Dodona CubeSat
Orbital Debris Assessment Report (ODAR)

07/01/2021

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Dodona CubeSat ODAR

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Orbital Debris Requirement Compliance Matrix

The following table summarizes the compliance status of the Dodona CubeSat, which will be flown as a payload on the D-Orbit S.p.A. ("D-Orbit") InOrbit NOW (ION) CubeSat Carrier. The D-Orbit CubeSat Carrier, ION, will be flown as the secondary payload on the SpaceX Falcon-9 launch vehicle. The CubeSat is fully compliant with all applicable requirements pertaining to NASA-STD-8719.14B and shown below using the format provided in Appendix A.2 of NASA-STD-8719.14.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	**Compliance Assessment**	**Comments**
4.3-1(a)	Not applicable	No planned debris release
4.3-1(b)	Not applicable	No planned debris release
4.3-2	Not applicable	No planned debris release
4.4-1	Compliant	On board batteries incapable of debris-producing failures
4.4-2	Compliant	On board batteries incapable of debris-producing failures
4.4-3	Not applicable	No intentional breakups
4.4-4	Not applicable	No intentional breakups
4.5-1	Compliant	
4.5-2	Not applicable	No End Of Mission (EOM) critical hardware
4.6-1(a)	Compliant	Orbital lifetime of 8.4 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 planned tether release

List of Revisions

Revision	Revision Date	Author	Revision Description
-	07/01/2021	Andrew McBride	Initial Release

Debris Assessment Software (DAS)

NASA Debris Assessment Software (DAS) version 3.1.2 was used for the DAS analysis outlined in this report.

Section 1: Mission Overview

The Dodona CubeSat is a collaborative effort between Lockheed Martin Corporation and the University of Southern California's Space Engineering Research Center. The primary focus of the mission is a proof-of-concept for Lockheed Martin Corporation's SmartSat™ software, which is designed for complex mission operations. SmartSat™ provides modularity, reprogrammability, and onboard CPU intensive algorithms. The CubeSat will capture visible and IR images of the Earth's surface, perform image processing, and downlink both performance telemetry and cropped images to the ground.

Dodona will be one of the CubeSat payloads onboard the D-Orbit ION CubeSat Carrier, which is the secondary payload on the SpaceX Falcon-9 launch vehicle. Dodona will be dispensed using a D-Orbit DPOD CubeSat dispenser at an altitude of 525 km ±25 km, and 97.5° inclination Sun-Synchronous Orbit (SSO). The CubeSat will begin operations upon first contact with the ground. Operations are expected to take place for 180 days.

Section 2: Spacecraft Description

The Dodona CubeSat consists of three main sections: the CubeSat bus, an Attitude Determination and Control System (ADACS), and a custom-built payload that sits atop the bus, shown in Figure 1 below. The primary functions of the bus are driven by a motherboard and processor module. The spacecraft is powered by a dual battery board and remote battery board. Charge is maintained through the Electrical Power Subsystem (EPS) board with power from 4 solar array panels, which are deployed using nichrome burn wires after dispense.

