Specifications of Thin Film Deployment Type De-orbit Device DOM1500

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1. Specifications of DOM1500

1.1. General

DOM is short form for De-Orbit Mechanism. It is a thin film deployment type de-orbit device jointly developed for microsatellites by Nakashimada Engineering works, Ltd. and Tohoku University. DOM deploys a thin film to drag microsatellites down to re-enter into the atmosphere. In the stored configuration before launch, the thin film connected with convex tapes is kept folded and stowed inside DOM by wires. On orbit, when a voltage is applied to ceramic resistors, the wires are cut by heat and the thin film is deployed.

DOM1500 is a model number of DOM. The number "1500" represents the size of its thin film. DOM1500 has a square thin film with edge length of 1500 mm.

1.2. External dimensions

External views in its stored and after-deployment configuration of DOM1500 are shown in Figure 1. DOM1500 has a cylindrical shape and is 110 mm in diameter by 73 mm high in the stored configuration. After deployment, the height of DOM1500 increases to 147 mm and the size of the thin film is 1500 mm square with a 500 mm square center cut-off.

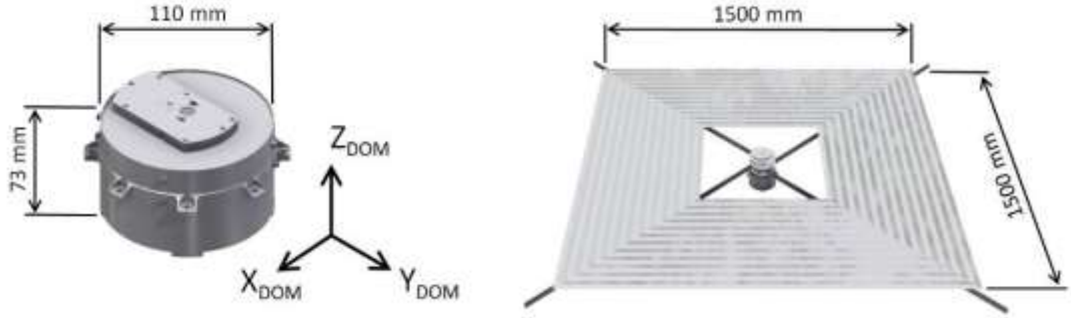

Figure 1. External views in stored (left) and after-deployed (right) configuration

1.3. Mechanism

Deployment mechanism of DOM is as follows.

1) Electric power is supplied from external batteries (DOM has no electric power source).
2) Joule heat of the ceramic resistors cuts the wires.
3) A compression coil spring pushes the wounded convex tapes and the folded film out of the container of DOM.
4) The convex tapes extend and the film is deployed.

Deployment mechanism is shown in Figure 2.

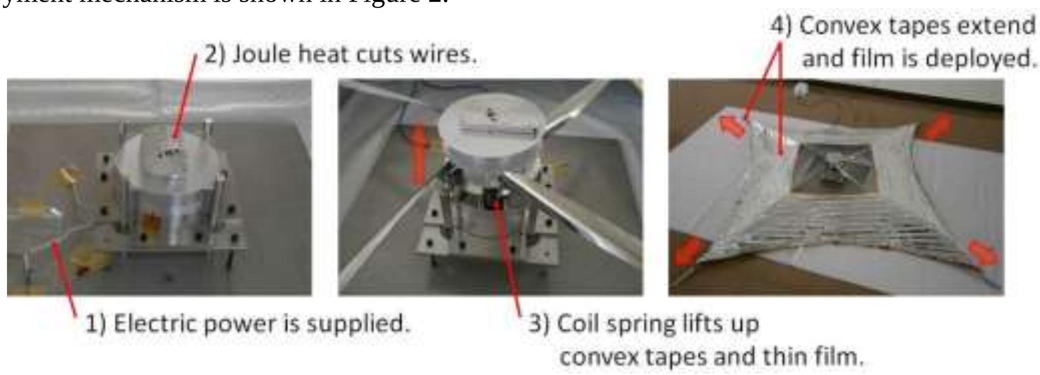

Figure 2. