Department of Mechanical Engineering

Orbital Debris Assessment Report (ODAR)

Prepared for:

National Aeronautics and Space Administration (NASA)

Report Date:

30 May 2019

Signature Page
ORBITAL FACTORY II
ODAR

Ahsan Choudhuri, PhD

Associate Vice President for Strategic Initiatives
Mr. and Mrs.MacIntosh Murchison Chair II in Engineering
Director, NASA MIRO Center for Space Exploration Technology Research
University of Texas at El Paso

Joel Quintana, Ph.D

Project Manager
Research Assistant Professor
Department of Mechanical Engineering
The University of Texas at El Paso

Arthur S Bruno

Researcher
Orbital Factory II

James P Holt

Researcher
Orbital Factory II

List of Revisions

Revision	Revision Date	Revised By	Revision Description
A	4/16/2019	James Holt	Initial Release
B	5/30/2019	Joel Quintana	Technical Description, designator Appendix 1 and 2 Update

Table of Contents

Self-assessment of the ODAR using the format in the Appendix of A.2 of NASA-STD-8719.14:

Provided below is a self-assessment in accordance with the assessment format provided in Appendix A.2 of NASA-STF-8719.14.

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	
4.4-2	Compliant	
4.4-3	Not applicable	No planned breakups
4.4-4	Not applicable	No planned breakups
4.5-1	Compliant	
4.5-2	Compliant	
4.6-1 (a)	Compliant	Approximate orbital lifetime of 2 years
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
4.7-1	Compliant	
4.8-1	Not applicable	No tether releases

ODAR Section 1: Mission Overview:

Orbital Factory 2 is a CubeSat under development at the University of Texas at El Paso. The spacecraft will have two primary experimental payloads, a conductive ink printer and an experimental S-band antenna that was fabricated using proprietary nano copper. The purpose of the printer experiment is to test a method of repairing electrical systems in orbit using a conductive paste. The missions for both our payload and our spacecraft itself are primarily 'proof of concept,' in that they are relatively low complexity tasks to establish experience in spacecraft flight, and to prove basic functionality of the research subjects. This is done in interest of future planned missions, which will involve more technically advanced payloads with a higher orbit. The launch will be via the Northrop Grumman Innovation System's (NGIS) Antares launch vehicle, to be deployed from the Cygnus spacecraft using a NanoRacks External CubeSat Deployer (ENRCSD) during the NG12 ISS resupply mission. The expected orbit will be at a 465 km orbital altitude and a 51.69-degree inclination. The printer experiment will take place within days after deployment, after the CubeSat is confirmed to be operational from the ground. After the printer experiment is completed, the patch antenna will be tested by downlinking data. Magnetorquers will also be utilized to test methods of rudimentary attitude control.

ODAR Section 2: Spacecraft Description:

The spacecraft is a 1U CubeSat with a skeletonized chassis and no exposed internals. Five of the six faces feature solar panels, with three of the panels having installed magnetorquers for rudimentary attitude control. Two of the faces additionally have communications devices installed, a UHF dipole antenna and an S-Band patch antenna. The CubeSat internal hardware is designed to the PC-104 form factor and will feature a UHF transceiver for uplink and downlink, an S-band transmitter for auxiliary downlink, a 5 MP external camera, a 0.3 MP internal camera, a 10.4 Watt hour capacity electrical power system with a lithium ion cell, and a payload board with an enclosed printer experiment. The printer experiment features a nozzle on a 1-axis motion platform driven by a lead screw and stepper motor. The nozzle will dispense a conductive ink onto a printed circuit board. The printer experiment will be enclosed in Kapton film to prevent debris from shedding from the satellite. In addition, the solar panels will surround the edges of the chassis.

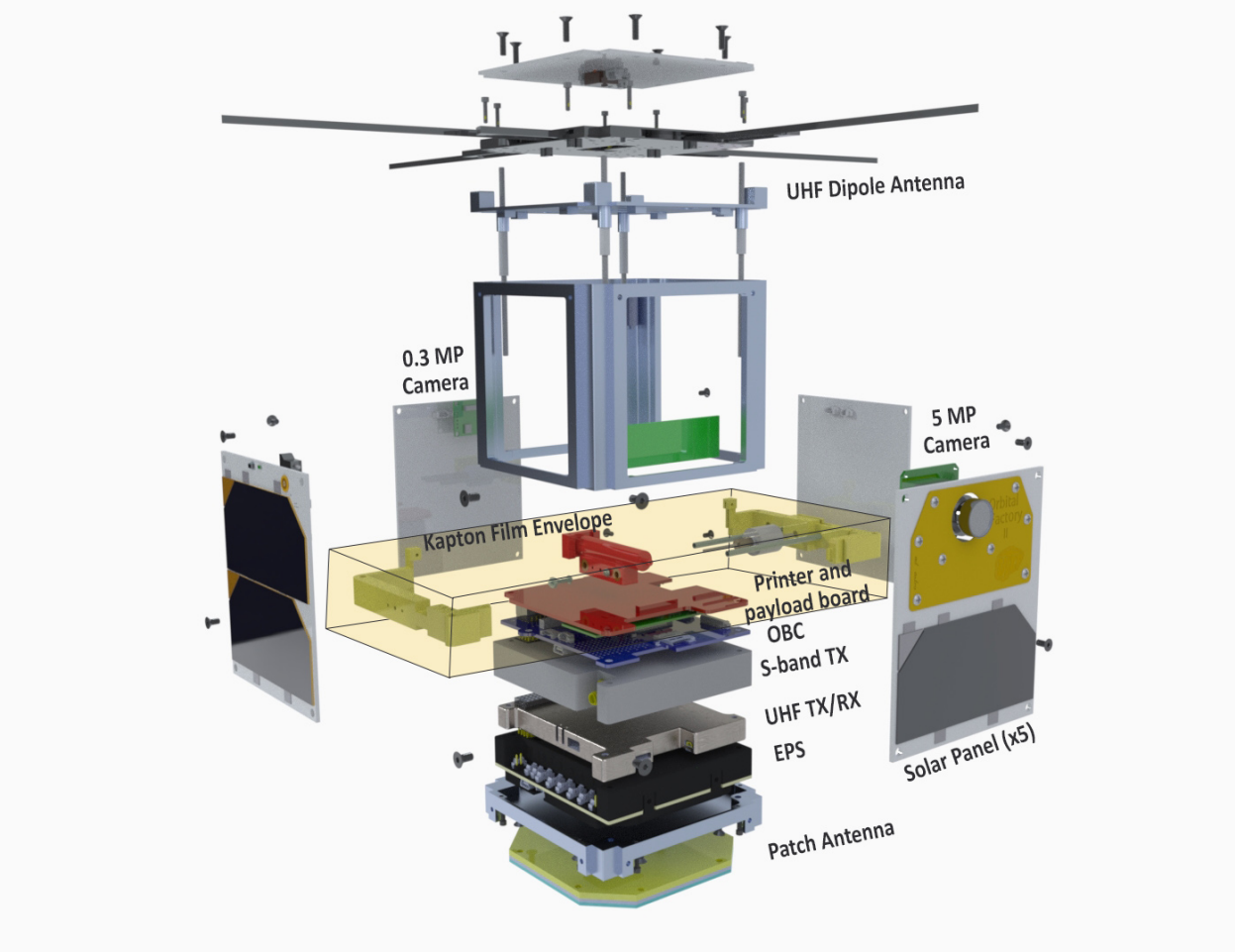


Figure 1: Exploded view of Orbital Factory 2. The Kapton film envelope for enclosing the printer experiment is shown in yellow.

ODAR Section 3: Assessment of Spacecraft Debris Released during Normal Operations:

Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material:

There are no intentional releases. All hardware and experiments on board the satellite are fixed to the spacecraft.

Rationale/necessity for release of each object:

N/A

Time of release of each object, relative to launch time:

N/A

Release velocity of each object with respect to spacecraft:

N/A

Expected orbital parameters (apogee, perigee, and inclination) of each object after release:

N/A

Calculated orbital life time of each object, including time spent in Low Earth Orbit (LEO):

N/A

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS 2.1.1):

4.3-1, Mission Related Debris Passing Through LEO: Compliant

4.3-2, Mission Related Debris Passing Near GEO: Compliant

ODAR Section 4: Assessment of Spacecraft Intentional Breakups and Potential for explosions:

Potential causes of spacecraft breakup during deployment and mission operation:

The only potential failure mode that could result in an explosion would be a failure of the battery in the electrical power system (EPS). A failure of the protection circuitry could cause a short, which could cause the battery cell to overheat and potentially explode.

Summary of failure modes and effects analysis of all credible failure modes which may lead to an accidental explosion:

The EnduroSat EPS is designed with overcurrent, overvoltage, overtemperature, overcharge, over discharge, and ESD protection to mitigate the risk of over-charging, over-discharging, and external shorts. An integrated circuit protection module is used to prevent overcurrent, overcharge, and over discharge. A firmware algorithm is implemented to protect from short circuit, deep discharge, and overheating. The battery operating temperature is from -40 to 150 degrees Celsius, and the overtemperature threshold is set to 155 degrees Celsius. If this threshold is reached, the module will turn off and restart automatically if the temperature decreases below 130 degrees Celsius.

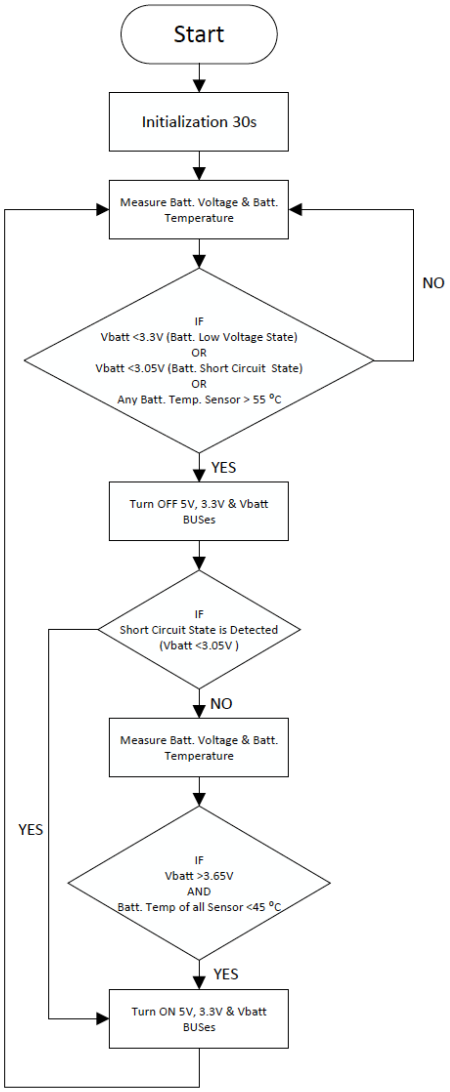


Figure 2: Algorithm for protection of battery from short circuit, deep discharge, and overheating

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:

Requirement 4.4-1: Limiting the probability of accidental explosion: Compliant

Refer to Appendix 1 'EnduroSat Test Report: Flight Acceptance Test Requirements For Lithium-ion Cells and Battery Packs – Applicable to NanoRacks Payload' for test data.

Requirement 4.4-2: Eliminating stored energy sources: Compliant

Requirement 4.4-3: N/A for satellites with no intentional breakups

Requirement 4.4-4: N/A for satellites with no intentional breakups

ODAR Section 5: Assessment of Spacecraft potential for on-orbit collisions:

Requirement 4.5-1: Limiting debris generated by collisions with large objects when operating in Earth orbit:

Compliance: Compliant

Large Object Impact and Debris Generation Probability: 0.00000

Requirement 4.5-2: Limiting debris generated by collisions with small object when operating in Earth orbit:

Compliance: Compliant

Small Object Impact and Debris Generation Probability:

On Board Computer: 0.000109

Battery: 0.000004

UHF Transceiver: 0.000003

Probability of PMD failure: 0.000116

ODAR Section 6: Assessment of Spacecraft post-mission disposal plans and procedures:

Description of spacecraft disposal option selected:

The satellite will naturally decay in orbit to burn up in the Earth's atmosphere upon reentry. There will be no deorbiting assistance through the use of propulsion systems.

Identification of all systems or components required to accomplish any post mission disposal operation, including passivation and maneuvering:

There will be no maneuvers. The satellite has no propulsion.

Calculation of area to mass ratio after post mission disposal, if the controlled reentry option is not selected:

Mass: 1.454 kg

Spacecraft Average Cross-Sectional Area: 0.015 m^2 (Calculated by DAS 2.1.1 cross sectional area tool)

Area/Mass ratio (m^2/kg): $\frac{0.015}{1.454} = 0.012116\ m^2/kg$

Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5:

Requirement 4.6-1: Disposal for space structures passing through LEO

The Orbital Factory 2 CubeSat will naturally reenter the atmosphere after approximately 2 years.