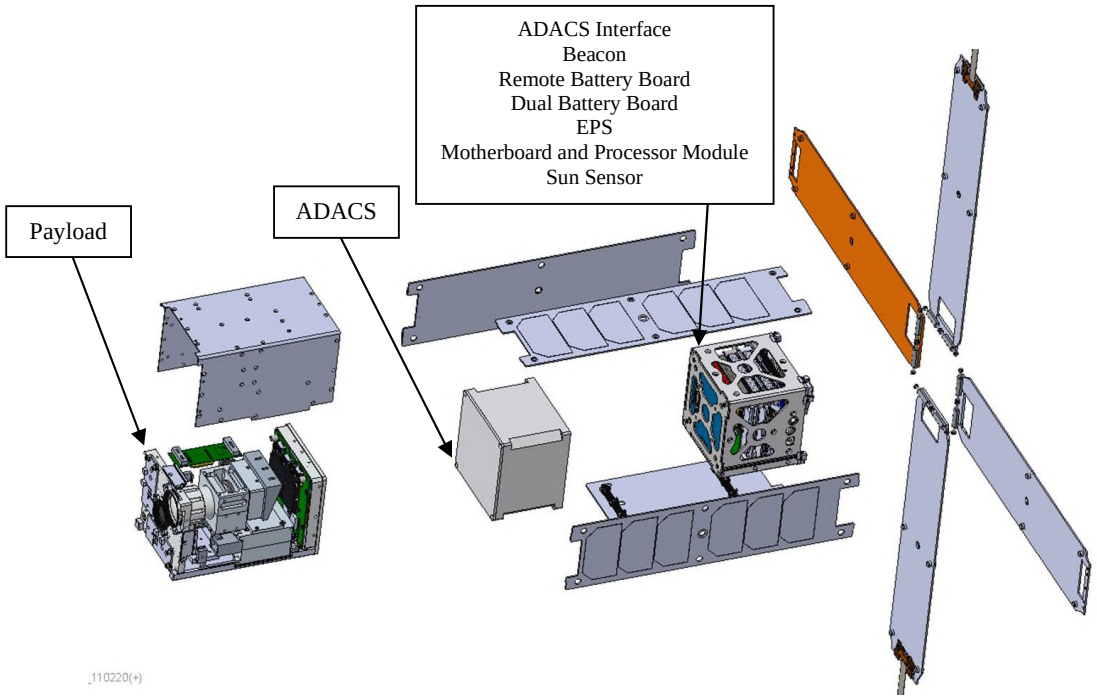

Figure 1 Dodona Exploded View

The total spacecraft mass at launch is 4.4 kg. There are neither propellants nor fluids on board; the CubeSat contains no propulsion systems. There are also no range safety or other pyrotechnic devices, no other sources of stored energy beyond what is noted above, and no radioactive materials on board. There are no planned proximity operations or docking with other spacecraft in Low Earth Orbit (LEO).

Dodona has one active attitude control system with two modes of operation.

The reaction wheel and magnetic torque rod assembly is the primary attitude control system. It is comprised of three orthogonal active micro-reaction control wheels that provide three axes of torque, and three independent magnetic torque rods that provide passive orientation control related to the magnetic field in orbit.

As shown in Figure 2 below, the normal flight mode of the CubeSat along the velocity vector is "sun pointing". That is, the sun sensor onboard the satellite is located at its base where the deployable panels intersect and release, and thus the orientation is in the 'flower pedal' configuration as viewed along the velocity vector. This orientation provides the highest amount of power to the satellite. The only other orientation the satellite will execute is a slew to point the aft end (opposite sun sensor) toward a spot on the ground in a target tracking mode to allow the payload to image and take a picture. This orientation is meant to be very short in duration as being off-axis of the sun begins to drain the power in batteries quickly.

Dodona contains an EPS, which consists of a quantity of six Adafruit 503562 Li-Polymer, 1200mAh, 3.7V batteries for flight and a primary coin cell for time backup. The coin cell battery is manufactured by Panasonic under the model number BR1225. There are no modifications to the cell cases as tested per UL 1642 file number MH12210 Oct 2002.

The Dodona payload consists of a visible camera and an infrared camera which will collect image data of the Earth's surface.

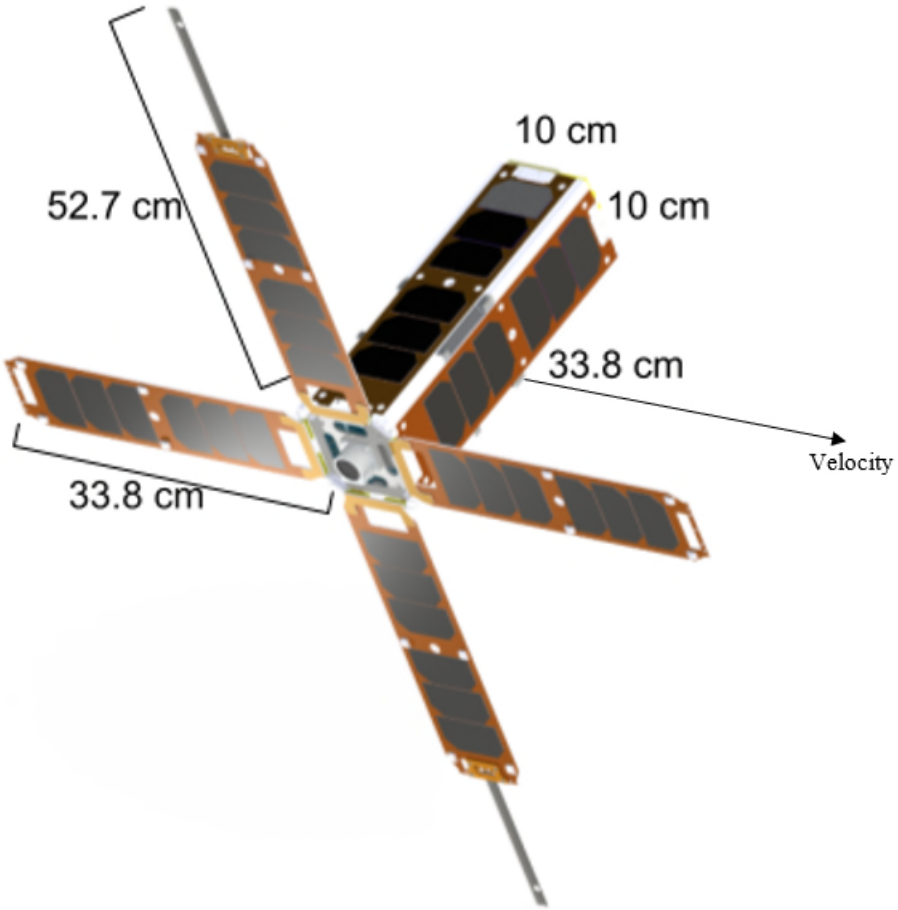

Figure 2 Dodona Normal Attitude

Section 3: Assessment of Spacecraft Debris Released During Normal Operations

This section calls for identification of any object (> 1mm) expected to be released from the spacecraft any time after launch. The Dodona CubeSat does not plan for any intentional releases during the mission or after EOM before breaking up during passive deorbit. All hardware and experiments in the bus and payload will remain fastened to the structure of the CubeSat body. Since no releases are planned for the Dodona CubeSat mission this section is not applicable.

As there are no planned releases of debris, the following items will not be included in this report: rationale/necessity for release of each object, time of release of each object, relative time of release from launch, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, time spent in LEO, and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

Requirement 4.3-1:
Not applicable, the mission does not plan for release of debris.

Requirement 4.3-2:
Not applicable, the mission does not plan for release of debris.

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

The mission operations for the Dodona CubeSat do not include a plan for intentionally designed spacecraft breakups, explosions, or collisions. The assessment of the spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum CubeSat lifetime of 8.4 years the Dodona CubeSat is compliant.

Requirement 4.4-1:

The battery charge circuitry contains both overcurrent and overcharge protection circuitry, which limits the probability of battery explosion. An overcurrent on any of the 3 buses triggers an EPS board timed disconnection of the power bus in question. The Battery Charge Regulator (BCR) charging system has two modes of operation. Maximum Power Point Tracking (MPPT) Mode occurs when the battery voltage is below the End of Charge (EoC) voltage, based on constant current charge method, operating at the maximum power point of the solar panel for maximum power transfer. Once the EoC voltage has been reached, the BCR changes to EoC mode, which is a constant voltage charging regime. The EoC voltage is held constant and a tapering current from the panels is supplied to top up the battery until at full capacity. In EoC mode, the MPPT circuitry moves the solar array operation point away from the maximum power point of the array, drawing only the required power from the panels. The excess power is left on the arrays as heat, which is transferred to the structure via the array's thermal dissipation methods.

Furthermore, due to the small envelope, mass, and orbital lifetime, if an explosion were to occur, the effects on the far-term LEO environment would be negligible.

Requirement 4.4-2:

CubeSats as a satellite class are not required to disconnect their batteries if flown in LEO with orbital lifetimes less than 25 years. Additionally, since the batteries will no longer be in use or charging, this further passivates the risk of damaging the batteries and leading to a potential explosion.

