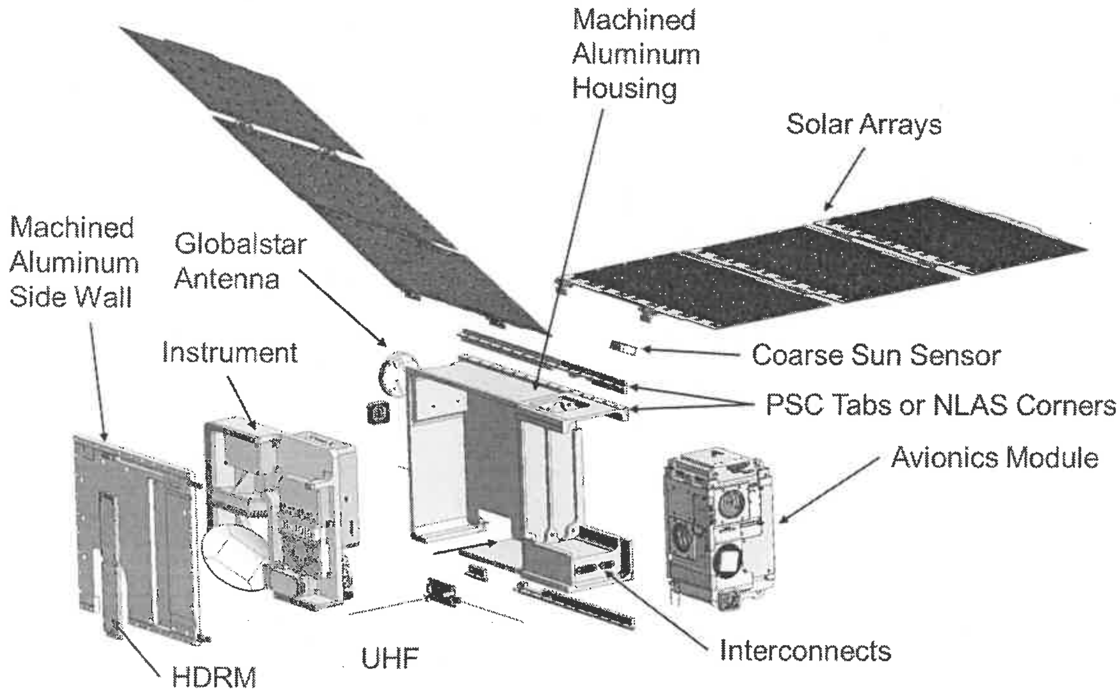

Figure 9: TEMPEST-D Expanded View

Overview

The objective of the TEMPEST-D mission is to reduce the risk, cost and development time for a future TEMPEST mission. A future five-satellite TEMPEST mission would provide the first temporal observations of cloud and precipitation processes on a global scale. These observations are important to understanding the linkages in and between Earth's water and energy balance and to the understanding of cloud model microphysical processes that are vital to climate change prediction. This understanding will also have significant impact on agricultural forecasting, forest management and disaster preparedness. Blue Canyon Technologies (BCT) will deliver the 6U spacecraft to the project, led by Colorado State University (CSU). TEMPEST-D is supported by NASA's Science Mission Directorate, Earth Science Division and is managed by NASA's Earth Science Technology Office. The NASA/CalTech Jet Propulsion Laboratory (JPL) will provide the five-channel millimeter-wave radiometer instrument.

CONOPS

After deployment, they rapidly boot-up and image the launch vehicle. Out of view of the upper stage, each will characterize the other's tumble using the cameras. At 30 mins, the cameras will be used to observe each PIC's own antenna deployment. At 45 mins, the system will downlink primary mission data, including telemetry used for evaluating system performance.

Materials

The majority of the bus is machined 6061-T6 aluminum structure, with carbon-fiber composite solar array panels, titanium thermal bench standoffs, fused silica star tracker optics, and various commercial electronics parts.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The power system consists of a peak power tracker that charges 6x lithium-ion batteries (2 strings of 3 cells). The battery design incorporates a cell balancing circuit and protection for over-charge, over-discharge and short-circuits. The UL-listing number is BBCV2.MH19896.

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 ELaNa-23 CubeSat mission 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 on the ELaNa-23 mission.

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 prevents a catastrophic failure, so that passivation at EOM is not necessary to prevent an explosion or deflagration large enough to release orbital debris.

The 6U CubeSats in this complement satisfy Requirements 4.4-1 and 4.4-2 if their batteries at equipped with protection circuitry, and they meet International Space Station (ISS) safety requirements for secondary payloads. Additionally, these CubeSats are being deployed from a very low altitude (ISS orbits at approximately 400 km), meaning any accidental explosions during mission operations or post-mission will have negligible long-term effects to the space environment.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum CubeSat lifetime of 4.3 years maximum, the ELaNa-23 CubeSats are 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.

The largest mean cross sectional area (CSA) among the 8 CubeSats is that of the Raincube CubeSat with solar arrays and Ka antenna deployed.

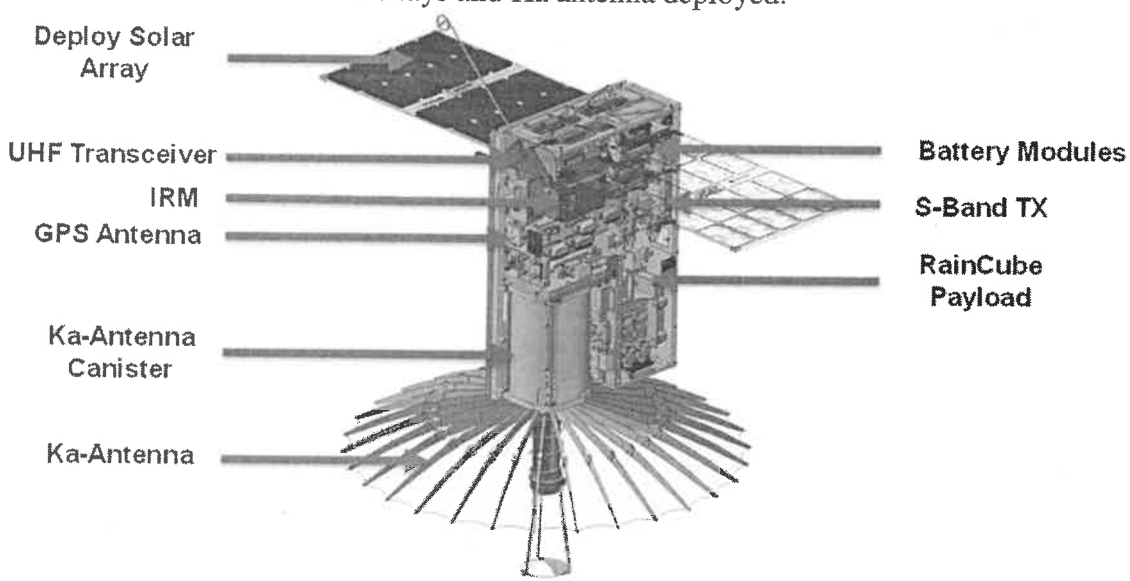

Figure 6: Raincube Deployed Configuration

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

Equation 2: Mean Cross Sectional Area for Complex Objects

All CubeSats evaluated for this ODAR are stowed in 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~~Equation 1~~. This configuration renders the longest orbital life times for all CubeSats.