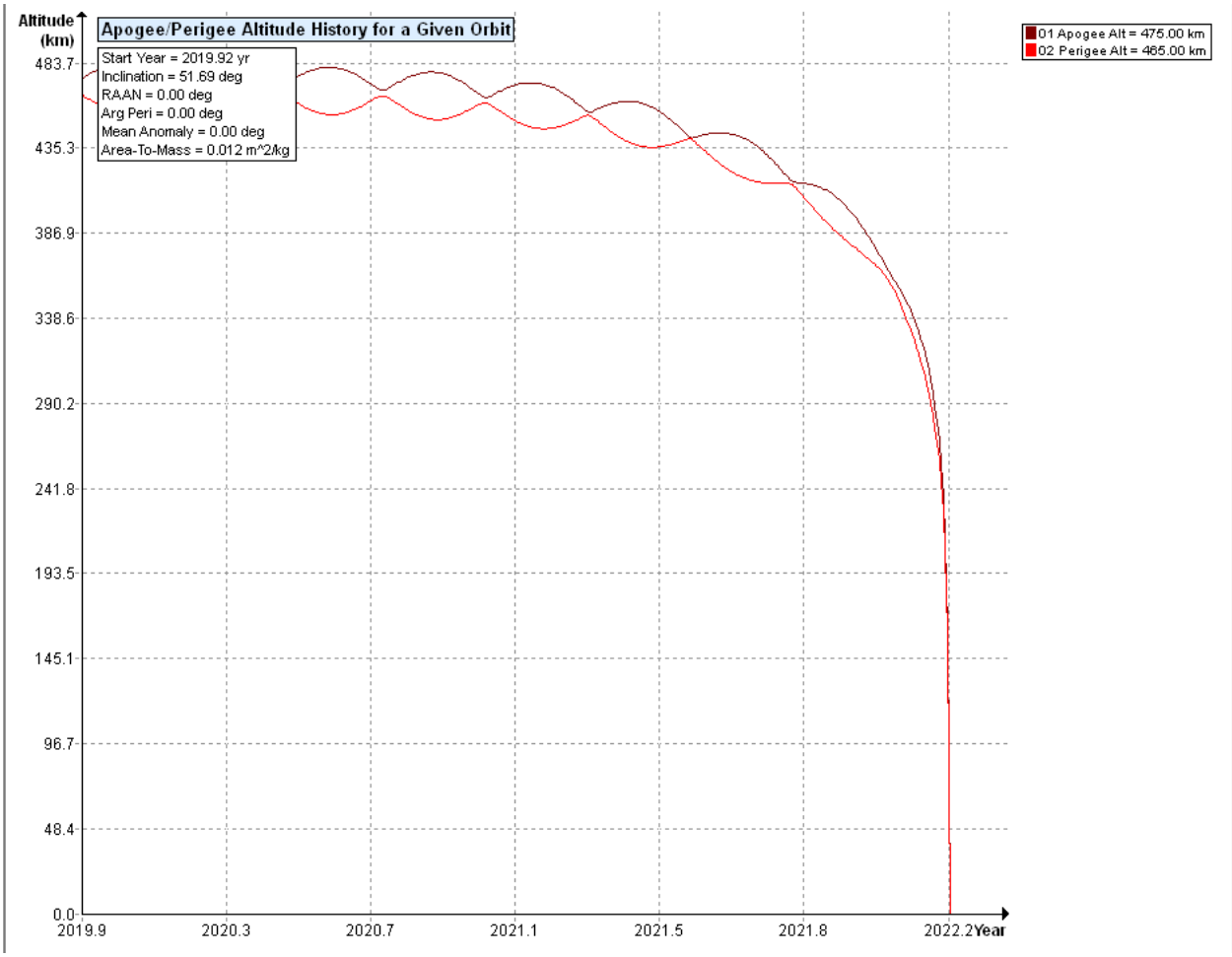


Figure 3: Satellite altitude history for orbital lifetime

Requirement 4.6-2: N/A due to orbit type

Requirement 4.6-3: N/A due to orbit type

Requirement 4.6-4: This requirement addresses the reliability of post mission disposal operations in Earth's orbit. NanoRack's satellites meet orbital lifetime requirements (< 25 years) without satellite operations, therefore reliability predictions are not necessitated.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards:

Requirement 4.7-1a: Component information was inputted into NASA DAS as accurately as possible, with some values overestimated to provide margin, and due to limitations with the software. The outputs and inputs to DAS are shown below:

Satellite	NASA Mandated Risk of Human Casualty	Calculated Risk of Human Casualty	Compliance?
Orbital Factory 2	Less than 1/10000 (< 0.0001)	1:100000000	Compliant

NASA DAS Inputs shown below:

Name	Qty	Material	Body Type	Thermal Mass	Diameter/Width	Length	Height
Orbital Factory 2	1	Aluminum 6061-T6	Box	1.454	0.1	0.1135	0.1
Solar Panel	5	Fiberglass	Flat Plate	0.053	0.083	0.098	
Patch Antenna	1	Aluminum 6061-T6	Box	0.117	0.1	0.1	0.007
UHF Antenna	1	Aluminum 6061-T6	Box	0.085	0.098	0.098	0.0056
OF-2 Body	1	Aluminum 6061-T6	Box	0.272	0.1	0.1135	0.1
UHF Transceiver	1	Aluminum 6061-T6	Box	0.0538	0.089	0.095	0.011
UHF Board	1	Fiberglass	Flat Plate	0.0402	0.089	0.095	
Sband Transceiver	1	Aluminum 6061-T6	Box	0.0899	0.0902	0.096	0.017
Sband Board	1	Aluminum 6061-T6	Flat Plate	0.1801	0.0902	0.096	
EPS	1	Aluminum 6061-T6	Box	0.066	0.0902	0.096	0.0212
EPS Board	1	Fiberglass	Flat Plate	0.058	0.0902	0.096	
Battery	1	Aluminum 6061-T6	Box	0.074	0.077	0.079	0.0098
Payload Board	1	Fiberglass	Flat Plate	0.058	0.095	0.095	

Camera 1	1	Polyimide	Box	0.004	0.02	0.03	0.01
Camera 2	1	Fiberglass	Cylinder	0.005	0.014	0.024	
Printer Rail	2	Polyimide	Box	0.004	0.03	0.093	0.012
Printer Nozzle	1	Polyimide	Box	0.00555	0.012	0.056	0.012
OBC	1	Fiberglass	Flat Plate	0.058	0.095	0.095	

NASA DAS Outputs shown below:

Name	Demise Alt	Total DCA	KE
Orbital Factory 2		0	
Solar Panel	76.9	0	0
Patch Antenna	75	0	0
UHF Antenna	75.7	0	0
OF-2 Body	75.5	0	0
UHF Transceiver	74.2	0	0
UHF Board	73.1	0	0
Sband Transceiver	73.6	0	0
Sband Board	67.3	0	0
EPS	74.1	0	0
EPS Board	72.8	0	0
Battery	71.2	0	0
Payload Board	74.3	0	0
Camera 1	74.1	0	0
Camera 2	73.2	0	0
Printer Rail	75.4	0	0
Printer Nozzle	75.3	0	0
OBC	74.3	0	0

ODAR Section 8: Assessment for tether missions:

Requirement 4.8-1: N/A as no tethers will be used.

Acronyms and Abbreviations:

DAS Debris Assessment Software

LEO Low Earth Orbit

LV Launch Vehicle

Appendix 1

EnduroSat Test Report

Flight Acceptance Test Requirements For Lithium-ion Cells and Battery Packs – Applicable to NanoRacks Payload

ENDUROSAT

Test report

Flight Acceptance Test Requirements for Lithium-ion Cells and Battery Packs – Applicable to NanoRacks Payload

Prepared	Revised	Approved
Vladimir Yankov	Ivan Ivanov	Giuseppe Sisinni
07/11/2018	07/11/2018	08/11/2018

TEST REPORT

TEST REPORT

BATTERY TEST REPORT

Four "VARTA 1/LPP 503759 8HH" Lithium Ion Polymer cells are used in two battery packs (1S2P) connected in parallel (1S4P). The total energy level is 20.8Wh.

All tests are performed according to the NanoRacks document "NR-SRD-139 Revision C". Numbering of the paragraphs is aligned with the above-mentioned document.

3 REQUIRED TEST PROCEDURES - PHYSICAL AND ELECTROCHEMICAL CHARACTERISTICS TEXT

3.1 Test documentation

Manufacturer	Storage GMBH
Cell model number	1ICP6/37/59 (VKB: 56427 201 020)
Date of manufacture	3rd week of May 2018 (058C)
Manufacturer cell / Battery specifications	VARTA/1400mAh 3.7V 5.2W
Cell chemistry	Lithium-Ion Polymer
Electrolyte type	Polymer Electrolyte
Date of battery cell testing	Oct. – Nov. 2018

3.2 Visual inspection

No scrapes, budges and dents were found on the battery cells after a visual inspection

3.3 Measurement of the physical properties

The following measurements are performed with 0.1mm precision

	Cell 1	Cell 4	Datasheet [Max]
Length [mm]	58.6	58.6	60.5
Width [mm]	36.2	36.2	37.5
Height [mm]	5.0	5.0	5.4

The following measurements are performed with 0.1g precision accuracy

	Cell 1	Cell 4	Datasheet [Max]
Weight [g]	24.60	24.60	Approx. 25

TEST REPORT

3.4 Electrochemical Characteristic

The test is performed on flight cells. All cells are charged with "Graupner Ultra Duo Plus 60 No.6478' to the manufacture's recommended voltage level (4.2V). Measurements are performed with more than 0.1V precision.

3.4 A Measurement of Open Circuit Voltage

Cell	Open Circuit Voltage [V]
1	4.2
4	4.2

3.4 B Measurement of Closed Circuit Voltage

Cell	Closed Loop Circuit Voltage (C/2, 30sec)
1	4.020
4	4.028

3.4 C Open Circuit Voltage (OCV) 14-day test

All cells are discharged to the minimal specified voltage by the manufacture (3V) and terminated when the current tapers below C/100 (14mA). Batteries were discharged in several steps with decreasing current. "Graupner Ultra Duo Plus 60 No.6478" was used to perform this test.

For the last step, the discharging current was set with 214 Ohm resistor connected to the batteries and monitored with multimeter. The cell open circuit voltage was monitored for 14 days.

The open circuit voltage at discharge termination for four cells is as follows:

Cell 1 [V]	Cell 4 [V]
24.60	24.60

	Day1	Day3	Day7	Day10	Day14
Cell1 [V]	3.140	3.165	3.171	3.172	3.171
Cell4 [V]	3.150	3.172	3.179	3.179	3.179

No declining voltage (>2.0[mV]) was monitored. All cells are accepted.

4 CHARGE CYCLING DATA PROCEDURES

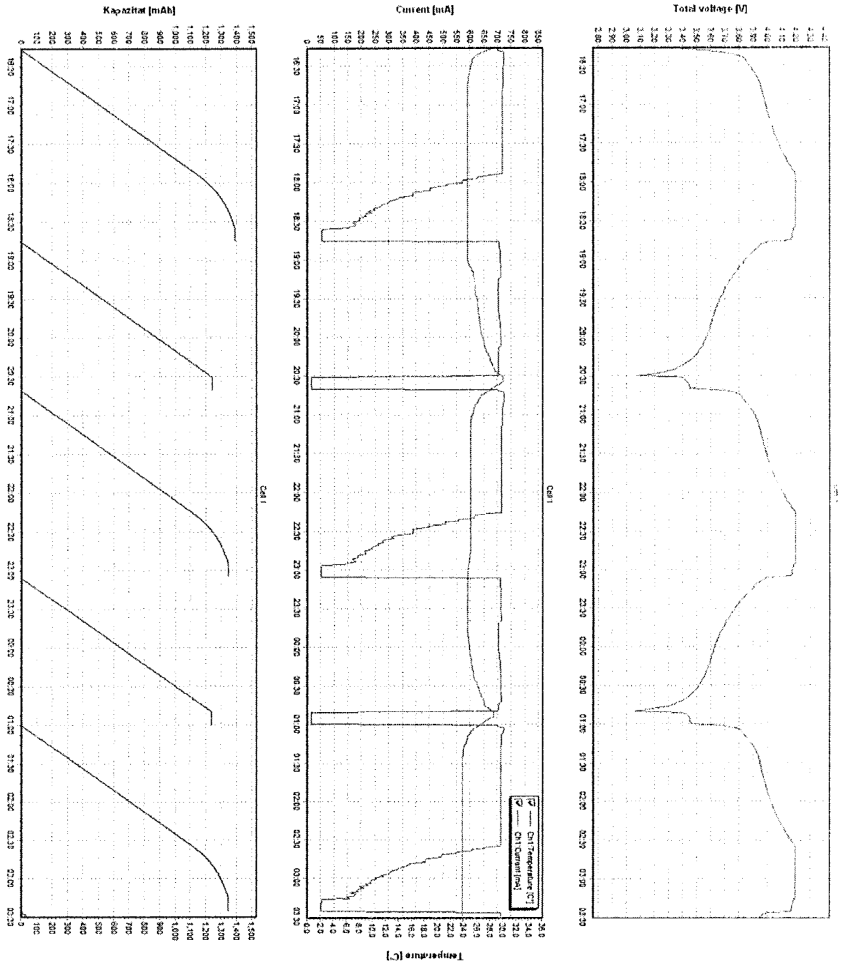
For this test, "Graupner Ultra Duo Plus 60 No.6478" cycle option was used. Batteries were charged and discharged to the recommended manufacture's voltage level - respectively 4.2V for charge and 3V for discharge. According to the test specification. Ten minutes rest to the batteries is provided between every cycle (charge and discharge). Temperature of the battery cells was monitored for the all duration of the test.