Requirement 4.4-3:

Not applicable, the mission does not plan for intentional breakups, explosions, or collisions.

Requirement 4.4-4:

Not applicable, the mission does not plan for intentional breakups, explosions, or collisions.

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

The calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft resulted in a collision probability of 5.8670E-07. The result is less than 0.001 and therefore passes requirement 4.5-1.

The Dodona CubeSat has no capability or plan for controlled end-of-mission disposal and has no EOM critical hardware, therefore requirement 4.5-2 is not applicable. There is no plan for debris avoidance capability.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

The satellite will naturally decay in orbit and will burn up in the Earth's atmosphere upon reentry within 25 years after the completion of the mission. There will be no deorbiting assistance through the use of propulsion systems.

$$Area\text{-}to\text{-}Mass\ Ratio = 0.007910\ {}^{m^2}/_{kg}$$

There is no plan for spacecraft controlled reentry.

Requirement 4.6-1 applies to Dodona as it will be in LEO below 2,000 km, and this requirement is met as natural forces will lead to atmospheric reentry within 25 years after the completion of the mission.

Section 7: Assessment of Spacecraft Reentry Hazards

Based on NASA DAS outputs, there are no objects expected to survive an uncontrolled reentry. The calculation of probability of human casualty for the expected year of uncontrolled reentry and the spacecraft orbital inclination is 1:100000000. Table 1 below shows the detailed description of the main CubeSat components.

Table 1 Detailed Description of Spacecraft Components

Component	Mass (g)	X-direction Dimension (mm)	Y-direction Dimension (mm)	Z-direction Dimension (mm)	Material(s)	Placement
Bus Chassis	144.28	99.68	99.54	89.23	Aluminum	Midpoint is 51.07mm from bottom of stack (the main 30cm x 10cm x 10cm structure in the diagram)
ADACS Module	1295.7	100	100	78	Aluminum	Midpoint is 135.4mm from bottom of stack
PC104 Stack	295.8	99.81	100.85	146.4	Silicon, Plastic, Aluminum	Midpoint is 240.91mm from bottom of stack
Payload Structure	1344	99	99	156.9		Midpoint is 258.04mm from bottom of stack
GPS Patch Antenna	48.22	60.05	60.06	6.06	Aluminum	Midpoint is 335.64mm from bottom of stack
Total Stack Dimensions		100	100	338.64		
Beacon Antenna	7.79	12.2	1.9	232	Aluminum	Attached to the outside edge of one solar panel
Bus H+S Comm Antenna	7.79	12.2	1.9	232	Aluminum	Attached to the outside edge of the opposite solar panel
Deployable Solar Array #1	207.53	82.05	340.90	1.82	Silicon, Aluminum	Attached at one end to one side of the bottom edge of stack
Deployable Solar Array #2	207.53	340.90	82.05	1.82	Silicon, Aluminum	Attached at one end to one side of the bottom edge of stack
Deployable Solar Array #3	207.53	82.05	340.90	1.82	Silicon, Aluminum	Attached at one end to one side of the bottom edge of stack
Deployable Solar Array #4	207.53	340.90	82.05	1.82	Silicon, Aluminum	Attached at one end to one side of the bottom edge of stack
Total Mass	4426.89					

The spacecraft complies with Requirement 4.7-1 based on demise altitude debris casualty area, and impact kinetic energy listed below.

Table 2 Requirement 4.7-1 Compliance

La Jument Dodona CubeSat		
Demise Altitude	77.994827	km
Debris Casualty Area	0.000000	m^2
Impact Kinetic Energy	0.000000	J
ADACS		
Demise Altitude	68.201233	km
Debris Casualty Area	0.000000	m^2
Impact Kinetic Energy	0.000000	J
Payload		
Demise Altitude	70.130325	km
Debris Casualty Area	0.000000	m^2
Impact Kinetic Energy	0.000000	J
Bus - Cards		
Demise Altitude	73.202599	km
Debris Casualty Area	0.000000	m^2
Impact Kinetic Energy	0.000000	J

Section 7A

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

Batteries: There are x6 Adafruit 503562 Li-Polymer, 1200mAh, 3.7V batteries. There is also a Panasonic coin cell for time backup, under the model number BR1225.

