ELVL-2019-0045507 Rev A
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# Orbital Debris Assessment for the Argus-02 CubeSat 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-2019-0045507 Rev A

Reply to Attn of: VA-H1

April 24, 2019

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 Argus-02 CubeSat

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6B, 16 February 2017
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 Argus-02 CubeSat, which will be deployed from the International Space Station. 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 CubeSat will passively reenter and therefore this ODAR will also serve as the EOMP (End of Mission Plan)

| RECORD OF REVISIONS | | |
|---|---|---|
| **REV** | **DESCRIPTION** | **DATE** |
| 0 | Original submission | January 2019 |
| A | Incorporated official name change from 'Argus' to 'Argus-02', updated CubeSat mass properties and materials list | April 2019 |

The following table summarizes the compliance status of the Argus-02 CubeSat to be deployed from the International Space Station. Argus-02 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 1.6 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 release for Argus-02 |

## Section 1: Program Management and Mission Overview

Argus-02 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:

Argus-02: Dr. Michael Swartwout, Principal Investigator, St. Louis University

| Program Milestone Schedule | |
|---|---|
| **Task** | **Date** |
| CubeSat Selection | November 1st, 2018 |
| Delivery to NanoRacks | August 1st , 2019 |
| Launch | October 19th, 2019 |

**Figure 1: Program Milestone Schedule**

Argus-02 will be launched as a payload on the Antares launch vehicle executing the NG-12 mission. Argus-02 will be deployed from the International Space Station. Each CubeSat is identified in Table 2: Attributes.

Argus-02 weighs approximately 1.3 kg.

## Section 2: Spacecraft Description

Table 2: outline the generic attributes of the spacecraft.

**Table 2: Argus-02 Attributes**

| CubeSat Names | CubeSat Quantity | CubeSat size ($mm^3$) | CubeSat Masses (kg) |
|---|---|---|---|
| Argus-02 | 1 | 100 x 100 x 113.5 | 1.3 |

The following pages describe the Argus-02 CubeSat.

## Argus-02 – St. Louis University – 1U

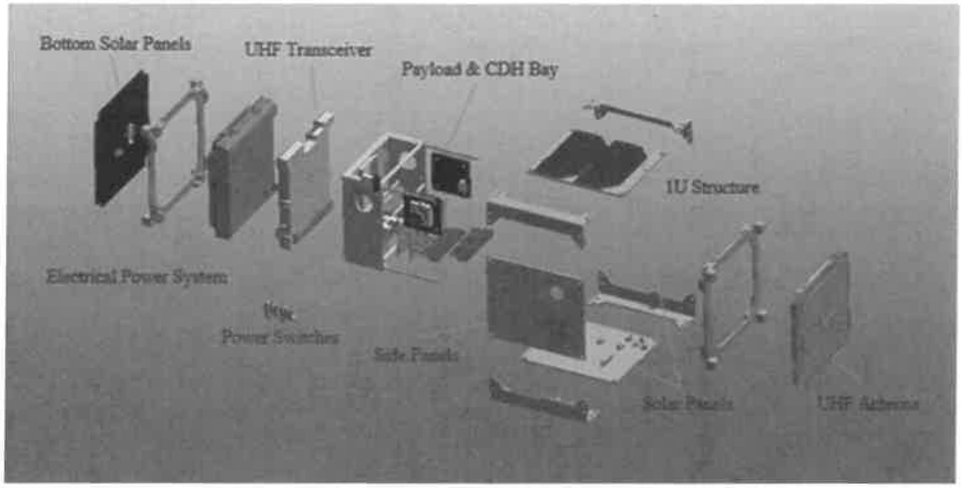


**Figure 2: Argus-02 exploded view**

### Overview

Argus-02 is a reflight of the original Argus mission lost on ELaNa 7. It continues the original Argus mission of characterizing the performance of modern electronics in the space environment, and has been augmented with an artificial intelligence demonstration (on board event detection using neural nets). The reasoning software use imagery from two onboard visible-light cameras to observe and predict local events; together with ground operators, the flight software will also observe the effects of radiation on memory storage.

### CONOPS

Argus-02 will be deployed from a NanoRacks deployer and will activate after 30 minutes. Upon booting it will deploy its antenna, and hold in safe mode until batteries are charged to the point to begin beacon operations. Once ground communication is established, Argus-02 will begin transmitting health data and basic telemetry as requested. Experimentation will begin once nominal spacecraft health is established.

### Materials

The spacecraft structure is made of aluminum 6061 which has a class III type 2 hard anodization. The side panels and the payload bay are constructed out of Nylon 12 and ABS 3D printing material. The EPS, transceiver, and antenna have an anodized aluminum shell. The antenna is constructed from shape memory alloy (SMA), and the PCBs are all FR-4. Nearly all electronic components are commercial-off-the-shelf (COTS), and the primary structure is also COTS.

## Hazards

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

## Batteries

The spacecraft batteries, which will store charge from solar panels, are lithium polymer cells which are in accordance with UL1642 and RoHS-compliant. There is also a lithium coin cell to power the real-time clock.

## 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 for Argus-02, 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 Argus-02 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 CubeSat batteries still meet Req. 56450 (4.4-2) by virtue of the HQ OSMA policy regarding CubeSat battery disconnect stating;

> "CubeSats as a satellite class need not disconnect their batteries if flown in LEO with orbital lifetimes less than 25 years." (ref. (h))

Limitations in space and mass prevent the inclusion of the necessary resources to disconnect the battery or the solar arrays at EOM. However, the low charges and small battery cells on the CubeSat's power system prevents 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 CubeSat lifetime of 1.6 years maximum, Argus-02 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.

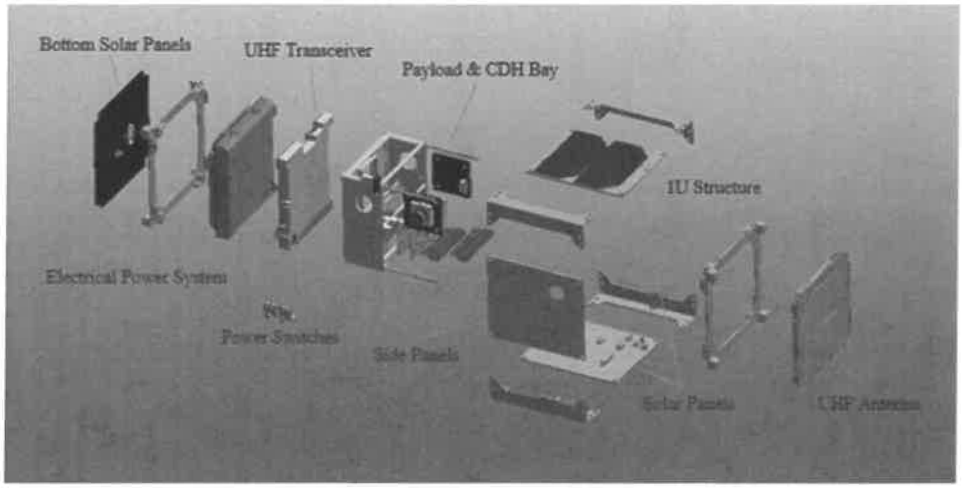


**Figure 4: Argus-02 Expanded View (with solar panels deployed)**

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

**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**

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 stowed CubeSat was calculated using Equation 1.

The Argus-02 (1.3 kg) orbit at deployment will be 423 x 407 km at a 51.6° inclination. With an area to mass ratio of ~.0122 $m^2$/kg, DAS yields ~1.6 years for orbit lifetime, which in turn is used to obtain the collision probability. Argus-02 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 | Argus-02 |
|---|---|
| Mass (kg) | 1.3 |

| | | |
|---|---|---|
| Stowed | Mean C/S Area (m^2) | 0.01568 |
| | Area-to Mass (m^2/kg) | 0.0122 |
| | Orbital Lifetime (yrs) | **1.6** |
| | Probability of collision (10^X) | **0.0000** |

**Solar Flux Table Dated**
**12/18/2018**

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

The probability of Argus-02 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 Argus-02 to be compliant.

Argus-02 has no capability or plans for end-of-mission disposal, therefore Requirement 4.5-2 is not applicable. Argus-02 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**

Argus-02 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.

In order to determine the area-to-mass ratio for the Argus-02 CubeSat, the area-to-mass is calculated as follows:

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

**Equation 3: Area to Mass**

$$\frac{0.01568\,m^2}{1.3\,kg} = .0122\frac{m^2}{kg}$$

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

<u>DAS 2.1.1 Orbital Lifetime Calculations:</u>
DAS inputs are: 423.5 km maximum apogee 407.8 km maximum perigee altitudes with an inclination of 51.6° at deployment no earlier than October 2019. An area to mass ratio of ~0.0122 $m^2$/kg for the Argus-02 CubeSat was used. DAS 2.1.1 yields a 1.6 years orbit lifetime for Argus-02.

