ArduSat Inc

ArduSat-X Orbital Debris Assessment Report (ODAR)

Revision #: 0

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Contents:

Summarized List of Compliance Status to Orbital Debris Requirements

For convenience, below is a summarized list of the compliance status to orbital debris requirements. Detailed explanations for each of these compliance statements are available in ODAR Sections 1 through 8.

4.3-1, Mission-Related Debris Passing Through LEO: **COMPLIANT**

4.3-2, Mission-Related Debris Passing Near GEO: **COMPLIANT**

4.4-1, Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon: **COMPLIANT**

4.4-2, Design for passivation after completion of mission operations while in orbit about Earth or the Moon: **N/A**

4.4-3, Limiting the long-term risk to other space systems from planned breakups: **COMPLIANT**

4.4-4, Limiting the short-term risk to other space systems from planned breakups: **COMPLIANT**

4.5-1, Probability of Collision with Large Objects: **COMPLIANT**

4.5-2, Probability of Damage from Small Objects: **COMPLIANT**

4.6-1, Disposal for space structures passing through LEO: **COMPLIANT**

4.6-2, Disposal for space structures passing through GEO: **N/A**

4.6-3, Disposal for space structures between LEO and GEO: **N/A**

4.6-4, Reliability of postmission disposal operations: **N/A**

4.8-1, Collision Hazards of Space Tethers: **N/A**

ODAR Section 1: Program Management and Mission Overview

Program / Project Manager	Peter Platzer
Mission Description	ArduSat-X, short for "Arduino Satellite", is an educational nanosatellite built in the CubeSat form factor that carries a suite of sensors and a payload computer that can be reprogrammed while in space. The user-programmable payload computer is comprised of an array of Arduino processors (AVR processors), and can run code developed on the ubiquitous, open-source Arduino software development platform. ArduSats were invented with the purpose of creating an inexpensive, accessible development platform in space on which students, teachers, hobbyists, and researchers could affordably create and run their own custom-built experiments and applications. Users can design their own space-based applications, experiments, and even space-games using the ubiquitous Arduino open-source prototyping platform. Once the application has passed ground testing on an ArduSat clone, users can upload their applications to the satellite's payload computer in space, where it is watchdogged and maintained by the satellite's main computer. From there, the applications are free to sample data from the payload sensors and bus, take pictures, and return data to the user's web browser whenever the satellite is in range of a participating ground station. At the end of the user's experiment period, which can be up to a week in length, any remaining data is downlinked and returned to the user. The satellite's payload consists a suite of sensors, including an optical spectrometer, Geiger counter, atmospheric sensor, infrared sensor, accelerometer & gyro, magnetometer, sun sensor, electromagnetic wave sensor, dual-frequency GPS receiver (for ionospheric studies), a megapixel camera, and more. The sensors (and other telemetry values) are sampled by the user-generated programs running on the payload computer. ArduSat fits in the 1U CubeSat form factor, with a total mass of only 1.3kg and outer envelope of 10cm x 10cm x 10cm (excluding the deployable dipole antenna). The ArduSat project was featured on the crowd-funding website Kickstarter where, in addition to raising substantial awareness and attracting nearly 700 private space enthusiasts as direct contributors, it raised enough support to fund the development of two 1U ArduSat satellites.
Project Milestones:	The development of the first ArduSat, a 1U CubeSat with a prototype of the Arduino-based payload computer, began in April 2012 as a volunteer effort by four graduate students at the International Space University. In June 2012, the founders formed the ArduSat Inc, a not-for-profit corporation whose purpose is to make the ArduSat space development platform accessible and affordable to students. At the time of delivery of the document, ArduSat-X was undergoing final integration at the GOMSpace facilities (an engineering partner of the ArduSat project) in Aalborg, Denmark.
Foreign Government Involvement	None
Proposed Launch Date:	July 15th, 2013
Proposed Launch Vehicle:	HII-B / HTV 4
Proposed Launch Site:	Tanegashima Space Centre, Japan
Launch Vehicle Operator:	NASA / JAXA (LSA via NanoRacks LLC)