Once a CubeSat has been ejected from the NanoRacks dispenser and deployables have been extended, Equation 2~~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

The RainCube (11.9 kg) orbit at deployment is 408 km apogee altitude by 400 km perigee altitude, with an inclination of 51.6 degrees. With an area to mass ratio of

$0.0041 m^2/kg$, DAS yields 3.9 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. Even with the variation in CubeSat design and orbital lifetime ELaNa-23 CubeSats see an average of 0.0 probability of collision. All CubeSats on ELaNa-23 were 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	CaNOP	CubeRRT	EquiSat	MemSat	RadSat
	Mass (kg)	2.75	11.4	2.12	.71	1.7
Stowed	Mean C/S Area (m^2)	0.027	0.070	.016	.016	.039
	Area-to Mass (m^2/kg)	0.015	0.006	.008	0.022	0.023
	Orbital Lifetime (yrs)	**2.0**	**3.5**	**3.2**	**1.2**	**2.9**
	Probability of collision (10^X)	**0.00000**	**0.00000**	**0.00000**	**0.00000**	**0.00000**
Deployed **	Mean C/S Area (m^2)		0.040			
	Area-to Mass (m^2/kg)		0.003			
	Orbital Lifetime (yrs)		**4.3**			
	Probability of collision (10^X)		**0.00000**			

Solar Flux Table Dated 1/26/2016

**Note: Blacked out areas represent CubeSats which do not have deployables

Table 3: CubeSat Orbital Lifetime & Collision Probability

CubeSat		RainCube		SORTIE	TEMPEST-D
Mass (kg)		11.9		9.5	11.5
Stowed	Mean C/S Area (m^2)	0.00490		0.0712	0.0409
	Area-to Mass (m^2/kg)	0.00412		0.00749	0.00355
	Orbital Lifetime (yrs)	**3.9**		**3.0**	**4.1**
	Probability of collision (10^X)	**0.00000**		**0.00000**	**0.00000**
Deployed	Mean C/S Area (m^2)	.054	[redacted]	[redacted]	.381
	Area-to Mass (m^2/kg)	.00453	[redacted]	[redacted]	.033
	Orbital Lifetime (yrs)	**3.8**	[redacted]	[redacted]	**4.14**
	Probability of collision (10^X)	**0.00000**	[redacted]	[redacted]	**0.0000**

Table 3: CubeSat Orbital Lifetime & Collision Probability (cont.)

The probability of any ELaNa-23 spacecraft collision 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.

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

Assessment of spacecraft compliance with Requirements 4.5-1 shows ELaNa-23 to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

All ELaNa-23 spacecraft 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 among the CubeSats finds RainCube 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

$$\frac{0.04088\ m^2}{11.5\ kg} = 0.00355\frac{m^2}{kg}$$

Tempest has the smallest Area-to-Mass ratio and as a result will have the longest orbital lifetime. The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

DAS 2.1.1 Orbital Lifetime Calculations:

DAS inputs are: 408 km maximum apogee 400 km maximum perigee altitudes with an inclination of 51.6° at deployment no earlier than April 2018. An area to mass ratio of 0.0041 m^2/kg for the RainCube CubeSat was used. DAS 2.1.1 yields a 4.1 years orbit lifetime for RainCube in its deployed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference Table 3: CubeSat Orbital Lifetime & Collision ProbabilityTable 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 ELaNa-23 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 possess the same negligible risk as stainless steel components.

Table 4: ELaNa-23 High Melting Temperature Material Analysis

CubeSat	Name	Material	Mass (kg)	Demise Alt (km)	Kenetic Energy (J)
CaNop	ADCS momentum wheel	Tungsten	0.09	0	55
CaNop	ADCS magnetic torquers	Iron	0.018	0	3
CubeRRT	Hinge retainer clip1	Titanium (generic)	0.002	0	0
CubeRRT	Hinge retainer clip 2	Titanium (generic)	0.0015	0	0
CubeRRT	Hinge retainer clip 3	Titanium (generic)	0.0014	0	0
CubeRRT	Hinge retainer clip 4	Titanium (generic)	0.0025	0	0
CubeRRT	Screws	Stainless Steel (generic)	0.0006	76.5	0
CubeRRT	Washers	Stainless Steel (generic)	0.0009	78.0	0
EQUISat	Hysteresis rods	Iron	0.0004	0	0
EQUISat	3/8 screws	Stainless Steel (generic)	0.0058	0	0
EQUISat	Nuts	Stainless Steel (generic)	0.0228	78	0
EQUISat	.6 studs	Stainless Steel (generic)	.0085	0	0
EQUISat	1.0 studs	Stainless Steel (generic)	.147	0	0

EQUISat	.1875 slotted screws	Stainless Steel (generic)	.004	78.0	0
EQUISat	1.75 slotted screws	Stainless Steel (generic)	.004	0	0
EQUISat	2-56 nuts	Stainless Steel (generic)	.004	0	0
EQUISat	½ screws	Stainless Steel (generic)	.005	0	0
EQUISat	¼ screws	Stainless Steel (generic)	.006	0	0
MemSat	Antennae	Steel (AISI 410)	.066	0	1
MemSat	Separation springs	Stainless Steel (generic)	.031	77.8	0
MemSat	Magnets	Neodymium	.0035	78.0	0
RadSat	Antenna	Steel (AISI 410)	.008	0	0
RadSat	Magnet	Neodymium	.005	77.8	0
RainCube	Ka band antenna	Stainless Steel (generic)	1.1	0	0
RainCube	fasteners	Steel (AISI 316)	.0005	76.5	0
SORTIE	Antennae	Steel (AISI 410)	.150	0	85
SORTIE	Separation switches	Steel (AISI 316)	.0019	0	0
SORTIE	Fasteners	Steel A-286	.0006	77.2	0
Tempest-D	Hinge retainer clip 1	Titanium (generic)	.002	0	0
Tempest-D	Hinge retainer clip 2	Titanium (generic)	.0015	0	1
Tempest-D	Hinge retainer clip 3	Titanium (generic)	.0014	0	0
Tempest-D	Hinge retainer clip 4	Titanium (generic)	.0025	0	0
Tempest-D	RHS structural standoff	Titanium (generic)	.397	0	157
Tempest-D	Motor mount structural standof	Titanium (generic)	.339	0	275

The majority of stainless steel components demise upon reentry. And all CubeSats comply 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
CaNop	Compliant	1:145200
CubeRRT	Compliant	1:0
EQUISat	Compliant	1:0
MemSat	Compliant	1:0
RadSat	Compliant	1:0
RainCube	Compliant	1:0
SORTIE	Compliant	1:136600
Tempest-D	Compliant	1:60600

*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 CubeSats that have surviving components like CubeRRT, EQUISat, and RainCube have a 1:0 probability as none of their components have more than 15J of energy. TEMPEST-D has 2 components with greater than 15J of energy but the CubeSat's probability of risk of human casualty still exceeds the NASA requirement on an order of magnitude. This issue is the same in the case of SORTIE, and CaNop.

All CubeSats launching under the ELaNa-23 mission are shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

ELaNa-23 CubeSats will not be deploying any tethers.

