April 10, 2014

# Orbital Debris Assessment for GRIFEX on the SMAP /ELaNa-10 Mission per NASA-STD 8719.14A

**Sensitive But Unclassified (SBU)**

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. SMAP / Delta II 7320-10 Interface Control Document, Orbital Document, ULA-Delta II-ICD-12-014, Baseline August 2013
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. Preliminary Mission Analysis For the Delta II 7320-10 / SMAP Spacecraft Missio, CRDL C4-1, PGAA No.2, ULA-TP-13-245
I. *UL Standard for Safety for Household and Commercial Batteries, UL 2054*. UL Standard. 2$^{nd}$ ed. Northbrook, IL, Underwriters Laboratories, 2005
J. HQ OSMA Policy Memo/Email to 8719.14: CubeSat Battery Non-Passivation, Suzanne Aleman to Justin Treptow, 10, March 2014


The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the GRIFEX CubeSat on the ELaNa-10 auxiliary mission launching in conjunction with the SMAP primary payload. 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 spacecraft and are not presented here.

The following table summarizes the compliance status of the GRIFEX CubeSat as part of the ELaNa-10 auxiliary payload mission flown on SMAP. The four CubeSats, manifested and back-ups, comprising the ELaNa-10 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 | Minimal risk to orbital environment, mitigated by orbital lifetime |
| 4.4-2 | Compliant | Minimal risk to orbital environment, mitigated by orbital lifetime |
| 4.4-3 | Not applicable | No planned breakups |
| 4.4-4 | Not applicable | No planned breakups |
| 4.5-1 | Compliant | |
| 4.5-2 | Not applicable | |
| 4.6-1(a) | Compliant | Worst case lifetime 8.0 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-10 mission |

## Section 1: Program Management and Mission Overview

The ELaNa-10 mission is sponsored by the Space 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:

GRIFEX: James Cutler, Principle Investigator; Tyler Rose, Project Manager

| Program Milestone Schedule | |
|---|---|
| **Task** | **Date** |
| CubeSat Selection | 3/4/13 |
| MRR | 7/9/14 |
| CubeSat Delivery to Cal Poly for Integration into P-PODs | 8/11/14 |
| Pre-Ship Review | 10/1/14 |
| CubeSat Delivery to VAFB/ Integration onto LV | 10/25/14 |
| Launch | 11/5/2014 |

**Figure 1: Program Milestone Schedule**

The ELaNa-10 mission will be launched as an auxiliary payload on the SMAP mission on a Delta II 7320-10 launch vehicle from Vandenberg Air Force Base, California. The ELaNa-10, will deploy 4 pico-satellites (or CubeSats). The CubeSat slotted position is identified in Table 2: . The ELaNa-10 manifest includes: ExoCube, FireBird-2, and GRIFEX. The current launch date is in November 2014. The four CubeSats will be ejected from 3 PPOD carriers attached to the launch vehicle, placing the CubeSats in an orbit approximately 670 X 450 km at inclination of 98 deg (ref. (h)).

## Section 2: Spacecraft Description

GRIFEX is a 3U CubeSat developed by the University of Michigan and NASA JPL manifested to be launched in October 2014 on a Delta-II rocket with the ELaNa 10 mission. GRIFEX houses a 1U imaging system built by JPL, which is designed to raise the technology level of the PanFTS, and imaging FTS designed for a geostationary imaging mission.

**Table 2: GRIFEX Properties**

| PPOD Slot | CubeSat Quantity | CubeSat size | CubeSat Names | CubeSat Masses (kg) |
|---|---|---|---|---|
| 3 | 1 | 3U (10 cm X 10 cm X 30 cm) | GRIFEX | 3.5 |