Mission Duration	Approximately 3 months following deployment from the ISS
Launch / Deployment Profile:	ArduSat-X will be launched in the soft-stowage compartment of the HTV-4 vehicle, and transferred to the manned portion of the ISS following docking of the HTV-4 vehicle to the station. Approximately 1 month (estimated) following the berthing of the HTV-4 vehicle to the ISS, ArduSat-X will be deployed to a free-flying orbit. Estimates of orbital decay performed using DAS 2.0.2 software indicate that the satellite will reenter the atmosphere approximately 3 months following deployment, depending on the deployment altitude and post-deployment solar activity. Apogee Altitude: 380-410km Perigee Altitude: 380-410km Inclination: 51.6 degrees
Selection of Orbit:	The selection of the ISS orbit was made due to available launch opportunities and a lack of onboard propulsion systems.
Potential Physical Interference with Other Orbiting Object:	As ArduSat-X has no active propulsion systems, its orbit will naturally decay following deployment from the ISS. Consequently, the only period during which there is potential physical interference with the station is during its deployment, after which normally-scheduled station maintenance maneuvers by the ISS will place it at a higher altitude. As detailed in Section 5, the probability of physical interference between ArduSat-X and any other orbiting bodies is sufficiently unlikely that the satellite complies requirement 4.5.

ODAR Section 2: Spacecraft Description

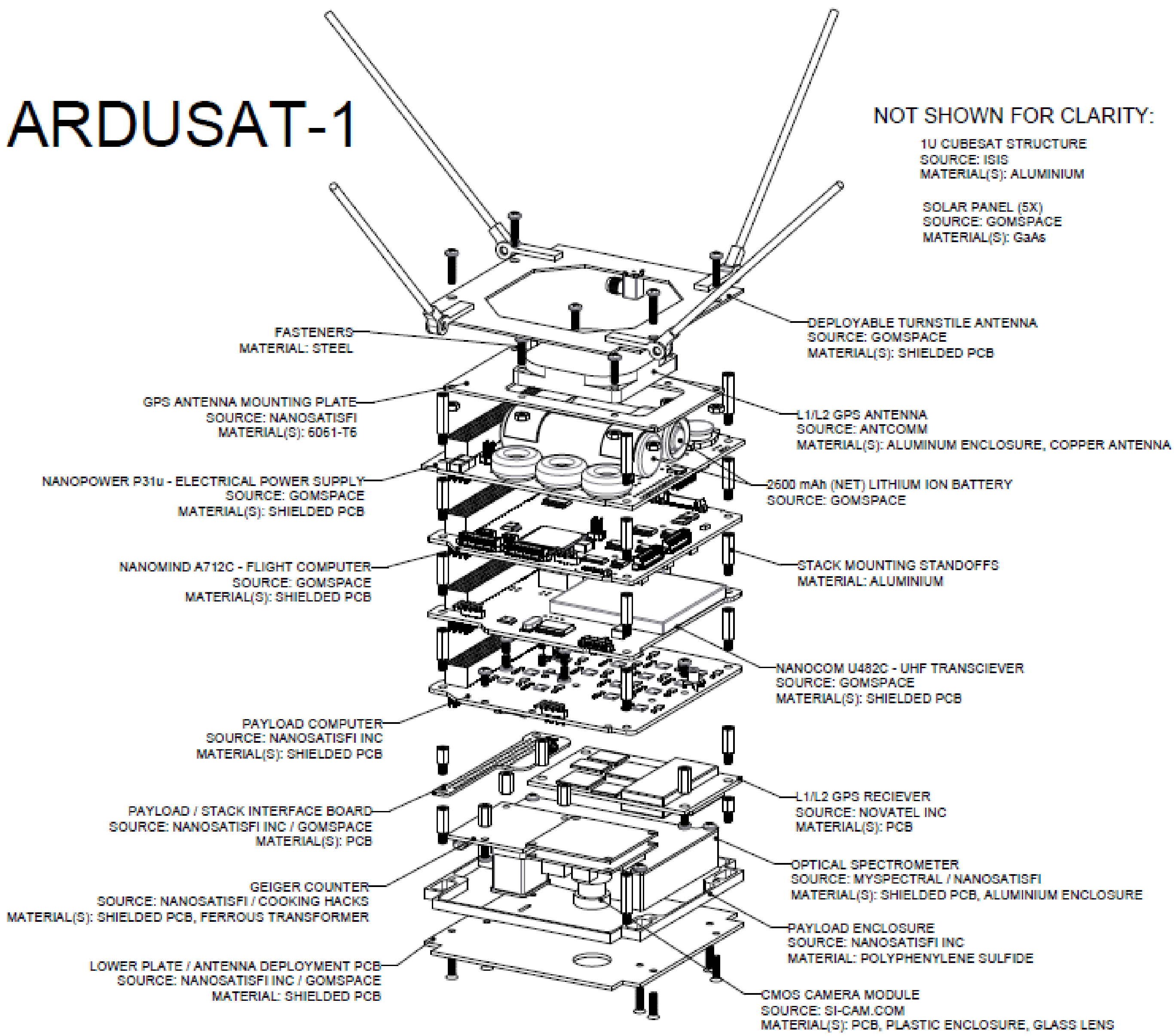
Physical Description:

ArduSat-X is a 1U “CubeSat” nanosatellite, in compliance with the CalPoly CubeSat standard. As such, it has a rectangular outer envelope of 100mm X 100mm X 113.5mm, and a net mass of 1.3kg, with its center of mass within 0.05m radial distance from the satellite geometric center. ArduSat-X does not have any deployable solar panels, instrument arrays, apertures, or booms. The only deployable system on the satellite are four turnstile ¼ wavelength antennae, which are released into turnstile configuration using redundant burn wires. The satellite uses three independent inhibits (1 hard switch and two soft switches) to prevent the satellite from transmitting or deploying its antenna prior to 30 minutes following deployment from the ISS.

ArduSat-X’s payload consists of an array of sensors, including an optical spectrometer, Geiger counter, atmospheric sensor, infrared sensor, accelerometer & gyro, magnetometer, sun sensor, electromagnetic wave sensor, dual-frequency GPS receiver for ionospheric studies, and 1.3 megapixel camera.

Detailed Illustration:

Below is an exploded view of the ArduSat-1 flight configuration, with significant subsystems labelled. Systems not shown for clarity include the satellite structure (a 1U CubeSat structure manufactured by ISIS), and the external solar panels. **ArduSat-X is an exact duplicate of the ArduSat-1 satellite.**



Total Mass at Launch: 1.3 kg

Dry Mass at Launch: N/A (to propellants / propulsion systems)

Description of Propulsion Systems: None

Identification of Fluids + Fluid Systems: None

Description of AOCS:

ArduSat-X uses an active 3-axis stabilization control system to determine its attitude to within +/- 5 degrees, and to control its attitude to within +/- degrees. The AOCS system consists of a 3-axis magnetometer, gyroscope, sun sensors, and three orthogonal magnetotorquer coils. The normal attitude of the satellite maintains the normal vector of the side of the antenna on which the turnstile antenna is mounted aligned with the zenith vector.

Range Safety / Pyrotechnic Devices: None

Electrical Generation / Storage System:

Power is generated using five body-mounted solar panels, manufactured by GOMSpace. All of the solar panels include triple-junction gallium arsenide photovoltaic cells, and an embedded sun sensor. Three of the solar panels also include an embedded magnetotorquer coil, used for attitude control as explained in the AOCS section.
Power generated by the solar cells is conditioned, stored and distributed with an integrated Electrical Power Supply (EPS), a NanoPower P31u from GOMSpace. The EPS collects power using three independent power conditioning units to perform power-point tracking. The EPS stores power using an on-board 2600mAh lithium ion battery pack. Power is then distributed using six independent latchup-protected buses, three at 3.3V and three at 5.0V.

Other Energy Storage Devices: None

Radioactive Materials: There are no radioactive materials onboard the ArduSat-X spacecraft.

ODAR Section 3: Assessment of Debris Released During Normal Operations

Objects larger than 1mm expected to be released during orbit: None

Rationale for release of each object: N/A

Time of release of each object: N/A

Release velocity of each object: N/A

Expected orbital parameters of each object: N/A

Calculated orbital lifetime of each object: N/A

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2:

4.3-1, Mission-Related Debris Passing Through LEO: **COMPLIANT**

4.3-2, Mission-Related Debris Passing Near GEO: **COMPLIANT**

A DAS 2.0.2 log demonstrating the compliance of ArduSat-X to the above requirements is available in Appendix A – "ArduSat-X DAS 2.0.2 Log".

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

Potential causes for spacecraft breakup:

As there are compressed fluids, energy-storage mechanics, pyrotechnics, moving parts, or propellants on board ArduSat-X, there is no plausible cause for breakup of ArduSat-X.

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

The batteries aboard ArduSat-X are 2600mAh Lithium-Ion cells, and represent the only credible failure mode during which stored energy is released. The main failure modes associated with Lithium Ion batteries result from overcharging, overdischarging, internal shorts, and external shorts.[1]

As ArduSat-X will be passing through the crewed component of the ISS, ArduSat-X's onboard batteries are in compliance with NASA's Crewed Space Vehicle Battery Safety Requirements (JSC-20793), and comply with all controls / process requirements identified in JSC-20793 Section 5.4.3 to mitigate chance of any accidental venting / explosion.

Detailed Plan for any designed spacecraft breakup, including explosions and intentional collisions:

There is no designed breakup of ArduSat-X on-orbit.

List of components passivated at EOM:

There are no components aboard ArduSat-X that require passivation or could be passivated.