ELaNa-23 CubeSats satisfy 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-G2/Mr. Treptow
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A.	ELaNa-23 Component List by CubeSat: CaNOP
Appendix B.	ELaNa-23 Component List by CubeSat: CubeRRT
Appendix C.	ELaNa-23 Component List by CubeSat: EQUISat
Appendix D.	ELaNa-23 Component List by CubeSat: MemSat
Appendix E.	ELaNa-23 Component List by CubeSat: RadSat
Appendix F.	ELaNa-23 Component List by CubeSat: RainCube
Appendix G.	
Appendix H.	ELaNa-23 Component List by CubeSat: SORTIE
Appendix I.	ELaNa-23 Component List by CubeSat: Tempest-D

Appendix A. ELaNa-23 Component List by CubeSat: CaNOP

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
CaNOP	1	CaNOP CubeSat 3U	1	Al 6082	Box	100	340	100	100	No	-	Demise
CaNOP	2	CubeSat Structure	1	Al 6082-T6	Hollow Box	100	340	100	100	No	-	Demise
CaNOP	3	3U Solar Panel	2	PCB	Panel	100	340	1.6	100	No	-	Demise
CaNOP	4	2U Solar Panel	1	PCB	Panel	100	200	1.6	100	No	-	Demise
CaNOP	5	S-Band Antenna	1	Aluminum 6061	Cylinder	76	76	4.1	76	No	-	Demise
CaNOP	6	GPS antenna	1	N/D	Box	20	20	4	20	No	-	Demise
CaNOP	7	Seperation Switches	2	N/D	N/D	N/D	N/D	N/D	N/D	No	-	Demise
CaNOP	8	Sun Sensors	4	N/D	N/D	N/D	N/D	N/D	N/D	No	-	Demise
CaNOP	9	Temperature Sensors	4	N/D	N/D	N/D	N/D	N/D	N/D	No	-	Demise
CaNOP	10	30 Whr Batteries	1	PCB, lithium ion polymer	Box	90.17	95.89	22.55	90.17	No	-	Demise
CaNOP	11	Camera	1	PCB	Box	46	46	38	46	No	-	Demise
CaNOP	12	GPS Receiver	1	PCB	Board	90	96	18.1	90	No	-	Demise
CaNOP	13	ADCS Momentum Wheel rotors	3	Tungsten Nickel alloy MT-17C	Box	33.02	33.02	38.35	33.02	Yes	6191 °	0 km
CaNOP	14	EPS board	1	PCB	Board	90.17	95.89	11.39	90.17	No	-	Demise
CaNOP	15	SDR Board	1	PCB	Board	90	96	8.6	90	No	-	Demise
CaNOP	16	Q7	1	PCB	Board	70	70	10	70	No	-	Demise
CaNOP	17	EP12	1	PCB	Board	90	96	20	90	No	-	Demise
CaNOP	18	OBC	1	PCB	Board	90.17	95.89	1.6	90.17	No	-	Demise
CaNOP	19	ADCS Board	1	PCB	Board	87	88	14	87	No	-	Demise
CaNOP	20	ADCS IREHS blocks	2	Al 6061-T651	Box	31.75	43.25	20.65	31.75	No	-	Demise
CaNOP	21	SDR Controller	1	PCB	Board	40	65	6.5	40	No	-	Demise
CaNOP	22	ADCS Magnetic torquers	3	Ferous alloy	Cylindrical	14.7	67.05	11.43	14.7	Yes	2800 °	0 km
CaNOP	23	SDR Transceiver	1	FR4	Board	16.4	40	65	6.5	No	-	Demise

CaNOP	24	ADCS Magnetometer	1	G10 (50%), 6061-t6 (50%)	Board	3.2	25.4	25.4	15.5	No	-	Demise
CaNOP	25	ADCS Shell	2	6061-T6	Hollow box	N/D	.97	97	51.64	No	-	Demise
CaNOP	26	Integration boards	1	G10	Board	N/D	90	96	N/D	No	-	Demise
CaNOP	27	Cabling	1	6061-t6(40%), Other (60%)	Wire	N/D	N/D	N/D	N/D	No	-	Demise
CaNOP	28	Antenna cables	1	6061-T6	Wire	N/D	N/D	N/D	N/D	No	-	Demise
CaNOP	29	Payload mount	1	Other	Hollow box	N/D	N/D	N/D	N/D	No	-	Demise
CaNOP	30	ADCS Base	1	6061-T6	Box	N/D	94.23	94.23	8.26	No	-	Demise

Appendix B. ELaNa-23 Component List by CubeSat: CubeRRT

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
CubeRRT	1	Chassis	1	Aluminum	Box	2164.9	100.0	226.3	365.0	No	-	Demise
CubeRRT	2	Side Panel	1	Aluminum	Box	598.4	8.5	226.3	287.5	No	-	Demise
CubeRRT	3	Rail, PSC, -1	1	Aluminum	Box	75.1	11.9	15.9	366.0	No	-	Demise
CubeRRT	4	Rail, PSC, -2	1	Aluminum	Box	6.6	11.9	15.9	33.5	No	-	Demise
CubeRRT	5	Rail, PSC, -3	1	Aluminum	Box	50.6	11.9	15.9	246.6	No	2642°	Demise
CubeRRT	6	Panel, Access	1	Aluminum	Box	26.2	1.3	70.0	111.3	No	1175°	Demise
CubeRRT	7	Mechanism, Release, Linear	2	Various	Box	103.4	6.1	33.0	187.6	No	-	Demise
CubeRRT	8	XB1, Avionics	1	Various	Box	2396.4	100.0	106.7	183.7	No	2370°	Demise
CubeRRT	9	Antenna, Globalstar	1	Various	Box	57.5	57.4	11.7	---	No	-	Demise
CubeRRT	10	Solar Array, Horizontal	1	Various	Box	581.9	17.3	354.7	594.8	No	-	Demise
CubeRRT	11	Solar Array, Canted	1	Various	Box	581.9	17.3	354.7	594.8	No	-	Demise
CubeRRT	12	CSS, Bathtub	2	Aluminum	Box	5.1	9.5	13.7	69.6	No	-	Demise
CubeRRT	13	CSS, +X & -X	2	Various	rectangular prism	8.5	7.6	10.2	53.0	No	-	Demise
CubeRRT	14	CSS, Bathtub	1	Aluminum	rectangular prism	3.5	9.5	17.8	53.1	No	-	Demise
CubeRRT	15	CSS, -Z	1	Various	cylinder	8.9	7.6	10.2	53.0	No	-	Demise
CubeRRT	16	Hinge, Retainer Clip, -1	4	Titanium	cylinder	2.0	5.7	10.0	27.9	Yes	3034 °	0 km
CubeRRT	17	Hinge, Retainer Clip, -2	2	Titanium	rectangular prism	1.5	5.7	9.6	27.9	Yes	3034 °	0 km
CubeRRT	18	Hinge, Retainer Clip, -3	1	Titanium	rectangular prism	1.4	5.7	9.4	27.9	Yes	3034 °	0 km
CubeRRT	19	Hinge, Retainer Clip, -4	1	Titanium	cube	2.5	9.4	22.2	23.1	Yes	3034 °	0 km

