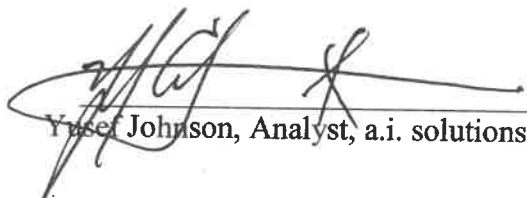


ELVL-2019-0045507 Rev A
April 24, 2019

**Orbital Debris Assessment for the Argus-02 CubeSat
per NASA-STD 8719.14A**

Signature Page

A handwritten signature in dark ink, appearing to read 'Yusef Johnson', written over a horizontal line.

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

A handwritten signature in dark ink, appearing to read 'Scott Higginbotham', written over a horizontal line.

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 1 st , 2018
Delivery to NanoRacks	August 1 st , 2019
Launch	October 19 th , 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 (mm³)	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

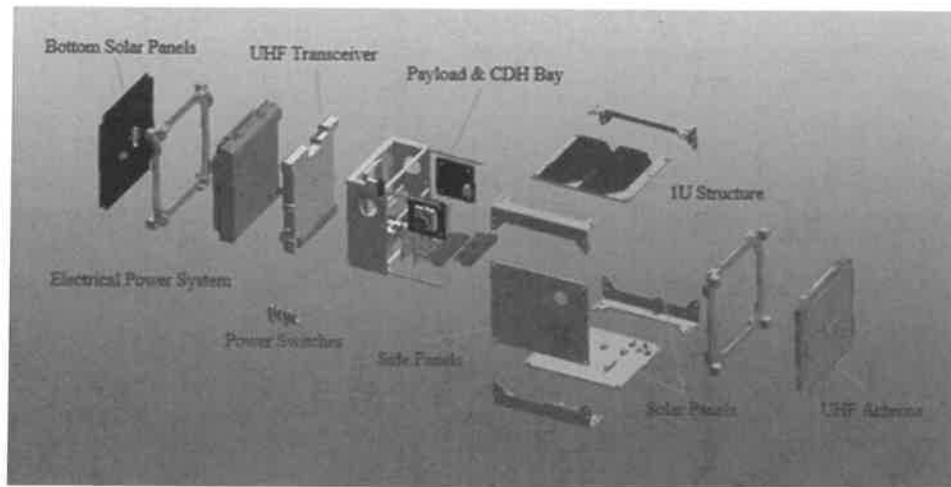


Figure 2: Argus-02 exploded view

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.

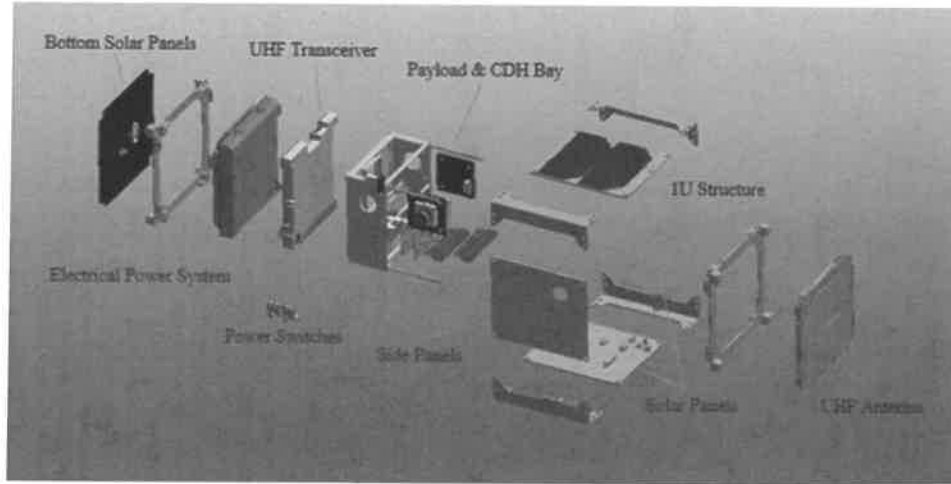


Figure 4: Argus-02 Expanded View (with solar panels deployed)

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

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 m²/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 (m²)	0.01568
	Area-to Mass (m²/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:

$$\frac{\text{Mean } C/s \text{ Area } (m^2)}{\text{Mass } (kg)} = \text{Area} - \text{to} - \text{Mass } \left(\frac{m^2}{kg} \right)$$

Equation 3: Area to Mass

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

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: 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 m²/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 by CubeSat

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 Transceiver	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 Sealant	-	6-1104 Silicone Sealant	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	Payload - 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 Structure	16	Stainless Steel	Cylinder	6.72	5.49	8.03	-	Yes	2750°	Demise
39	M3 X 6 Screw in Structure	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