The Charge Cycling Data Procedures include the following cycle order:

- Charge
- Discharge
- Charge
- Discharge
- Charge

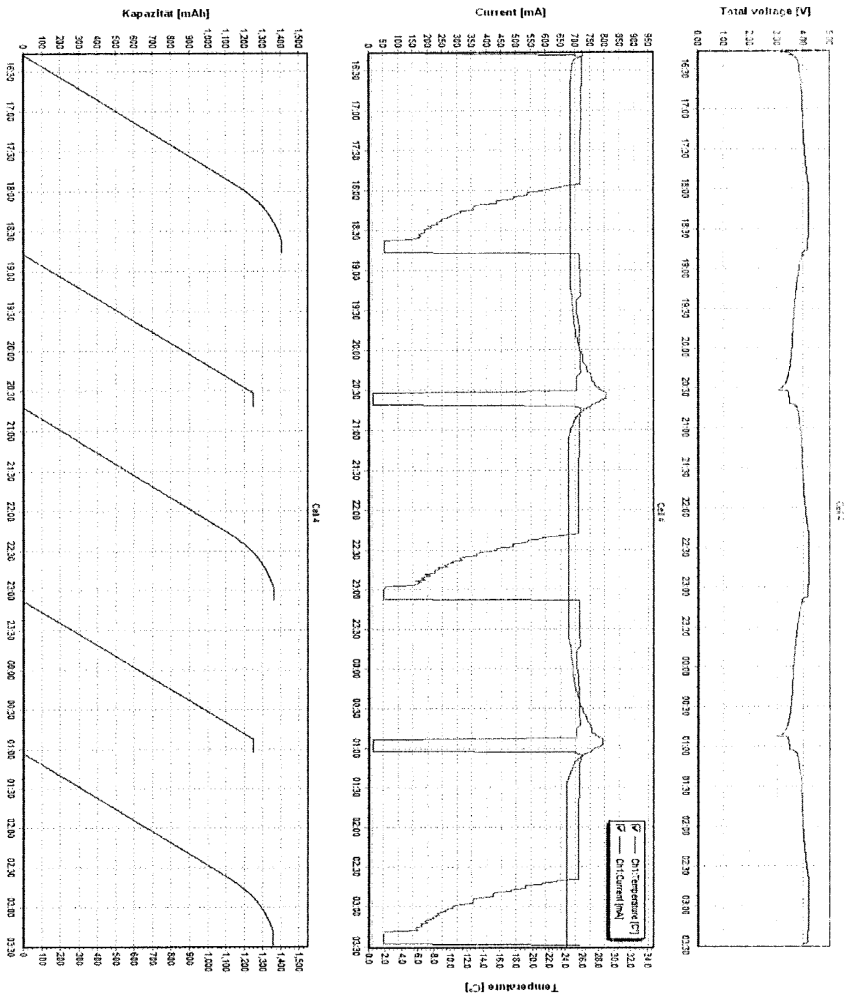
TEST REPORT

Cell 1			
Cycle Order	Voltage [V]	Capacity [mAh]	Temperature [°C]
1.Charge	3.16 → 4.20	1393	28.8 → 24.7
2.Delay	4.20 → 4.17	1393	24.7 → 24.7
3.Discharge	4.15 → 3.01	1244	24.7 → 30.1
4.Delay	3.00 → 3.46	1244	30.1 → 28.2
5.Charge	3.46 → 4.20	1351	28.2 → 24.8
6.Delay	4.20 → 4.17	1351	24.8 → 24.7
7.Discharge	4.15 → 3.01	1240	24.7 → 28.6
8.Delay	3.00 → 3.47	1240	28.6 → 26.7
9.Charge	3.47 → 4.20	1351	26.7 → 23.9



TEST REPORT

Cell 4			
Cycle Order	Voltage [V]	Capacity [mAh]	Temperature [°C]
1.Charge	3.17 → 4.20	1406	26.1 → 24.6
2.Delay	4.20 → 4.17	1406	24.6 → 24.6
3.Discharge	4.15 → 3.01	1252	24.6 → 29.0
4.Delay	3.00 → 3.49	1252	29.0 → 27.2
5.Charge	3.49 → 4.20	1360	27.2 → 24.4
6.Delay	4.20 → 4.17	1360	24.4 → 24.4
7.Discharge	4.15 → 3.01	1251	24.4 → 28.6
8.Delay	3.00 → 3.49	1251	28.6 → 27.0
9.Charge	3.49 → 4.20	1359	27.0 → 24.2



5 CELL OVER-CHARGE PROCEDURES

Battery cells will not be charged while on or at ISS. Over-charge tests was performed to the non-flight cell/battery.

5A
In order to establish overcharge battery protection "RIGOL DP832A Programmable DC Power Supply" device was used. Protection is activated at 4.267V.

5B
To determine the voltage at which the protection circuit module (PCM) feature is reset the same battery cell from 5A was used and discharged with C/5 (300mA). The battery cell immediately reset the overcharge protection. Hysteresis was not found or is too small to be measured.

6 CELL OVER-DISCHARGE PROCEDURE

Over-discharge tests was performed on non-flight cell/battery.

6A
In order to establish over-discharge battery protection "RIGOL DL3021 Programmable DC Electronic Load" was used. Protection is activated at 2.293V.

6B
To determine the voltage at which the protection circuit module feature is resetted, the same battery cell from 6A was used and charge with C/5 (300mA). The battery cell immediately reset the over-discharge protection. Hysteresis was not found or is too small to be measured.

7 EXTERNAL PROTECTION

For the short circuit protection were used the same non-flight battery cell of the procedure described in the section above (Section 6). All cells have integrated protection circuit module. We verified that when short-circuit occurs, the dedicated protection circuit module disconnects the cell till it is removed.

Experimentally, the overcurrent protection activates at 2.285A (using RIGOL DL3021 Programmable DC Electronic Load).

TEST REPORT

8 CIRCUIT SCHEMATIC ANALYSIS

Specification from the Manufacturer:

ELECTRICAL SPECIFICATION

Rated Capacity	1320mAh min., 1400mAh typical
Nominal Voltage	3.7V
Watt-Hour Rating	5.2Wh
Charging Method	Constant Current + Constant Voltage
Max. Charge Voltage	4.2V (±50mV)
Max. Continuous Charge Current	1980mA (limited by cell DS)
Rec. Charge Cut Off	50mA or timer 2.5h
Max. Continuous Discharge Current	2000mA (limited by PCM)
Rec. Discharge Cut Off	3V
Internal Impedance	approx. 100mΩ
Exp. Cycle Life @ (1C/0.5C) @ 23 ±2°C	500 cycles ≥ 1098mAh

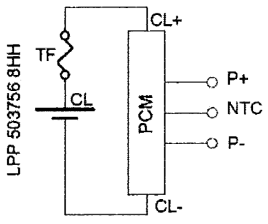
CELL PROTECTION

Overcharge Detection	4.275V ± 25mV (0.7 to 1.3sec. delay, resume 4.275V ± 25mV)
Overdischarge Detection	2.3V ± 58mV (14 to 26msec. delay, resume 2.3V ± 58mV)
Overcurrent Detection	2A to 4.5A (8 to 16msec. delay @ discharge)

AMBIENT CONDITIONS: Temperature Range

Charge	0 to +45°C
Discharge	-20 to +60°C
Storage Capacity Recovery Rate	1 month at -10 to +45°C > 85%
Humidity	65 ± 20%RH

CIRCUIT DIAGRAM



9 VIBRATION TEST

The vibration test has been performed on flight cells installed in the power module following the spectrum as specified in paragraph 9 of the NR-SDR-139 Rev. C. Test report will be provided in hard copy.