Rationale for all items required to be passivated that can not be due to design:

N/A

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

4.4-1, Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon: **COMPLIANT**

4.4-2, Design for passivation after completion of mission operations while in orbit about Earth or the Moon:

COMPLIANT

Upon completion of its mission, ArduSat-X will naturally reenter Earth's atmosphere; consequently, there is zero probability that ArduSat-X will release orbital debris post-mission.

4.4-3, Limiting the long-term risk to other space systems from planned breakups: **COMPLIANT**

There are no planned breakups of ArduSat-X.

4.4-4, Limiting the short-term risk to other space systems from planned breakups: **COMPLIANT**

There are no planned breakups of ArduSat-X.

[1] *Crewed Space Vehicle Battery Safety Requirements,* NASA Engineering Directorate Energy Systems Division, Revision B

ODAR Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Probability for Collision with Objects >10cm:

The probability of a collision of ArduSat-X with an orbiting object larger than 10cm in diameter was sufficiently small that the simulation performed using DAS 2.0.2 software returned a probability value of 0.

Assessment of spacecraft compliance with Requirement 4.5-1 and 4.5-2:

4.5-1, Probability of Collision with Large Objects: **COMPLIANT**

4.5-2, Probability of Damage from Small Objects: **COMPLIANT**

A DAS 2.0.2 log demonstrating the compliance of ArduSat-X to the above requirements is available in Appendix A – "ArduSat-X DAS 2.0.2 Log".

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

Description of Disposal Option Selected:

Following its deployment from the ISS, ArduSat-X's orbit will naturally decay until the satellite reenters the atmosphere after approximately 3 months. As detailed in Section 7, ArduSat-X will completely disintegrate during reentry, with no components surviving reentry to the ground.

Identification of Systems Required for Postmission Disposal: None

Plan for Spacecraft Maneuvers required for Postmission Disposal: N/A

Calculation of final Area-to-Mass Ratio if Atmospheric Reentry Not Selected: N/A

Assessment of Spacecraft Compliance with Requirements 4.6-1 through 4.6-4:

4.6-1, Disposal for space structures passing through LEO: **COMPLIANT**

ArduSat-X will reenter the atmosphere within 25 years of mission completion and 30 years of launch.

4.6-2, Disposal for space structures passing through GEO: **N/A**

4.6-3, Disposal for space structures between LEO and GEO: **N/A**

4.6-4, Reliability of postmission disposal operations: **N/A**

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

Detailed description of spacecraft components by size, mass, material, shape, and original location on the space vehicle:

A system-level mass breakdown and primary materials list included in ArduSat-X is available in the table below:

Subsystem	Material(s)	Mass (g)
AOCS		
GPS Receiver	PCB, aluminum	22
GPS Antenna	Aluminum, copper	59
Payload		
Payload Computer	PCB	60
Spectruino Card + optics	PCB, glass	16
Geiger Counter	PCB, iron (transformer)	27
Camera	PCB, glass	20
Bottom Sensor Plate	PCB	40
Communications		
Transceiver	PCB, aluminum	75
UHF/VHF Antenna	PCB, copper	30
OBDH		
Main Computer	PCB	55
Power		
Solar Panel (1u top)	GaAs	50
Solar Panel 2x(1u side)	GaAs	118
Solar Panel 2x(1u side)	GaAs	118
EPS W/ int Battery	PCB, Li-Ion	225
Structure		
Primary Structure	Aluminum	200
GPS Antenna Mounting Plate	Aluminum	12
Spectruino enclosure	Aluminum	25
Mounting Hardware	Aluminum, zinc-plated steel	30
Harness		100
TOTAL		**1282**

The system-level mass breakdown and shape approximations for each system used during the atmospheric reentry risk assessment is available in Appendix A – "ArduSat-X DAS 2.0.2 Log".

Summary of objects expected to survive an uncontrolled reentry (using DAS 2.0.2 software): None

Calculation of probability of human casualty for expected reentry year and inclination: 0%

Assessment of spacecraft compliance with Requirement 4.7-1:

4.7-1, Casualty Risk from Reentry Debris: **COMPLIANT**

A DAS 2.0.2 log demonstrating the compliance of ArduSat-X to Requirement 4.7-1 is available in Appendix A – "ArduSat-X DAS 2.0.2 Log".