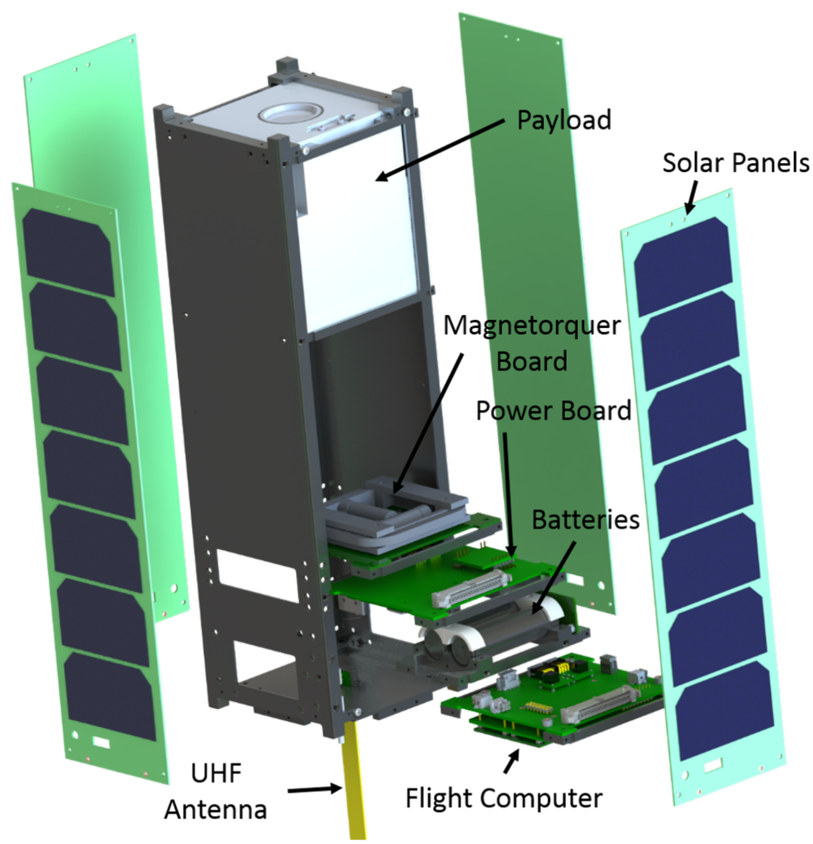


**Figure 2: GRIFEX Expanded View**

CONOPS: Upon P-POD ejection, GRIFEX will begin a countdown timer to delay antenna deployment and UHF beaconing. After 30 minutes have passed, GRIFEX will activate a burn resistor, deploying the UHF antenna. Approximately 45 minutes after P-POD ejection, GRIFEX will begin transmitting beacons via a UHF radio.

Materials: The GRIFEX structure is made of Aluminum 6061. The avionics contain PCBs, commercial off the shelf (COTS) electrical components, sensors, and solar cells.

Hazards: There are no pressure vessels, hazardous or exotic materials, or materials likely to be a re-entry concern.

Batteries: The electrical power storage system consists of Panasonic cylindrical Lithium-Ion cells (Panasonic NCR18650A) with overcharge/current protection circuitry. The cells carry the UL-listing number MH12210.