The battery cells were fully charged and stacked into battery packs. Measured voltage is 4.165V.

10 VACUUM TEST

The vacuum test has been performed on flight cells installed in the power module following the spectrum as specified in paragraph 10 of the NR-SDR-139 Rev. C.

10A / 10B

Physical properties before the vacuum test are specified in paragraph 3.3.

10C

Cells were fully charged once, before vibration test.

10D

Test has been performed as specified in point D of paragraph 10. Test report will be provided in hard copy

10E

No leaks, deformations or bulges were found after a visual inspection of the cells.

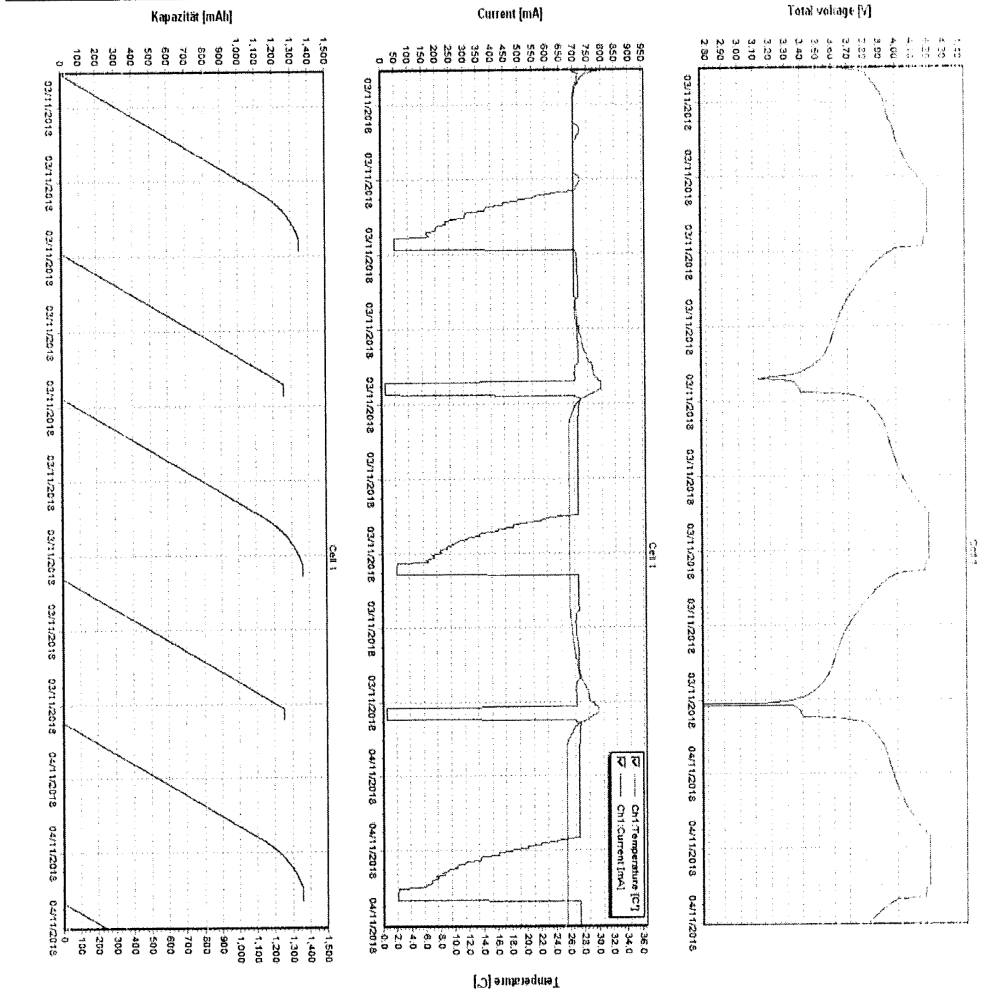
10F and 10G

Physical properties of the cells are the same as in paragraph 3.3. All cells meet criteria (less than 0.1% change in mass).