ODAR Section 7A: Assessment of Spacecraft Hazardous Materials

Summary of Hazardous Materials Contained on Spacecraft: None

ODAR Section 8: Assessment for Tether Missions

Type of tether: N/A

Description of tether system: N/A

Determination of minimum size of object that will cause the tether to be severed: N/A

Tether mission plan, including duration and postmission disposal: N/A

Probability of tether colliding with large space objects: N/A

Probability of tether being severed during mission or after postmission disposal: N/A

Maximum orbital lifetime of a severed tether fragment: N/A

Assessment of compliance with Requirement 4.8-1:

4.8-1, Collision Hazards of Space Tethers: **N/A**

Appendix A: ArduSat-X DAS 2.0.2 Log

Below is a log of an assessment performed of the ArduSat-X mission using DAS 2.0.2 software, copied unmodified from the software log file.

```
03 22 2013; 12:32:00PM DAS Application Started
03 22 2013; 12:36:56PM Processing Requirement 4.3-1: Return Status : Not Run
=====================
No Project Data Available
=====================
=============== End of Requirement 4.3-1 ===============
03 22 2013; 12:36:58PM Processing Requirement 4.3-2: Return Status : Passed
=====================
No Project Data Available
=====================
=============== End of Requirement 4.3-2 ===============
03 22 2013; 12:37:01PM Requirement 4.4-3: Compliant
=============== End of Requirement 4.4-3 ===============
03 22 2013; 12:37:04PM Processing Requirement 4.5-1: Return Status : Passed
==============
Run Data
==============
**INPUT**
Space Structure Name = ArduSat-X
Space Structure Type = Payload
Perigee Altitude = 410.000000 (km)
Apogee Altitude = 410.000000 (km)
Inclination = 51.600000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.009692 (m^2/kg)
Start Year = 2013.000000 (yr)
Initial Mass = 1.300000 (kg)
Final Mass = 1.300000 (kg)
Duration = 0.575000 (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 ===============
03 22 2013; 12:37:07PM Requirement 4.5-2: Compliant
03 22 2013; 12:37:09PM Processing Requirement 4.6 Return Status : Passed
==============
Project Data
==============
**INPUT**
Space Structure Name = ArduSat-X
Space Structure Type = Payload
Perigee Altitude = 410.000000 (km)
Apogee Altitude = 410.000000 (km)
Inclination = 51.600000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.009692 (m^2/kg)
Start Year = 2013.000000 (yr)
Initial Mass = 2.600000 (kg)
Final Mass = 2.600000 (kg)
Duration = 0.575000 (yr)
Station Kept = False
Abandoned = True
PMD Perigee Altitude = 141.114123 (km)
PMD Apogee Altitude = 143.623859 (km)
PMD Inclination = 51.568766 (deg)
PMD RAAN = 5.721620 (deg)
PMD Argument of Perigee = 59.900725 (deg)
PMD Mean Anomaly = 0.000000 (deg)
**OUTPUT**
Suggested Perigee Altitude = 141.114123 (km)
Suggested Apogee Altitude = 143.623859 (km)
Returned Error Message = Passes LEO reentry orbit criteria.
Released Year = 2013 (yr)
Requirement = 61
Compliance Status = Pass
==============
=============== End of Requirement 4.6 ===============
03 22 2013; 12:37:17PM *********Processing Requirement 4.7-1
```

```
Return Status : Passed
***********INPUT****
Item Number = 1
name = ArduSat-X
quantity = 1
parent = 0
materialID = 5
type = Box
Aero Mass = 2.600000
Thermal Mass = 2.600000
Diameter/Width = 0.100000
Length = 0.227000
Height = 0.100000
name = Structure+Antennae
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.390000
Thermal Mass = 0.390000
Diameter/Width = 0.100000
Length = 0.227000
Height = 0.100000
name = Battery
quantity = 1
parent = 1
materialID = 39
type = Cylinder
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.015000
Length = 0.060000
name = Electronics
quantity = 1
parent = 1
materialID = 19
type = Box
Aero Mass = 2.060000
Thermal Mass = 2.060000
Diameter/Width = 0.095000
Length = 0.200000
Height = 0.095000
name = Transformer
quantity = 1
parent = 1
materialID = 38
type = Box
Aero Mass = 0.050000
```

```
Thermal Mass = 0.050000
Diameter/Width = 0.020000
Length = 0.050000
Height = 0.014000
*************OUTPUT****
Item Number = 1
name = ArduSat-X
Demise Altitude = 77.996980
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
*************************************
name = Structure+Antennae
Demise Altitude = 75.736793
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
*************************************
name = Battery
Demise Altitude = 77.440996
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
*************************************
name = Electronics
Demise Altitude = 69.388925
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
*************************************
name = Transformer
Demise Altitude = 68.616253
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
*************************************
```

=============== End of Requirement 4.7-1 ===============