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 of Argus-02 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: Argus-02 High Melting Temperature Material Analysis**

| Name | Material | Total Mass (kg) | Demise Alt (km) | Kinetic Energy (J) |
|---|---|---|---|---|
| Hysteresis Rods | HyMu80 | .00663 | 77.4 | 0 |
| Payload Shelf M2.5 Threaded Rods | Stainless Steel | .00413 | 77.4 | 0 |
| Watchdog Threaded Rods M2.5 | Stainless Steel | .0012 | 76.8 | 0 |
| Cam Nut M2 | Stainless Steel | .00028 | 0 | 0 |
| Cam Bolt M2 | Stainless Steel | .00072 | 77.5 | 0 |
| Shelf Nut M2.5 | Stainless Steel | .00224 | 77.6 | 0 |
| Payload Washers M2.5 | Stainless Steel | .0008 | 77.8 | 0 |
| M3 x 5 Screws | Stainless Steel | .0046 | 74.9 | 0 |
| M2 x 6 Screws | Stainless Steel | .00336 | 77.0 | 0 |
| M3 X 8 Screws | Stainless Steel | .00672 | 77.2 | 0 |
| M3 x 6 Screws | Stainless Steel | .00168 | 77.6 | 0 |
| M3 Hex Nut | Stainless Steel | .00875 | 77.6 | 0 |
| M3 Washer | Stainless Steel | .0012 | 77.7 | 0 |

The majority of stainless steel components demise upon reentry and Argus-02 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 for Argus-02**

| Name | Status | Risk of Human Casualty |
|---|---|---|
| Argus-02 | 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 Argus-02 has a 1:0 probability as none of its components survive to the ground with more than 15J of energy.

Argus-02 is shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

**Section 8: Assessment for Tether Missions**

Argus-02 will not be deploying any tethers.