CubeRRT	20	UHF Monopole Antenna	1	Various	rectangular prism	10.6	27.9	31.7	151.0	No	-	Demise
CubeRRT	21	Harnessing	1	Various	Box	89.5	100.0	226.3	365.0	No	-	Demise
CubeRRT	22	RDB MAIN PCB Assy	1	Various	Box	2679.1	125.5	245.0	238.0	No	-	Demise
CubeRRT	23	RDB POWER PCB Assy	1	Various	Box	102.0	23.5	137.0	100.0	No	-	Demise
CubeRRT	24	RFE LO/IF Assembly	1	Various	Box	68.0	15.6	127.0	100.0	No	-	Demise
CubeRRT	25	RFE LO/IF Chassis	1	Aluminum	Box	1245.0	1.5	112.3	197.4	No	-	Demise
CubeRRT	26	RFE LO/IF Control-Side Lid	1	Aluminum	Box	444.0	33.0	112.3	197.4	No	-	Demise
CubeRRT	27	RFE LO/IF RF-Side Lid	1	Aluminum	Box	199.6	4.4	112.3	197.4	No	-	Demise
CubeRRT	28	RFE LO/IF Control Board PCB Assy	1	Various	Box	303.9	12.9	112.3	197.4	No	-	Demise
CubeRRT	29	RFE LO/IF RF Board PCB Assy	1	Various	Box	149.0	9.9	101.6	163.8	No	-	Demise
CubeRRT	30	RFE MWA Assembly	1	Various	Box	149.0	9.9	101.9	150.1	No	-	Demise
CubeRRT	31	MWA Base	1	Aluminum	Box	584.6	39.4	73.7	88.9	No	-	Demise
CubeRRT	32	MWA Walls	1	Aluminum	Box	104.0	17.6	63.5	88.9	No	-	Demise
CubeRRT	33	MWA Top Lid	1	Aluminum	Box	73.0	7.0	63.5	88.9	No	-	Demise
CubeRRT	34	MWA Bottom Lid	1	Aluminum	Box	104.0	11.1	63.5	88.9	No	-	Demise
CubeRRT	35	MWA Choke	2	Aluminum	Box	73.0	7.6	63.5	88.9	No	-	Demise
CubeRRT	36	MWA RF Board PCB	1	PTFE	Box	104.0	1.3	25.6	35.0	No	-	Demise
CubeRRT	37	MWA Control Board Assy	1	Polymide	Box	109.0	0.1	63.5	88.9	No	-	Demise
CubeRRT	38	Hybrid Coupler	1	Various	Box	2.9	1.6	63.5	88.9	No	-	Demise
CubeRRT	39	Mixer	2	Various	Box	1.8	15.2	33.0	43.2	No	-	Demise
CubeRRT	40	RFE Coaxial RF Cables	3	PTFE	---	100.0	7.4	13.2	14.2	No	-	Demise
CubeRRT	41	Antenna to MWA, RF Harness	1	PTFE	---	67.0	---	---	---	No	-	Demise
CubeRRT	42	MWA to Hybrid Couper, RF Harnesses	2	PTFE	---	10.0	---	---	---	No	-	Demise
CubeRRT	43	Hybrid Coupler to Mixer, RF Harness	2	PTFE	---	254.0	---	---	---	No	-	Demise
CubeRRT	44	LO to Mixer LO Port, RF Harness	2	PTFE	---	18.0	---	---	---	No	-	Demise
CubeRRT	45	Mixer to LO/IF IF Input, RF Harness	1	PTFE	---	25.0	---	---	---	No	-	Demise

CubeRRT	46	RFE Output to RDB Input, RF Harnesses	1	PTFE	---	15.0	---	---	---	No	-	Demise
CubeRRT	47	RFE Test Port, RF Harneses	1	PTFE	---	25.0	---	---	---	No	-	Demise
CubeRRT	48	RFE Electrical Harnesses	1	Various	---	25.0	---	---	---	No	-	Demise
CubeRRT	49	Payload Power Harness (25S, 15S, 15S)	1	Various	---	20.0	---	---	---	No	-	Demise
CubeRRT	50	Payload Command/Telemetry Harness (9S, 25P, 25P)	1	Various	---	25.0	---	---	---	No	-	Demise
CubeRRT	51	LO/IF to MWA Harness (21P, 21P)	1	Various	---	425.0	---	---	---	No	-	Demise
CubeRRT	52	Instrument, ECCOSORB Foam, -1	1	Silicone Rubber	Flat Plate	175.0	---	---	---	No	-	Demise
CubeRRT	53	Instrument, ECCOSORB Foam, -2	1	Silicone Rubber	Flat Plate	150.0	---	---	---	No	-	Demise
CubeRRT	54	Instrument, ECCOSORB Foam, -3	1	Silicone Rubber	Flat Plate	100.0	---	---	---	No	-	Demise
CubeRRT	55	Screw, #6-32, 0.50L	10	Steel	Cylinder	65.0	5.7	16.2	---	Yes	2750 °	76.5 km
CubeRRT	56	Screw, #6-32, 0.75L	4	Steel	Cylinder	115.0	5.7	22.6	---	Yes	2750 °	76.5 km
CubeRRT	57	Washer, #6, 0.016 THK	14	Steel	Cylinder	75.0	6.8	0.4	---	Yes	2750 °	76.5 km
CubeRRT	58	Screw, #4-40, 0.375L	2	Steel	Cylinder	1.6	4.7	12.4	---	Yes	2750 °	76.5 km
CubeRRT	59	Screw, #4-40, 0.50L	35	Steel	Cylinder	2.1	4.7	15.5	---	Yes	2750 °	76.5 km
CubeRRT	60	Washer, #4, 0.016 THK	37	Steel	Cylinder	0.1	5.3	0.4	---	Yes	2750 ° °	76.5 km
CubeRRT	61	Screw, #4-40, FLTHD, 0.313L	14	Steel	Cylinder	0.8	5.4	7.9	---	Yes	2750 °	76.5 km
CubeRRT	62	Screw, #4-40, FLTHD, 0.438L	15	Steel	Cylinder	1.0	5.4	11.1	---	Yes	2750 °	76.5 km
CubeRRT	63	Screw, #4-40, FLTHD, 0.313L	2	Steel	Cylinder	0.1	5.4	7.9	---	Yes	2750 °	76.5 km
CubeRRT	64	Screw, #4-40, FLTHD, 0.438L	2	Steel	Cylinder	0.4	5.4	11.1	---	Yes	2750 °	76.5 km
CubeRRT	65	Screw, #4-40, FLTHD, 0.313L	10	Steel	Cylinder	0.6	5.4	7.9	---	Yes	2750 °	76.5 km
CubeRRT	66	Screw, #4-40, FLTHD, 0.438L	10	Steel	Cylinder	0.4	5.4	11.1	---	Yes	2750 °	76.5 km
CubeRRT	67	Screw, #2-56, FLTHD, 0.188L	16	Steel	Cylinder	0.6	4.1	4.8	---	Yes	2750 °	76.5 km
CubeRRT	68	Screw, #2-56, FLTHD, 0.25L	6	Steel	Cylinder	0.4	4.1	6.4	---	Yes	2750 °	76.5 km

CubeRRT	69	Screw, #2-56, FLTHD, 0.313L	2	Steel	Cylinder	0.6	4.1	7.9	---	Yes	2750 °	76.5 km
CubeRRT	70	Screw, #2-56, FLTHD, 0.188L	2	Steel	Cylinder	0.2	4.1	4.8	---	Yes	2750 °	76.5 km
CubeRRT	71	Screw, #2-56, FLTHD, 0.313L	6	Steel	Cylinder	0.2	4.1	7.9	---	Yes	2750 °	76.5 km
CubeRRT	72	Screw, #8-32, SHCS, 0.5L	4	Steel	Cylinder	0.3	6.9	16.9	---	Yes	2750 °	76.5 km
CubeRRT	73	Washer, #8, 0.016 THK	4	Steel	Cylinder	0.2	7.7	0.4	---	Yes	2750 °	76.5 km
CubeRRT	74	Screw, #2-56, SHCS, 0.5L	4	Steel	Cylinder	0.3	3.6	14.9	---	Yes	2750 °	76.5 km
CubeRRT	75	Washer, #2, 0.016 THK	4	Steel	Cylinder	2.4	3.8	0.4	---	Yes	2750 °	76.5 km
CubeRRT	76	Screw, #2-56, FLTHD, 0.188L	2	Steel	Cylinder	0.1	4.1	4.8	---	Yes	2750 °	76.5 km
CubeRRT	77	Screw, #2-56, FLTHD, 0.313L	2	Steel	Cylinder	0.5	4.1	7.9	---	Yes	2750 °	76.5 km
CubeRRT	78	Screw, #2-56, FLTHD, 0.188L	2	Steel	Cylinder	0.0	4.1	4.8	---	Yes	2750 °	76.5 km
CubeRRT	79	Screw, #2-56, FLTHD, 0.313L	2	Steel	Cylinder	0.2	4.1	7.9	---	Yes	2750 °	76.5 km
CubeRRT	80	Screw, #2-56, FLTHD, 0.375L	2	Steel	Cylinder	0.3	4.1	9.5	---	Yes	2750 °	76.5 km