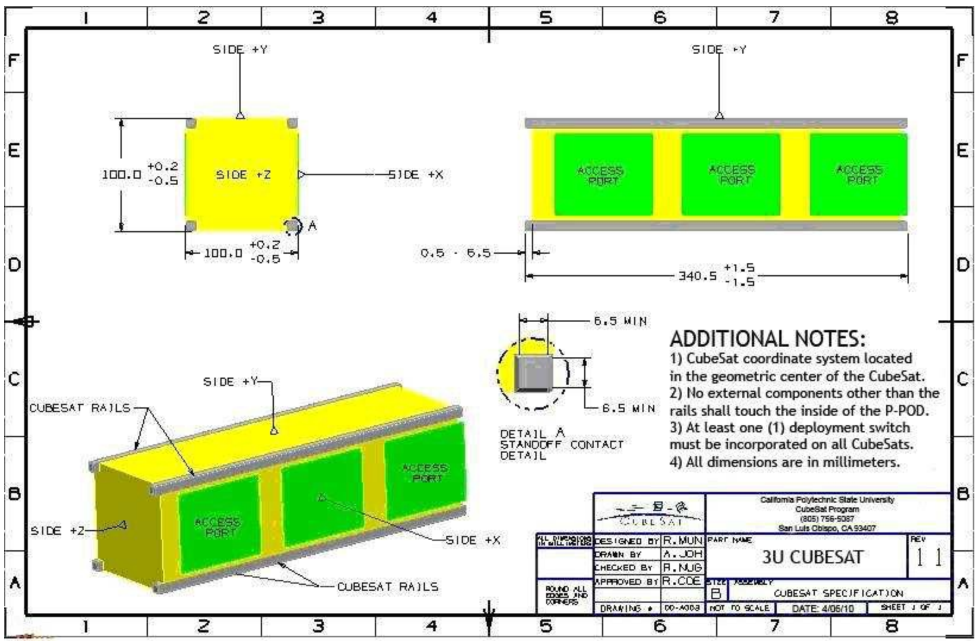


**Figure 3: 3U CubeSat Specification**

## 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-10 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-10 mission. No passivation of components is planned at the End of Mission for the RACE CubeSat.

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 (j)).

GRIFEX's batteries still meet Req. 56450 (4.4-2) by virtue of the HQ OSMA policy statement 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. (j))

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a lifetime of 8.0 years maximum the GRIFEX CubeSat 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.

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

**Equation 1: Mean Cross Sectional Area for Cubic Objects**

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

**Equation 2: Mean Cross Sectional Area for Complex Objects**

GRIFEX was 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. This configuration renders the longest orbital life times for all CubeSats.

Once GRIFEX has been ejected from the P-POD 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 dimensions used in these calculations

The GRIFEX orbit at deployment is 670 km apogee altitude by 450 km perigee altitude, with an inclination of 98 degrees. With an area to mass (3.5 kg) ratio of 0.0129 $m^2$/kg, DAS yields 7.4 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. GRIFEX's probability of collision is $10^{-5.9}$ in the stowed configuration and $10^{-5.85}$ deployed. **Table 3** below provides complete results.

**Table 3: CubeSat Orbital Lifetime & Collision Probability**

| | CubeSat | GRIFEX |
|---|---|---|
| | **Mass (kg)** | 3.5 |
| Stowed | **Mean C/S Area (m^2)** | 0.0390 |
| Stowed | **Area-to Mass (m^2/kg)** | 0.0129 |
| Stowed | **Orbital Lifetime (yrs)** | 7.4 |
| Stowed | **Probability of collision (10^X)** | -5.9 |
| Deployed | **Mean C/S Area (m^2)** | 0.0400 |
| Deployed | **Area-to Mass (m^2/kg)** | 0.0132 |
| Deployed | **Orbital Lifetime (yrs)** | 7.4 |
| Deployed | **Probability of collision (10^X)** | -5.85 |