Argus-02 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
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.** Argus-02 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 | Argus 1U CubeSat | 1 | | Box | **1280.66** | 100 | 100 | 113.5 | No | - | Demise |
| 2 | Endurosat Structure: Top Element | 1 | Aluminum 6061-T6 | Box | 26.4 | 100 | 100 | 7 | No | - | Demise |
| 3 | Endurosat Structure: Bottom Element | 1 | Aluminum 6061-T6 | Box | 23.9 | 100 | 100 | 6.5 | No | - | Demise |
| 4 | Endurosat Structure: Legs | 4 | Aluminum 6061-T6 | Box | 37.79 | 2.5 | 2.5 | 100 | No | - | Demise |
| 5 | Solar Panel Z+ With UHF Antenna | 1 | FR-4, Shape Memory Alloy | Box | 95 | 98 | 98 | 16.3 | No | - | Demise |
| 6 | Solar Panel Z- | 1 | FR-4 | Box | 48 | 98 | 98 | 8.6 | No | - | Demise |
| 7 | Solar Panels X/Y | 3 | FR-4 | Box | 132 | 82.6 | 98 | 8.6 | No | - | Demise |
| 8 | Side Panel | 1 | Aluminum 6061-T6 | Box | 32.95 | 82.7 | 98.2 | 1.6 | No | - | Demise |
| 9 | Payload Bay | 1 | Polyamide 2200 | Box | 37.06 | 86.2 | 91.6 | 40.2 | No | - | Demise |
| 10 | Cable Bracket | 1 | Polyamide 2200 | Irregular | 8.12 | 40.0 | 25.0 | 40.0 | No | - | Demise |
| 11 | Edurosat EPS | 1 | Aluminum 6061, FR-4, Lithium Polymer Battery | Box | 198 | 90 | 96 | 21 | No | - | Demise |
| 12 | Endurosat UHF Transciever | 1 | Aluminum 6061, FR-4 | Box | 94 | 89 | 95 | 23.2 | No | - | Demise |
| 13 | Raspberry Pi Zero | 1 | FR-4 | Box | 11.56 | 30.5 | 65.1 | 10.3 | No | - | Demise |
| 14 | Zeus Board | 1 | FR-4 | Box | 18.65 | 29.9 | 65.0 | 11.1 | No | - | Demise |
| 15 | Raspberry Pi Camera V2 | 1 | FR-4 | Box | 3.53 | 1.0 | 23.8 | 24.9 | No | - | Demise |
| 16 | Connection Circuit Board | 1 | FR-4 | Box | 50.89 | 90.0 | 97.0 | 25 | No | - | Demise |
| 17 | Watchdog Timer Board | 1 | FR-4 | Box | 9.97 | 33.3 | 63.4 | 10 | No | - | Demise |
| 18 | RTC Battery | 1 | Lithium (coin cell battery with metal exterior) | Cylinder | 0.75 | 12.4 | - | 2.0 | No | - | Demise |
| 19 | Magnet | 1 | NdFeB | Cylinder | 1.51 | 3.175 | - | 25.4 | No | - | Demise |
| 20 | Hysteresis Rods | 2 | HY-MU 80 | Cylinder | 6.63 | 3.4 | - | 42 | No | 2642° | Demise |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | Roller Switches | 3 | ABS housing, FR-4 board | Box | 15 | 5.12 | 20 | 14.52 | No | - | Demise |
| 22 | Antenna Cables | 1 | Copper | Cylinder | 100 | 5 | 100 | - | No | - | Demise |
| 23 | Watchdog Cables | 4 | Copper | Cylinder | 2.4 | 2 | 150 | - | No | - | Demise |
| 24 | Kapton Tape | - | Polyimide Film | Amorphous | 12 | - | - | - | No | - | Demise |
| 25 | Epoxy | - | 0151 Hysol | Amorphous | 20 | - | - | - | No | - | Demise |
| 26 | Solder | - | Tin (63%) Lead (37%) | Amorphous | 0.00 | - | - | - | No | - | Demise |
| 27 | Cabling, USB and HDMI (processor output) | - | | Cylinders | 100 | 3,8 | 100 | - | No | - | Demise |
| 28 | Dow Corning 6-1104 Silicone Sealent | - | 6-1104 Silicon Sealent | Amorphous | 142 | - | - | - | No | - | Demise |
| 29 | Threaded rods M3 for 1U structure | 4 | Brass | Cylinder | 16.92 | 2.84 | 95.35 | - | No | - | Demise |
| 30 | Payload Shelf M2.5 Threaded Rods | 4 | Stainless Steel | Cylinder | 4.16 | 2.21 | 36.68 | - | Yes | 2750° | Demise |
| 31 | Watchdog Threaded Rods M2.5 | 4 | Stainless Steel | Cylinder | 1.12 | 2.21 | 10.00 | - | Yes | 2750° | Demise |
| 32 | Paylaod - Cam Nut M2 | 4 | Stainless Steel | Cylinder | 0.28 | 3.86 | 1.14 | - | Yes | 2750° | Demise |
| 33 | Payload - Cam Bolt M2 | 4 | Stainless Steel | Cylinder | 0.72 | 4.17 | 13.46 | - | Yes | 2750° | Demise |
| 34 | Payload - Shelf Nut M2.5 | 32 | Stainless Steel | Cylinder | 2.24 | 4.90 | 1.50 | - | Yes | 2750° | Demise |
| 35 | Payload Washers M2.5 | 8 | Stainless Steel | Cylinder | 0.8 | 5.84 | 0.46 | - | Yes | 2750° | Demise |
| 36 | M3 x 5 Screw in Structure | 20 | Stainless Steel | Cylinder | 4.6 | 5.61 | 5.00 | - | Yes | 2750° | Demise |
| 37 | M2 x 6 Screw in Structure | 8 | Stainless Steel | Cylinder | 3.36 | 3.91 | 7.59 | - | Yes | 2750° | Demise |
| 38 | M3 X 8 Screw in Strucutre | 16 | Stainless Steel | Cylinder | 6.72 | 5.49 | 8.03 | - | Yes | 2750° | Demise |
| 39 | M3 X 6 Screw in Strucutre | 4 | Stainless Steel | Cylinder | 1.68 | 5.61 | 6.00 | - | Yes | 2750° | Demise |
| 40 | M3 Hex Nut | 25 | Stainless Steel | Cylinder | 8.75 | 5.50 | - | 2.4 | Yes | 2750° | Demise |
| 41 | M3 Washer | 12 | Stainless Steel | Cylinder | 1.2 | 6.00 | - | 0.5 | Yes | 2750° | Demise |