Appendix C. ELaNa-23 Component List by CubeSat: EQUISat

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
EQUISat	1	CubeSat Chassis	1	Aluminum 6061	Box	212	100	100	113.5	-	-	-
EQUISat	2	Radio	1	Misc	Box	40	46.6	69.8	11.2	No	-	Demise
EQUISat	3	Antenna	1	Nitinol	Thin Rods	1.54	0.635	202	N/A	No	-	Demise
EQUISat	4	Antenna Connector	1	Aluminum	Hexagonal Prism	4.44	8	9.24	16.7	No	-	Demise

EQUISat	5	Antenna Posts	3	Aluminum	Concentric Cylinders	4.8	9.53	N/A	16.37	No	-	Demise
EQUISat	6	Battery (LiFePO4)	4	Li-Iron-Phosphate	Cylinder	196	18.2	N/A	64.95	No	-	Demise
EQUISat	7	Battery (Li-ion)	2	Lithium	Cylinder	90	18	N/A	64.8	No	-	Demise
EQUISat	8	Solar Trisol cell (.190g each)	128	Galium Arsenide	Right Triangle	22.4	10	26.3	0.16	No	-	Demise
EQUISat	9	Battery Block	2	Delrin	Rectangle with cutouts	115	80	60	15	No	-	Demise
EQUISat	10	Attachment Plate	1	Aluminum 6061	Rectangle	16.73	77.47	83.2	0.48	No	-	Demise
EQUISat	11	Solar PCB (top/bottom)	2	FR-4 Fiberglass/Copper/Tin	Rectangle without corners	83.16	99.5	99.5	1.46	No	-	Demise
EQUISat	12	Solar PCB (sides)	3	FR-4 Fiberglass/Copper/Tin	Rectangle	102.81	82.5	99.5	1.6	No	-	Demise
EQUISat	13	LED Top PCB (Flash Panel)	1	FR-4 Fiberglass/Copper/Tin	Rectangle	17	82.5	99.5	1.6	No	-	Demise
EQUISat	14	Battery Board PCB	1	FR-4 Fiberglass/Copper/Tin	Rectangle	40	76.2	76.2	1.46	No	-	Demise
EQUISat	15	Control Board PCB	1	FR-4 Fiberglass/Copper/Tin	Rectangle	40	76.2	76.2	1.46	No		Demise
EQUISat	16	Driver Board PCB	1	FR-4 Fiberglass/Copper/Tin	Rectangle	80	76.2	76.2	1.46	No	-	Demise
EQUISat	17	Radio Adapter Board PCB	1	FR-4 Fiberglass/Copper/Tin	Rectangle	40	76.2	76.2	1.46	No	-	Demise
EQUISat	18	CHM-27 LED	4	N/A	Rectangle	8	31.5	31.5	1.37	No	-	Demise
EQUISat	19	Magnet (perp to flash)	1	Samarium Cobalt	Rectangle	17.89	5	10	5	No	-	Demise
EQUISat	20	Hysteresis rods	2	Iron	Cylinder	1.16	1	N/A	16	Yes	2800°	0 km
EQUISat	21	IR sensor	6	N/A	Cylinder	5.508	9.8	N/A	4.1	No	-	Demise
EQUISat	22	Cable	N/A	Copper and Teflon FEP	Cable	48	0.4	N/A	9144	No	-	Demise
EQUISat	23	Cable	N/A	Copper and Teflon FEP	Cable	79	1.63	N/A	3048	No	-	Demise
EQUISat	24	cylindrical spacers	4	Aluminum 2011	Cylinder	1.68	6.35	N/A	6.35	No	-	Demise

EQUISat	25	4-40 screws 3/8"	16	Stainless Steel 18-8	Screw	9	100	100	113.5	Yes	2750°	0 km
EQUISat	26	4-40 nuts	31	Stainless Steel 18-8	Nut	15	8	26.3	0.16	Yes	2750°	78 km
EQUISat	27	4-40 studs (0.6)	2	Stainless Steel 18-8	Stud	1	1.0	Est. 330-380	-	Yes	2750°	0 km
EQUISat	28	4-40 studs (1.0)	5	Stainless Steel 18-8	Stud	4	N/A	N/A	0.01	Yes	2750°	0 km
EQUISat	29	Machine Screw Slotted round head 2-56 0.1875"	8	Stainless Steel 18-8	Screw	4	7.5	3	-	Yes	2750°	78 km
EQUISat	30	Machine Screw Slotted round head 2-56 1.75"	4	Stainless Steel 18-8	Screw	4	2	Varies (4, 8)	-	Yes	2750°	0 km
EQUISat	31	2-56 nuts	8	Stainless Steel 18-8	Nut	5	3	95.4	-	Yes	2750°	78 km
EQUISat	32	4-40 screws 1/2"	8	Stainless Steel 18-8	Screw	6	3	93.4	-	Yes	2750°	0 km
EQUISat	33	4-40 screw 1/4	4	Stainless Steel 18-8	Screw	2	5.5	2.4	-	Yes	2750°	0 km
EQUISat	34	10 Pin J-Tek (surface mount)	8	PPS/ Copper/ Gold / Tin	Connector	13.85	4.5	1.6	-	No	-	Demise
EQUISat	35	20 Pin J-Tek	2		Connector	4.934	5.55	30	7.55	No	-	Demise
EQUISat	36	10 Pin Archer	27	Polyamide (Nylon) 6T/ Copper / Tin / Gold / Brass	Connector	3.294	8	30	5.55	No	-	Demise
EQUISat	37	6 pin Mix-Tex	8		Connector	7.312	5.5	6.35	4.68	No	-	Demise
EQUISat	38	36 pin J-Tex	2		Connector	6.176	8	16	6	No	-	Demise
EQUISat	39	30 Pin AVX	1		Connector	0.212	7.7	37	6.05	No	-	Demise
EQUISat	40	USB-C	1		Connector	0.75	5.5	13	2.5	No	-	Demise
EQUISat	41	CubeSat Chassis	1	Aluminum 6061	Box	212	9.2	10.5	3.28	No	-	Demise
EQUISat	42	Radio	1	Misc	Box	40	5.55	30	7.55	No	-	Demise