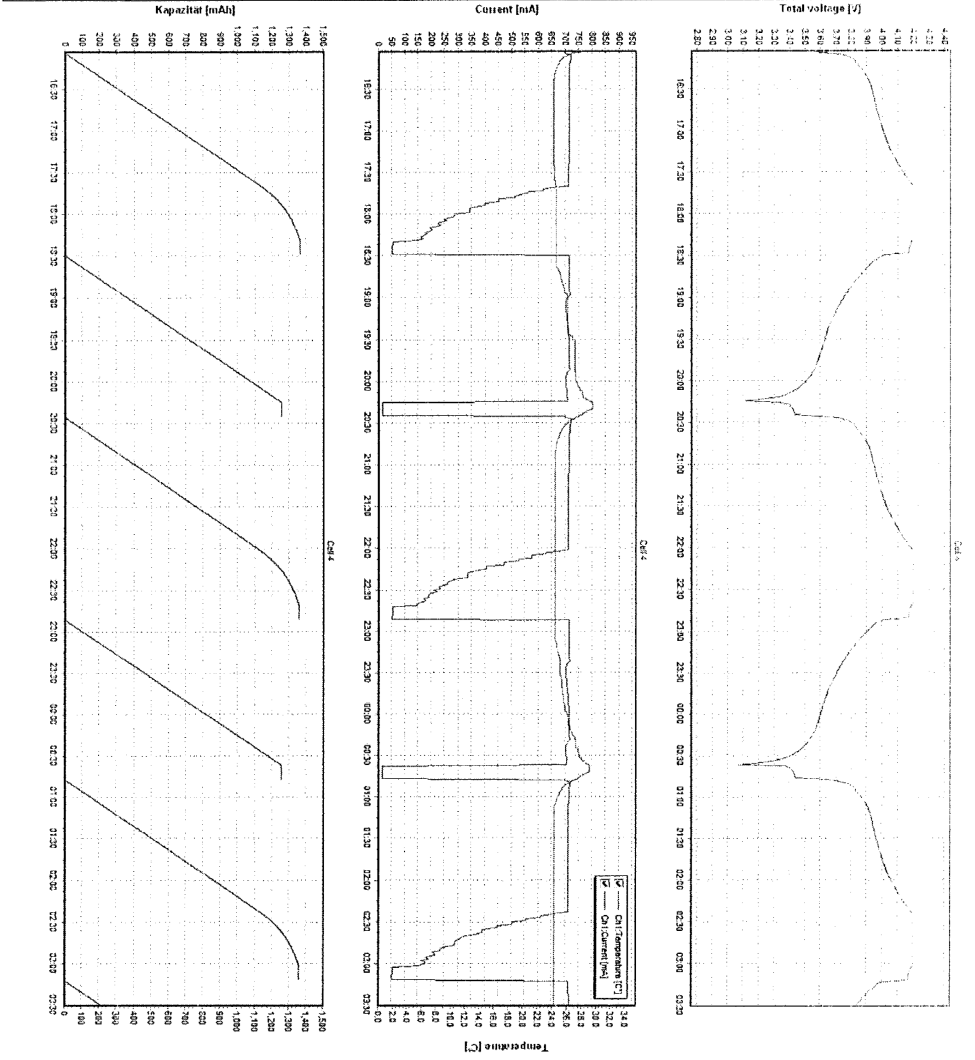
TEST REPORT

10H Charge/discharge cycle after Vacuum test as specified in Section 4:

Cell 1			
Cycle Order	**Voltage [V]**	**Capacity [mAh]**	**Temperature [°C]**
1.Charge	3.53→ 4.20	1351	30.5 → 26.8
2.Delay	4.20 → 4.17	1351	26.8 → 26.8
3.Discharge	4.15 → 3.01	1258	26.8 → 30.5
4.Delay	3.00 → 3.40	1258	30.5 → 29.1
5.Charge	3.40 → 4.20	1364	29.1 → 26.0
6.Delay	4.20 → 4.17	1364	26.0 → 26.0
7.Discharge	4.15 → 3.01	1255	26.0 → 29.9
8.Delay	3.00 → 3.40	1255	29.9 → 28.5
9.Charge	3.40 → 4.20	1360	28.5 → 25.5



Cell 4			
Cycle Order	**Voltage [V]**	**Capacity [mAh]**	**Temperature [°C]**
1.Charge	3.43 → 4.20	1367	27.8 → 24.6
2.Delay	4.20 → 4.17	1367	24.6 → 24.6
3.Discharge	4.15 → 3.01	1260	24.6 → 29.5
4.Delay	3.00 → 3.44	1260	29.5 → 27.7
5.Charge	3.44 → 4.20	1362	27.7 → 24.5
6.Delay	4.20 → 4.17	1362	24.5 → 24.5
7.Discharge	4.15 → 3.01	1258	24.5 → 29.1
8.Delay	3.00 → 3.44	1258	29.1 → 27.5
9.Charge	3.44 → 4.20	1364	27.5 → 24.4



Measured voltage of two packs after vacuum test is 4.162V, change in capacity is less than 5 percent (see results in 10H).

All batteries have successfully passed the test.