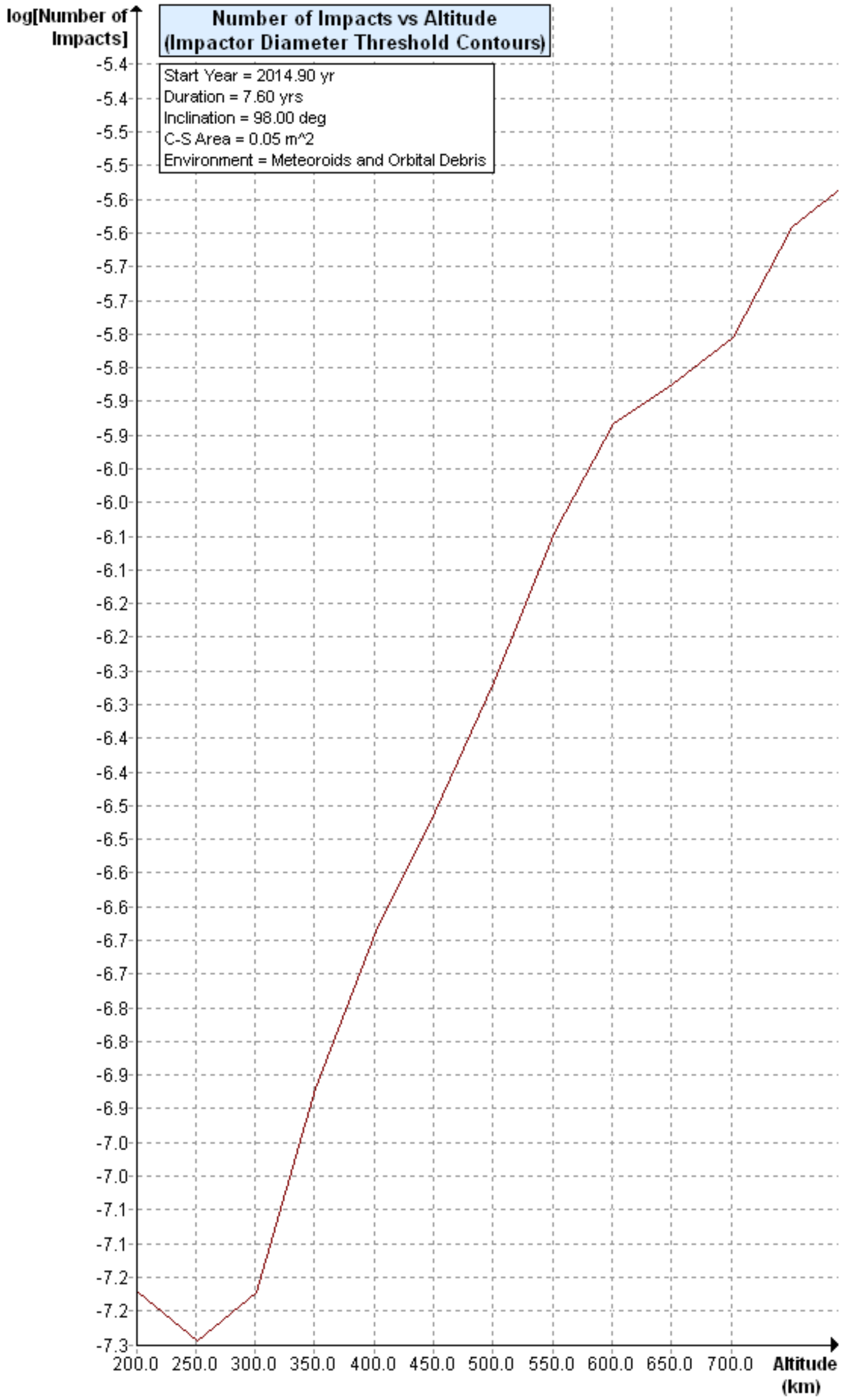


**Figure 4: Highest Risk of Orbit Collision vs. Altitude**

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

The probability of a GRIFEX collision with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal is less than $10^{-5.9}$, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Since GRIFEX has 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 GRIFEX to be compliant. Requirement 4.5-2 is not applicable to this mission.

**Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures**

GRIFEX 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 postmission 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 GRIFEX in its stowed configuration as the worst case. The area-to-mass is calculated for is as follows:

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

**Equation 3: Area to Mass**

$$\frac{0.0390\ m^2}{3.5\ kg} = \ 0.0129\frac{m^2}{kg}$$

The assessment of GRIFEX illustrates it is compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS 2.0.2 Orbital Lifetime Calculations:</u>

DAS inputs are: 450 km minimum perigee X 670 km apogee altitudes with an inclination of 98 degrees at deployment in November of 2014. An area to mass ratio of 0.0129 $m^2$/kg for the GRIFEX CubeSat was inputted. DAS 2.0.2 yields a 7.4 years orbit lifetime for GRIFEX 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

The DAS assessment shows compliance.

**Section 7: Assessment of Spacecraft Reentry Hazards**

A detailed assessment of the components to be flown on GRIFEX was performed. The assessment used DAS 2.0, a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a CubeSat's component during re-entry. For example, when DAS shows a component surviving reentry it is not taking into account the material ablating away or charring due to oxidative heating. Both physical effects are experienced upon reentry and will decrease the mass and size of the real-life components as the reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a components potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event the survive reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.

2. The remaining high temperature materials are shown to pose negligible risk to human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component is of similar dimensions and has a melting temperature between 1000 °C and 1500°C, it can be expected to posses the same negligible risk as stainless steel components. See Table 4.