Appendix D. ELaNa-23 Component List by CubeSat: MemSat

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
MemSat	1	CubeSat Structure	1	Aluminum 6061	Hollow box	87.2	100	113.5	100	No	-	Demise
MemSat	2	Antennae	2	Steel 410	Flat Plate	66	1.6	170	6	Yes	2750°	0 km
MemSat	3	Antennae Sub-chassis	1	polymeric material	Box	12	82.6	98	6.5	No	-	Demise
MemSat	4	Separation springs	4	Stainless Steel	Cylinder	31.1064	1.78	11.1	N/A	Yes	2750°	77.8 km
MemSat	5	Nd2Fe14B (Magnets)	4	neodymium	Cy;inder	3.505	5	2.5	N/A	No	1870°	78.0 km
MemSat	6	Payload Board (4 Experiment Chips/PCB)	6	Silicon	Flat Plate	160.284	95	95	1.6	No	-	Demise
MemSat	7	Payload Board (Controller and secondary sensors)	1	FR-4, copper	Flat Plate	26.714	95	95	1.6	No	-	Demise
MemSat	8	Comm Board	1	FR-4, copper	Flat Plate	26.714	95	95	1.6	No	-	Demise
MemSat	9	C&DH Board	1	FR-4, copper	Flat Plate	26.714	95	95	1.6	No	-	Demise
MemSat	10	Cabling	72	Copper alloy	Cylinder	42.048	26 gauge	N/A	N/A	No	-	Demise
MemSat	11	Batteries - ICR18650	2	Lithium, metal casing	Cylinder	48	18.4	65	18.4	No	-	Demise
MemSat	12	Solar Panels - Ultra Triple Junction Solar Cells	12	GaInP2, GaAs, Ge	Flat Plate	26.832	2662 (mm^2)	N/A	0.6	No	-	Demise
MemSat	13	Ceramic Multilayer Capacitors	30	X7R Dielectric, metal leads	Cylinder	0.18	2	1.27	1.5	No	-	Demise
MemSat	14	LTC3245 Voltage Regulator	5	Plastic casing, silicon	Cylinder	0.25	3	3	N/A	No	-	Demise
MemSat	15	Schottky Rectifiers (MBRS360)	3	Si	Cylinder	0.84	7.15	2.25	2.45	No	-	Demise
MemSat	16	LTC3105 MPPT IC	12	Plastic casing, silicon	Box	0.6	3	3	1.6	No	-	Demise
MemSat	17	LTC4071 Battery Charger IC	1	Plastic casing, silicon	Box	0.05	2	3	N/A	No	-	Demise
MemSat	18	Thin-Film Resistors	30	Aluminum Nitride	Flat Plate	1.5	2	3	N/A	No	-	Demise
MemSat	19	Power Supply Board	1	FR-4, copper	Flat Plate	26.714	95	95	1.6	No	-	Demise

Appendix E. Elana-23 Component List by CubeSat: RadSat

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
RadSat	1	RadSat-g	1	CubeSat	Box	4000	100	100	340.5	No	-	Demise
RadSat	2	CubeSat Structure	1	5052-H32/7075-T6 Aluminum	Box	570.9	100	100	340.5	No	-	Demise
RadSat	3	Antennae	1	Spring Steel 410	Flat Plate	8	10	100	<1	Yes	2750°	0 km
RadSat	4	Solar Panels	4	FR4 PCB Fiberglass	Flat Plate	23.5	85	260	1.5	No	-	Demise
RadSat	5	Sep Switches	2	Steel and Delrin	Flat Plate	10	6.35	19.84	12.27	No	-	Demise
RadSat	6	Batteries	4	LiCoO2/Graphite/Steel/FR4 PCB/Copper	Cylinder	190	70	72	20	No	-	Demise
RadSat	7	ADCS Magnets	1	Nickel-plated Neodymium Grade N52	Cylinder	5.09	9.52	N/A	9.52	Yes	1870°	77.8 km
RadSat	8	Payload Boards	4	FR4 PCB Fiberglass	Flat Plate	38	95	95	1.5	No	-	Demise
RadSat	9	Comm Board	1	FR4 PCB Fiberglass	Flat Plate	78	95	95	1.5	No	-	Demise
RadSat	10	EPS Board	1	FR4 PCB Fiberglass	Flat Plate	158	95	95	1.5	No	-	Demise
RadSat	11	C&DH Board	1	FR4 PCB Fiberglass	Flat Plate	92	95	95	1.5	No	-	Demise
RadSat	12	MFIB Board	1	FR4 PCB Fiberglass	Flat Plate	69	95	95	1.5	No	-	Demise
RadSat	13	Fasteners	50	CRES/SS/Nylon	Cylinder	0.25	5.6	5	5	No	-	Demise
RadSat	14	Cabling	~5ft	22/24 AWG Copper	Cylinder	0.882/ft	1.25	1524	N/A	No	-	Demise
RadSat	15	Standoffs	28	5052-H32 Aluminum	Cylinder	2.24	5.6	20	N/A	No	-	Demise

Appendix F. Elana-23 Component List by CubeSat: RainCube

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
RainCube	1	RainCube	1	Aluminum 7075	Box	154	100	341.8	100	No	-	Demise
RainCube	2	CubeSat Structure (PSC 6U)	1	Aluminum 7075-T7	Box	2209	116	366	239	No	-	Demise
RainCube	3	Ka-Band Antenna	1	6061-T6 Gold Plated Molybdenum Mesh	Parabolic Dish	1100	150	---	93	Yes	2750°	0 km
RainCube	4	Solar Panels	2	FR4	Flat Plate	196	180	300	3	No	-	Demise
RainCube	5	S-Band Patch Antenna	1	Ceramic	Flat Plate	20	67	67	5.5	No	-	Demise
RainCube	6	UHF Deployment Housing	1	Delrin	Rectangle Box	10	6.5	80	50	No	-	Demise
RainCube	7	UHF Antenna Elements	2	BeCu / TH02	Tape Spring	3	0.1	175	3	No	-	Demise
RainCube	8	UHF Antenna Bobbins	2	Accura SL 5530 / Thermal Post Cure	Round Bobbin	1	4	20	20	No	-	Demise
RainCube	9	Sep Switches (PT5M3B-01)	3	SUS304	Round, Threaded	3	3.5	3.5	10	No	-	Demise
RainCube	10	Batteries	12	Li-Ion, StainlessSteel	Cylindrical	50	18.4	--	60.5	No	-	Demise
RainCube	11	Ka-Band Antenna Motor	1	Stainless Steel	Cylindrical	32	12	---	30	No	-	Demise
RainCube	12	Ka-Band Antenna Motor Controller	1	FR4	Flat Plate	74	16	30	2	No	-	Demise
RainCube	13	Radar Power Distribution Unit	1	FR4	Box	186	66.0	200.9	11.4	No	-	Demise
RainCube	14	Radar Pulse Power Supply	1	Polyimide (Arlon 85N)	Box	150	76.2	72.0	16.3	No	-	Demise
RainCube	15	Radar Digital Electronics Board	1	Polyimide (Arlon 85N)	Box	188	60.0	177.2	1.8	No	-	Demise
RainCube	16	Radar Medium Power Amplifier	1	6061-T6	Box	880	67.6	67.6	67.6	No	-	Demise
RainCube	17	Radar Up-Converter Pre-Amplifier Assembly	1	6061-T6	Box	57	29.7	29.7	29.7	No	-	Demise
RainCube	18	Radar Down Converter Assembly	1	6061-T6	Box	125	40.6	66.0	25.8	No	-	Demise