Section 8: Assessment for Tether Missions

Requirement 4.8-1:

This requirement is not applicable to the Dodona CubeSat, as no tethers will be used throughout the duration of the mission.

Section 9-14

ODAR section 9 through 14 for the launch vehicle are not covered in this document.

If you have any questions, contact:
Ryan N. Terry
Director, Regulatory Licensing & Policy
703-413-5747 (virtual desk)
ryan.n.terry@lmco.com

Appendix 1: DAS Activity Log

06 08 2021; 11:43:55AM Processing Requirement 4.3-1: Return Status : Not Run

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

========== End of Requirement 4.3-1 ==========
06 08 2021; 11:44:11AM Processing Requirement 4.3-2: Return Status : Passed

==========
No Project Data Available
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========== End of Requirement 4.3-2 ==========
06 08 2021; 12:01:59PM Processing Requirement 4.5-1: Return Status : Passed

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

INPUT

Space Structure Name = La Jument CubeSat
Space Structure Type = Payload
Perigee Altitude = 525.000 (km)
Apogee Altitude = 525.000 (km)
Inclination = 97.580 (deg)
RAAN = 0.000 (deg)
Argument of Perigee = 0.000 (deg)
Mean Anomaly = 0.000 (deg)
Final Area-To-Mass Ratio = 0.0079 (m^2/kg)
Start Year = 2021.000 (yr)
Initial Mass = 4.426 (kg)
Final Mass = 4.426 (kg)
Duration = 0.500 (yr)
Station-Kept = False
Abandoned = True

OUTPUT

Collision Probability = 5.8670E-07
Returned Message: Normal Processing
Date Range Message: Normal Date Range
Status = Pass

==========

========== End of Requirement 4.5-1 ==========

06 08 2021; 12:02:33PM Project Data Saved To File
06 08 2021; 12:02:40PM Requirement 4.5-2: Compliant

========== End of Requirement 4.5-2 ==========

06 08 2021; 12:02:46PM Processing Requirement 4.6 Return Status : Passed

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

INPUT

Space Structure Name = La Jument CubeSat
Space Structure Type = Payload

Perigee Altitude = 525.000000 (km)
Apogee Altitude = 525.000000 (km)
Inclination = 97.580000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.007910 (m^2/kg)
Start Year = 2021.000000 (yr)
Initial Mass = 4.426000 (kg)
Final Mass = 4.426000 (kg)
Duration = 0.500000 (yr)
Station Kept = False
Abandoned = True
PMD Perigee Altitude = 513.601861 (km)
PMD Apogee Altitude = 535.354990 (km)
PMD Inclination = 97.587740 (deg)
PMD RAAN = 181.461237 (deg)
PMD Argument of Perigee = 42.458963 (deg)
PMD Mean Anomaly = 0.000000 (deg)

OUTPUT

Suggested Perigee Altitude = 513.601861 (km)
Suggested Apogee Altitude = 535.354990 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2029 (yr)
Requirement = 61
Compliance Status = Pass

==========

========== End of Requirement 4.6 ==========
07 01 2021; 14:55:37PM **********Processing Requirement 4.7-1
Return Status : Passed

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

name = La Jument CubeSat
quantity = 1
parent = 0
materialID = 5
type = Box

Aero Mass = 4.426000
Thermal Mass = 4.426000
Diameter/Width = 0.100000
Length = 0.300000
Height = 0.100000

name = ADACS
quantity = 1
parent = 1
materialID = 3
type = Box
Aero Mass = 1.293000
Thermal Mass = 1.293000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = Payload
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 1.380000
Thermal Mass = 1.380000
Diameter/Width = 0.100000
Length = 0.150000
Height = 0.100000

name = Bus-Cards
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 1.753000
Thermal Mass = 1.753000
Diameter/Width = 0.100000
Length = 0.500000
Height = 0.100000

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

name = La Jument CubeSat
Demise Altitude = 77.994827
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = ADACS
Demise Altitude = 68.201233
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Payload
Demise Altitude = 70.130325

Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Bus-Cards
Demise Altitude = 73.202599
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

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