**Table 4: GRIFEX Stainless Steel DAS Analysis**

| CubeSat | Stainless Steel Components | Mass (g) | Length / Diameter (cm) | Width (cm) | Height (cm) | Demise Alt (km) | KE (J) |
|---|---|---|---|---|---|---|---|
| GRIFEX | Antenna | 18.9 | 1.27 | 16.675 | 0.1 | 0 | 0 |
| GRIFEX | Sep Switch Plunger | 2.35 | 0.45 | 2.65 | 0.45 | 74.9 | 0 |
| GRIFEX | HuMy80 Hysteresis Material | 2 | 0.76 | 2.4 | 0.1 | 0 | 0 |
| GRIFEX | Mounting Screw | 0.1 | 0.411 | 0.635 | | 60.4 | 0 |

The majority of stainless steel components demise upon reentry. The components that DAS conservatively identifies as reaching the ground have 1 or less joules of kinetic energy, far below the requirement of 15 joules. No stainless steel component will pose a risk to human casualty as defined by the Range Commander's Council. In fact, any injury incurred or inflicted by an object with such low energy would be negligible and wouldn't require the individual to seek medical attention.

Through the method described above, Table 4: GRIFEX Stainless Steel DAS Analysis, and the full component lists in the Appendix GRIFEX is conservatively shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

See the Appendix for a complete accounting of the survivability of GRIFEX components.

## Section 8: Assessment for Tether Missions

GRIFEX will not be deploying any tethers.

GRIFEX satisfies Section 8's requirement 4.8-1.

**Section 9-14**

ODAR sections 9 through 14 for the launch vehicle are addressed in ref. (g), and are not covered here.

## **Appendix A.** GRIFEX Component List

| Name | External/Internal (Major/Minor Components) | Qty | Material | Body Type | Mass (g) | Diameter/ Width (mm) | Length (mm) | Height (mm) | Low Melting | Melting Temp (°C) | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GRIFEX | | 1 | Aluminum 6061 | Box - 3 U | | | | | Yes | | Demise |
| CubeSat Structure | External - Major | 1 | Aluminum 6061 | Box - 3 U | 315.94 | 100.01 | 100.02 | 340.5 | Yes | | Demise |
| Antenna | External - Major | 1 | Steel 410 | Flat Strip | 10 | 12.7 | 166.75 | 1 | | 1532 | Negligible Risk: KE ~ 0 J See Table 4 |
| Solar Cells | External - Major | 28 | Gallium Arsenide Solar Cell | Flat Rectangle | 2.2 | 0.5 | 39.55 | 68.96 | Yes | | Demise |
| | | | | | | | | | Yes | | Demise |
| Sep Switch Plunger | External - Minor | 2 | Stainless Steel 18-8 | Rectangle | 2.35 | 4.5 | 26.5 | 4.5 | | 1450 | Demise See Table 4 |
| Sep Switches | External - Minor | 2 | Plastic | Cylinder | 1.3 | 12.33 | 19.95 | 6.4 | Yes | | Demise |
| Solar Cell Mounting PCB | External - Minor | 4 | FR4 PCB | Rectangle | 99.6 | 1.57 | 82.5 | 99.5 | Yes | | Demise |
| Solar Panel Coverglass | External - Minor | 4 | Glass | Rectangle | 1 | 1 | 68.9 | 40 | Yes | | Demise |
| | | | | | | | | | | | Demise |
| Batteries | Internal - Major | 2 | Li-ion | Cylinder | 45 | 18.034 | N/A | 64.1668 | Yes | | Demise |
| ADCS Coil | Internal - Major | 1 | Copper | Wrapped Wire | 44 | 70.1 | N/A | 6.35 | Yes | | Demise |
| ADCS Magnet | Internal - Major | 1 | AlNiCo-5 | Cylinder | 6.779 | 2.4 | N/A | 5.4 | Yes | | Demise |
| Payload Board | Internal - Major | 1 | FR4 PCB | Square with Components | 35 | 3.2487 | 90.17 | 95.885 | Yes | | Demise |
| AstroDev UHF Lithium Radio | Internal - Major | 1 | Aluminium + PCB | Mounted on C&DH Board | 35 | 30.4 | 60.4 | 8.07 | Yes | | Demise |
| Solar Board | Internal - Major | 1 | FR4 PCB | Square with Components | 50 | 1.102 | 96 | 90 | Yes | | Demise |
| Battery Board | Internal - Major | 1 | FR4 PCB | Square with Components | 50 | 1.102 | 96 | 90 | Yes | | Demise |
| C&DH Board | Internal - Major | 1 | FR4 PCB | Square with Components | 75 | 17.81 | 94.6 | 90 | Yes | | Demise |
| Camera Sensor + Board | Internal - Major | 1 | PCB + CCD Sensor | Rectangular PCB | | 1.28 | 20.75 | 12.5 | Yes | | Demise |
| Camera Lens | Internal - Major | 1 | Plastic | Cylinder | | 6.36 | 1.2 | n/a | Yes | | Demise |
| Camera Housing | Internal - Major | 1 | Plastic | Cube | | 8.5 | 8.5 | 5.81 | yes | | Demise |