RainCube	19	Radar Dielectric Resonator Oscillator	1	6061-T6	Box	141	23.4	57.2	17.0	No	-	Demise
RainCube	20	Radar Front End Switch Assembly	1	6061-T6	Box	189	50.8	38.1	20.3	No	-	Demise
RainCube	21	Radar Front End Switch Assembly Driver	1	6061-T6	Box	125	73.7	78.7	20.3	No	-	Demise
RainCube	22	Reaction Wheels (Fly Wheels)	3	Bronze C1800	Cylinder	38.7	41	---	8	No	-	Demise
RainCube	23	Reaction Wheels (Housing)	3	Aluminum 7075-T7	Box	22	44	44	13	No	-	Demise
RainCube	24	Torque Coils (Housing)	3	Copper	Box	31	46	63	4	No	-	Demise
RainCube	25	Star Trackers (Housing)	2	Aluminum 7075-T7	Box	26	38	33	22	No	-	Demise
RainCube	26	Torque Coils (Winding)	3	Delrin	Box	7	46	63	4	No	-	Demise
RainCube	27	Star Trackers (Lens)	2	Glass	Cylinder	10	16	---	4	No	-	Demise
RainCube	28	Star Trackers (PCB)	2	FR4	Box	5	1.5	38	38	No	-	Demise
RainCube	29	Ka-Band Antenna Canister	1	6061-T6	Cylinder	365	97	---	97	No	-	Demise
RainCube	30	Radar Interface Plate	1	6061-T6	Box	866	180	13	97	No	-	Demise
RainCube	31	Radar Waveguides	2	6061-T6	Cylinder	18	26.162	26.162	26.162	No	-	Demise
RainCube	32	Radar Electronics Chassis	1	6061-T6	Box	432	30	180	65	No	-	Demise
RainCube	33	Payload Interface Board	2	FR4	Box	120	1.5	100	40	No	-	Demise
RainCube	34	UHF Radio	1	FR4	Box	20	35	73	7	No	-	Demise
RainCube	35	S-Band Radio	1	FR4	Box	36	31.75	86.36	7.62	No	-	Demise
RainCube	36	Battery Board	2	FR4	Box	8	38.2	83.75	1.58	No	-	Demise
RainCube	37	C&DH Board	1	FR4	Box	120	1.9	82	80	No	-	Demise
RainCube	38	Fasteners	200	316 Stainless	Cylinder	0.5	4.64	---	6.35	Yes	2750°	76.5 km
RainCube	39	Wired Harnessing	20	Copper	Cylinder	10	2	40	---	No	-	Demise
RainCube	40	Flat-Flex Connectors	4	Copper	Box	20	5	20	2	No	-	Demise

Appendix G. ELaNa-23 Component List by CubeSat: SORTIE

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
SORTIE	1	SORTIE	-	-	-	-	-	-	-	-	-	-
SORTIE	2	CubeSat Structure	1	Aluminum 6061	Box	3000	239.19	365	115.37	No	-	Demise
SORTIE	3	Antennae	1	Steel 410/DELRIN 150	Box	150	38.6	67.95	43.18	Yes	2750°	0 km
SORTIE	4	Solar Panels	3	Aluminum 6061	Cylinder	500	7.26	309.88	200	No	-	Demise
SORTIE	5	Sep Springs	4	Steel	Hinge	N/A	N/A	N/A	N/A	No	-	Demise
SORTIE	6	Sep Switches	2	aluminum : steel	Tape	1.95	6.25	22.565	24.546	Yes	2750°	0 km
SORTIE	7	Payload mIVM	1	Copper Alloy ;Aluminum 6061: FR-4	Board	800	97.23	94.183	63.42	No	-	Demise
SORTIE	8	Payload uPLP	1	Copper Alloy ;Aluminum 6061: FR-4	Box	300	82.55	100	2.68	No	-	Demise
SORTIE	9	Batteries	3	Lithium-Ion	Board	1410	41.22	76.38	64.27	No	-	Demise
SORTIE	10	ADCS Components	1	PCB FR-4 ; FR-4 PCB ;	Cylinder	825	100	100	50	No	-	Demise
SORTIE	11	Comm Board	1	PCB FR-4 ;Aluminum 6061	Square Coil	350	82.5	82.5	17	No	-	Demise
SORTIE	12	Battery Board	1	PCB FR-4	Board	400	91.1	97.7	25.7	No	-	Demise
SORTIE	13	C&DH Board	1	PCB FR-4	Board	200	96	90	20	No	-	Demise
SORTIE	14	Fasteners	53	Steel	Board	0.62	6.16	8.92	6.16	Yes	2750°	77.2 km
SORTIE	15	Cabling	---	Teflon insulated Copper alloy	Board	3000	239.19	365	115.37	No	-	Demise

Appendix H. ELaNa-23 Component List by CubeSat: Tempest-D

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
Tempest-D	1	Chassis	1	Aluminum 6061	Box	2164.9	100.0	226.3	365.0	No	-	Demise
Tempest-D	2	Side Panel	1	Aluminum 6061	Box	598.4	8.5	226.3	287.5	No	-	Demise
Tempest-D	3	Rail, PSC, -1	1	Aluminum 7075	Box	75.1	11.9	15.9	366.0	No	-	Demise
Tempest-D	4	Rail, PSC, -2	1	Aluminum 7075	Box	6.6	11.9	15.9	33.5	No	-	Demise
Tempest-D	5	Rail, PSC, -3	1	Aluminum 7075	Box	50.6	11.9	15.9	246.6	No	-	Demise
Tempest-D	6	Panel, Access	1	Aluminum 6061	Box	26.2	1.3	70.0	111.3	No	-	Demise
Tempest-D	7	Mechanism, Release, Linear	2	Various	Box	103.4	6.1	33.0	187.6	No	-	Demise
Tempest-D	8	XB1, Avionics	1	Various	Box	2396.4	100.0	106.7	183.7	No	-	Demise
Tempest-D	9	Antenna, Globalstar	1	Various	Cylinder	57.5	19	4	-	Yes	2642°	Yes
Tempest-D	10	Solar Array, Horizontal	1	Various	Box	581.9	17.3	354.7	594.8	Yes	1205°	Demise
Tempest-D	11	Solar Array, Canted	1	Various	Box	581.9	17.3	354.7	594.8	Yes	1205°	Demise
Tempest-D	12	CSS, Bathtub	2	Aluminum 6061	Box	5.1	9.5	13.7	69.6	No	-	Demise
Tempest-D	13	CSS, +X & -X	2	Various	Box	8.5	7.6	10.2	53.0	No	-	Demise
Tempest-D	14	CSS, Bathtub	1	Aluminum 6061	Box	3.5	9.5	17.8	53.1	No	-	Demise
Tempest-D	15	CSS, -Z	1	Various	Box	8.9	7.6	10.2	53.0	No	-	Demise
Tempest-D	16	Hinge, Retainer Clip, -1	4	Titanium 6AL-4V	Box	2.0	5.7	10.0	27.9	Yes	3034°	0 km
Tempest-D	17	Hinge, Retainer Clip, -2	2	Titanium 6AL-4V	Box	1.5	5.7	9.6	27.9	Yes	3034°	0 km
Tempest-D	18	Hinge, Retainer Clip, -3	1	Titanium 6AL-4V	Box	1.4	5.7	9.4	27.9	Yes	3034°	0 km
Tempest-D	19	Hinge, Retainer Clip, -4	1	Titanium 6AL-4V	Box	2.5	9.4	22.2	23.1	Yes	3034°	0 km
Tempest-D	20	UHF Monopole Antenna	1	Various	Box	10.6	27.9	31.7	151.0	No	-	Demise
Tempest-D	21	Harnessing	1	Various	Box	89.5	100.0	226.3	365.0	No	-	Demise
Tempest-D	22	Instrument	1	Various	Box	4253.4	125.5	245.0	238.0	No	-	Demise
Tempest-D	23	Structure	1	Various	Box	1421.2	---	---	---	No	-	Demise