Appendix 2

DAS Activity Log

Activity log from NASA Debris Assessment Software

```
05 30 2019; 07:22:18AM Activity Log Started
05 30 2019; 07:22:18AM Opened Project C:\NASA\DAS2.1.1\OFII_b\
05 30 2019; 07:22:45AM Activity Log Started
05 30 2019; 07:22:45AM Opened Project C:\NASA\DAS2.1.1\OFII_b\
05 30 2019; 07:26:05AM Mission Editor Changes Applied
05 30 2019; 07:26:12AM Processing Requirement 4.3-1:     Return Status :
Not Run

=====================
No Project Data Available
=====================

============== End of Requirement 4.3-1 ===============
05 30 2019; 07:26:19AM Processing Requirement 4.3-2: Return Status :
Passed

=====================
No Project Data Available
=====================

============== End of Requirement 4.3-2 ===============
05 30 2019; 07:26:22AM Requirement 4.4-3:  Compliant

============== End of Requirement 4.4-3 ===============
05 30 2019; 07:30:36AM Processing Requirement 4.5-1:     Return Status :
Passed

==============
Run Data
==============

**INPUT**

      Space Structure Name = Orbital Factory II
      Space Structure Type = Payload
      Perigee Altitude = 465.000000 (km)
      Apogee Altitude = 475.000000 (km)
      Inclination = 51.692000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass Ratio = 0.012116 (m^2/kg)
      Start Year = 2019.000000 (yr)
      Initial Mass = 1.454000 (kg)
      Final Mass = 1.454000 (kg)
      Duration = 10.000000 (yr)
      Station-Kept = False
```

```
      Abandoned = True
      PMD Perigee Altitude = -1.000000 (km)
      PMD Apogee Altitude = -1.000000 (km)
      PMD Inclination = 0.000000 (deg)
      PMD RAAN = 0.000000 (deg)
      PMD Argument of Perigee = 0.000000 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Collision Probability = 0.000000
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range
      Status = Pass

==============

=============== End of Requirement 4.5-1 ===============
05 30 2019; 07:35:54AM Requirement 4.5-2:  Compliant

================================================
Spacecraft = Orbital Factory II
Critical Surface = On Board Computer
================================================

**INPUT**

      Apogee Altitude = 475.000000 (km)
      Perigee Altitude = 465.000000 (km)
      Orbital Inclination = 51.692000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.012116 (m^2/kg)
      Initial Mass = 1.454000 (kg)
      Final Mass = 1.454000 (kg)
      Station Kept = No
      Start Year = 2019.000000 (yr)
      Duration = 10.000000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 2.320000 (g/cm^2)
      CS Surface Area = 0.019190 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 0.200000 (cm)

**OUTPUT**
```

```
      Probabilty of Penetration = 0.000156 (0.000156)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

================================================
Spacecraft = Orbital Factory II
Critical Surface = Battery
================================================

**INPUT**

      Apogee Altitude = 475.000000 (km)
      Perigee Altitude = 465.000000 (km)
      Orbital Inclination = 51.692000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.012116 (m^2/kg)
      Initial Mass = 1.454000 (kg)
      Final Mass = 1.454000 (kg)
      Station Kept = No
      Start Year = 2019.000000 (yr)
      Duration = 10.000000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 2.700000 (g/cm^2)
      CS Surface Area = 0.025213 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 0.200000 (cm)
      Outer Wall 2   Density: 2.700000 (g/cm^2)  Separation: 0.200000 (cm)

**OUTPUT**

      Probabilty of Penetration = 0.000005 (0.000005)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

================================================
Spacecraft = Orbital Factory II
Critical Surface = UHF  Receiver
================================================

**INPUT**

      Apogee Altitude = 475.000000 (km)
      Perigee Altitude = 465.000000 (km)
```

```
      Orbital Inclination = 51.692000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.012116 (m^2/kg)
      Initial Mass = 1.454000 (kg)
      Final Mass = 1.454000 (kg)
      Station Kept = No
      Start Year = 2019.000000 (yr)
      Duration = 10.000000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 2.700000 (g/cm^2)
      CS Surface Area = 0.020958 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 0.200000 (cm)
      Outer Wall 2   Density: 2.700000 (g/cm^2)  Separation: 0.200000 (cm)

**OUTPUT**

      Probabilty of Penetration = 0.000004 (0.000004)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range


05 30 2019; 07:36:56AM Processing Requirement 4.6   Return Status :
Passed

==============
Project Data
==============

**INPUT**

      Space Structure Name = Orbital Factory II
      Space Structure Type = Payload

      Perigee Altitude = 465.000000 (km)
      Apogee Altitude = 475.000000 (km)
      Inclination = 51.692000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.012116 (m^2/kg)
      Start Year = 2019.000000 (yr)
      Initial Mass = 1.454000 (kg)
      Final Mass = 1.454000 (kg)
```

```
      Duration = 10.000000 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = -1.000000 (km)
      PMD Apogee Altitude = -1.000000 (km)
      PMD Inclination = 0.000000 (deg)
      PMD RAAN = 0.000000 (deg)
      PMD Argument of Perigee = 0.000000 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Suggested Perigee Altitude = 465.000000 (km)
      Suggested Apogee Altitude = 475.000000 (km)
      Returned Error Message = Reentry during mission (no PMD req.).

      Released Year = 2022 (yr)
      Requirement = 61
      Compliance Status = Pass

==============

=============== End of Requirement 4.6 ===============
05 30 2019; 07:38:40AM *********Processing Requirement 4.7-1
      Return Status :  Passed

***********INPUT****
 Item Number = 1

name = Orbital Factory II
quantity = 1
parent = 0
materialID = 8
type = Box
Aero Mass = 1.454000
Thermal Mass = 1.454000
Diameter/Width = 0.100000
Length = 0.113500
Height = 0.100000

name = Solar Panel
quantity = 5
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.053000
Thermal Mass = 0.053000
```

```
Diameter/Width = 0.083000
Length = 0.098000

name = Patch Antenna
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.117000
Thermal Mass = 0.117000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.007000

name = UHF Antenna
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.085000
Thermal Mass = 0.085000
Diameter/Width = 0.098000
Length = 0.098000
Height = 0.005600

name = OFII Body
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.972550
Thermal Mass = 0.272000
Diameter/Width = 0.100000
Length = 0.113500
Height = 0.100000

name = UHF Transceiver
quantity = 1
parent = 5
materialID = 8
type = Box
Aero Mass = 0.094000
Thermal Mass = 0.053800
Diameter/Width = 0.089000
Length = 0.095000
Height = 0.011000
```

```
name = UHF Board
quantity = 1
parent = 6
materialID = 23
type = Flat Plate
Aero Mass = 0.040200
Thermal Mass = 0.040200
Diameter/Width = 0.089000
Length = 0.095000

name = Sband Transceiver
quantity = 1
parent = 5
materialID = 8
type = Box
Aero Mass = 0.270000
Thermal Mass = 0.089900
Diameter/Width = 0.090200
Length = 0.096000
Height = 0.017000

name = Sband Board
quantity = 1
parent = 8
materialID = 8
type = Flat Plate
Aero Mass = 0.180100
Thermal Mass = 0.180100
Diameter/Width = 0.090200
Length = 0.096000

name = EPS
quantity = 1
parent = 5
materialID = 8
type = Box
Aero Mass = 0.198000
Thermal Mass = 0.066000
Diameter/Width = 0.090200
Length = 0.096000
Height = 0.021200

name = EPS Board
quantity = 1
parent = 10
materialID = 23
type = Flat Plate
```

```
Aero Mass = 0.058000
Thermal Mass = 0.058000
Diameter/Width = 0.090200
Length = 0.096000

name = Battery
quantity = 1
parent = 10
materialID = 8
type = Box
Aero Mass = 0.074000
Thermal Mass = 0.074000
Diameter/Width = 0.077000
Length = 0.079000
Height = 0.009800

name = Payload Board
quantity = 1
parent = 5
materialID = 23
type = Flat Plate
Aero Mass = 0.067000
Thermal Mass = 0.058000
Diameter/Width = 0.095000
Length = 0.095000

name = Camera 1
quantity = 1
parent = 13
materialID = 50
type = Box
Aero Mass = 0.004000
Thermal Mass = 0.004000
Diameter/Width = 0.020000
Length = 0.030000
Height = 0.010000

name = Camera 2
quantity = 1
parent = 13
materialID = 23
type = Cylinder
Aero Mass = 0.005000
Thermal Mass = 0.005000
Diameter/Width = 0.014000
Length = 0.024000
```

```
name = Printer Rail
quantity = 2
parent = 5
materialID = 50
type = Box
Aero Mass = 0.004000
Thermal Mass = 0.004000
Diameter/Width = 0.030000
Length = 0.093000
Height = 0.012000

name = Printer Nozzle
quantity = 1
parent = 5
materialID = 50
type = Box
Aero Mass = 0.005550
Thermal Mass = 0.005550
Diameter/Width = 0.012000
Length = 0.056000
Height = 0.012000

name = OBC
quantity = 1
parent = 5
materialID = 23
type = Flat Plate
Aero Mass = 0.058000
Thermal Mass = 0.058000
Diameter/Width = 0.095000
Length = 0.095000

**************OUTPUT****
Item Number = 1

name = Orbital Factory II
Demise Altitude = 77.997513
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Solar Panel
Demise Altitude = 76.867035
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
```

```
name = Patch Antenna
Demise Altitude = 75.008255
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = UHF Antenna
Demise Altitude = 75.702698
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = OFII Body
Demise Altitude = 75.491394
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = UHF Transceiver
Demise Altitude = 74.154922
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = UHF Board
Demise Altitude = 73.070686
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Sband Transceiver
Demise Altitude = 73.571815
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Sband Board
Demise Altitude = 67.264984
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = EPS
Demise Altitude = 74.144539
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
************************************
name = EPS Board
Demise Altitude = 72.812515
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Battery
Demise Altitude = 71.239212
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Payload Board
Demise Altitude = 74.335960
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Camera 1
Demise Altitude = 74.113480
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Camera 2
Demise Altitude = 73.216194
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Printer Rail
Demise Altitude = 75.440567
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Printer Nozzle
Demise Altitude = 75.303802
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = OBC
Demise Altitude = 74.316193
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
************************************

=============== End of Requirement 4.7-1 ===============
05 30 2019; 07:39:10AM Science and Engineering - Apogee/Perigee History
for a Given Orbit

**INPUT**

      Perigee Altitude = 465.000000 (km)
      Apogee Altitude = 475.000000 (km)
      Inclination = 51.692000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.012116 (m^2/kg)
      Start Year = 2019.920000 (yr)
      Integration Time = 10.000000 (yr)

**OUTPUT**

      Plot
05 30 2019; 07:40:25AM Project Data Saved To File
```