| Name | External/Internal (Major/Minor Components) | Qty | Material | Body Type | Mass (g) | Diameter/ Width (mm) | Length (mm) | Height (mm) | Low Melting | Melting Temp (°C) | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Minus Z Interface Board | Internal - Major | 1 | FR4 PCB | Square with Components | 71.8 | 1.1 | 96 | 90 | Yes | | Demise |
| Camera Interface Board | Internal - Major | 1 | FR4 PCB | Rectangular | 2.6 | 57.43 | 24.25 | 5.11 | Yes | | Demise |
| GRIFEX Payload Enclosure | Internal - Major | 1 | Aluminum 6061 | Box <1U | 269.8 | 95 | 95 | 96.3 | Yes | | Demise |
| Middle U Ballast | Internal - Major | 1 | Aluminum 6061 + PCB | Box | 1000 | 97 | 97 | 97 | Yes | | Demise |
| | | | | | | | | | | | Demise |
| Active Coil Mount | Internal - Minor | 4 | Delryn | Beam | 20 | 74.93 | 74.93 | 11.17 | Yes | | Demise |
| HuMy80 Hysteresis Material | Internal - Minor | 2 | HyMu-80 | Rectangle | 2 | 7.6 | 24 | 1 | No | 1454 | Negligible Risk: KE ~ 0 J See Table 4 |
| Gyros | Internal - Minor | 2 | PCB + sensor | Rectangle | 3 | 3 | 5 | 3 | Yes | | Demise |
| Battery Case | Internal - Minor | 1 | Alluminum 6061 | Extruded Arbelos | 25 | 15.75 | 43.18 | 10.15 | Yes | | Demise |
| SMA/SMA Coax Cable | Internal - Minor | 1 | RG316 Wire | Cable | 12 | n/a | n/a | n/a | Yes | | Demise |
| Board Mounts | Internal - Minor | 8 | Alluminum 6061 | Beam | 5.5 | 5 | 97 | 17 | Yes | | Demise |
| Wiring and Harnesses | Internal - Minor | 1 | Teflon Coated Wire | Wire | 20 | n/a | n/a | n/a | yes | | Demise |
| Mounting Screw | Internal - Minor | 56 | 316 Stainless Steel | Cylinder | 0.1 | 4.11 | 6.35 | | No | 1399 | Demise See Table 4 |
| Camera Housing Lid | Internal - Minor | 1 | Aluminum 6061 | Square Plate | 79 | 95 | 95 | 9.5 | Yes | | Demise |
| Lens Mount Spider | Internal - Minor | 1 | Aluminum 6062 | Square fixture | 41.6 | 88.24 | 88.24 | 14.48 | Yes | | Demise |
| Camera Lens | Internal - Minor | 1 | Glass/ Aluminum | Cylinder | 48.9 | 30.5 | n/a | 34.7 | Yes | | Demise |
| Payload Controller Board | Internal - Minor | 1 | FR4 PCB | Square with Components | 59.9 | 90 | 90 | 1.6 | Yes | | Demise |
| Detector Circuit Board | Internal - Minor | 1 | FR4 PCB | Square with Components | 59.4 | 90 | 90 | 1.6 | Yes | | Demise |
| Miscellaneous Payload Fasteners | Internal - Minor | 1 | Stainless Steel 18-8 | Cylinders (Screws) | 23 | 2 | 2 | 5 | yes | | Demise |