Tempest-D	24	Bench	1	Aluminum 6061	Box	557.8	9.5	76.7	238.0	No	-	Demise
Tempest-D	25	CAL Target Mount	1	Aluminum 6061	Box	76.7	20.0	74.9	91.4	No	-	Demise
Tempest-D	26	Ecosorb Mount	1	Aluminum 6061	Box	31.9	12.7	65.0	75.6	No	-	Demise
Tempest-D	27	Thermal Standoff	1	Polycarbonate	Box	18.5	6.4	21.3	102.6	No	-	Demise
Tempest-D	28	Structural Standoff, RHS	1	Titanium 6AL-4V	Box	396.9	36.8	89.1	186.4	Yes	3034°	0 km
Tempest-D	29	Structural Standoff, Motor Mount	1	Titanium 6AL-4V	Box	339.4	21.3	52.4	142.7	No	3034°	0 km
Tempest-D	30	Feedhorn Assembly	1	Various	Box	122.1		26.8	38.1	No	-	Demise
Tempest-D	31	Structure	1	Brass	Box	118.2	9.5	76.7	238.0	No	-	Demise
Tempest-D	32	Fasteners	4	Stainless Steel 286	Cylinder	0.6	---	---	---	No	-	Demise
Tempest-D	33	Split Block, Socket head, 2-56, 1/2" length	4	Stainless Steel 286	Cylinder	0.4	3.6	14.9	3.6	No	-	Demise
Tempest-D	34	Face Plate, Socket head, 2-56, 1/4" length	4	Stainless Steel 286	Cylinder	0.1	3.6	8.5	3.6	No	-	Demise
Tempest-D	35	Alignment Pin, 1/16", 5/16" length	2	Stainless Steel 416	Box	48.1	2.2	7.9	2.2	No	-	Demise
Tempest-D	36	Power Tee	1	Brass	Cylinder	40.3	8.9	25.4	27.9	No	-	Demise
Tempest-D	37	Waveguide Bends	1	Brass	Wire	119.4	19.1	27.8	43.8	No	-	Demise
Tempest-D	38	WR5 Front End Assembly	1	Aluminum 6061	Box	87.9	30	5	-	No	-	Demise
Tempest-D	39	WR5 Detector Assembly V1	1	Various	Box	226.3	34	48	5.5	No	-	Demise
Tempest-D	40	WR5 Detector Assembly V2	1	Various	Cylinder	152.2	5	30		No	-	Demise
Tempest-D	41	Power Divider Assembly	1	Various	Box	69.9	3.2	14.25	4.2	No	-	Demise
Tempest-D	42	Filter Assemblies	1	Various	Box	82.7	-	-	-	No	-	Demise
Tempest-D	43	WR10 Front End Assembly	1	Various	Box	163.4	-	-	-	No	-	Demise
Tempest-D	44	WR10 Detector Assembly	1	Various	Box	629.3	-	-	-	No	-	Demise
Tempest-D	45	Calibration Target	1	Various	Box	78.0	-	-	-	No	-	Demise
Tempest-D	47	Reflector Assembly	1	Various	Box	285.3	-	-	-	No	-	Demise
Tempest-D	48	Electronics Enclosure	1	Aluminum 6061	Box	37.5	-	-	-	No	-	Demise
Tempest-D	49	Motor Controller Assembly	1	Various	Box	339.9	-	-	-	No	-	Demise
Tempest-D	50	Motor, Reflector	1	Various	Box	350.0	64.9	62.9	89.3	No	-	Demise

Tempest-D	51	Cabling	1	Copper	-	65.0	-	-	-	No	-	Demise
Tempest-D	52	Instrument, ECCOSORB Foam, -1	1	Silicone Rubber	Flat Plate	115.0	-	-	-	No	-	Demise
Tempest-D	53	Instrument, ECCOSORB Foam, -2	1	Silicone Rubber	Flat Plate	75.0	-	-	-	No	-	Demise
Tempest-D	54	Instrument, ECCOSORB Foam, -3	1	Silicone Rubber	Flat Plate	0.8	-	-	-	No	-	Demise
Tempest-D	55	Screw, #6-32, 0.50L	10	Steel A286	Cylinder	1.0	5.7	16.2	7.916	No	-	Demise
Tempest-D	56	Screw, #6-32, 0.75L	4	Steel A286	Cylinder	0.1	5.7	22.6	7.916	No	-	Demise
Tempest-D	57	Washer, #6, 0.016 THK	14	Steel A286	Cylinder	0.8	6.8	0.4	7.8	No	-	Demise
Tempest-D	58	Screw, #4-40, 0.375L	2	Steel A286	Cylinder	1.0	4.7	12.4	7.916	No	-	Demise
Tempest-D	59	Screw, #4-40, 0.50L	35	Steel A286	Cylinder	0.1	4.7	15.5	7.916	No	-	Demise
Tempest-D	60	Washer, #4, 0.016 THK	37	Steel A286	Cylinder	0.4	5.3	0.4	7.8	No	-	Demise
Tempest-D	61	Screw, #4-40, FLTHD, 0.313L	14	Steel A286	Cylinder	0.6	5.4	7.9	7.916	No	-	Demise
Tempest-D	62	Screw, #4-40, FLTHD, 0.438L	15	Steel A286	Cylinder	0.4	5.4	11.1	7.916	No	-	Demise
Tempest-D	63	Screw, #4-40, FLTHD, 0.313L	2	Steel A286	Cylinder	0.6	5.4	7.9	7.916	No	-	Demise
Tempest-D	64	Screw, #4-40, FLTHD, 0.438L	2	Steel A286	Cylinder	0.4	5.4	11.1	7.916	No	-	Demise
Tempest-D	65	Screw, #4-40, FLTHD, 0.313L	10	Steel A286	Cylinder	0.6	5.4	7.9	7.916	No	-	Demise
Tempest-D	66	Screw, #4-40, FLTHD, 0.438L	10	Steel A286	Cylinder	0.2	5.4	11.1	7.916	No	-	Demise
Tempest-D	67	Screw, #2-56, FLTHD, 0.188L	16	Steel A286	Cylinder	0.2	4.1	4.8	7.916	No	-	Demise
Tempest-D	68	Screw, #2-56, FLTHD, 0.25L	6	Steel A286	Cylinder	0.3	4.1	6.4	7.916	No	-	Demise
Tempest-D	69	Screw, #2-56, FLTHD, 0.313L	2	Steel A286	Cylinder	2.4	4.1	7.9	7.916	No	-	Demise
Tempest-D	70	Screw, #2-56, FLTHD, 0.188L	2	Steel A286	Cylinder	0.2	4.1	4.8	7.916	No	-	Demise
Tempest-D	71	Screw, #2-56, FLTHD, 0.313L	6	Steel A286	Cylinder	0.3	4.1	7.9	7.916	No	-	Demise
Tempest-D	72	Screw, #8-32, SHCS, 0.5L	4	Steel A286	Cylinder	2.4	6.9	16.9	7.916	No	-	Demise
Tempest-D	73	Washer, #8, 0.016 THK	4	Steel A286	Cylinder	0.1	7.7	0.4	7.8	No	-	Demise
Tempest-D	74	Screw, #2-56, SHCS, 0.5L	4	Steel A286	Cylinder	0.5	3.6	14.9	7.916	No	-	Demise

Tempest-D	75	Washer, #2, 0.016 THK	4	Steel A286	Cylinder	0.0	3.8	0.4	7.8	No	-	Demise
Tempest-D	76	Screw, #2-56, FLTHD, 0.188L	2	Steel A286	Cylinder	0.2	4.1	4.8	7.916	No	-	Demise
Tempest-D	77	Screw, #2-56, FLTHD, 0.313L	2	Steel A286	Cylinder	0.3	4.1	7.9	7.916	No	-	Demise
Tempest-D	78	Screw, #2-56, FLTHD, 0.188L	2	Steel A286	Cylinder	0.2	4.1	4.8	7.916	No	-	Demise
Tempest-D	79	Screw, #2-56, FLTHD, 0.313L	2	Steel A286	Cylinder	0.3	4.1	7.9	7.916	No	-	Demise
Tempest-D	80	Screw, #2-56, FLTHD, 0.375L	2	Steel A286	Cylinder	0.3	4.1	9.5	7.916	No	-	Demise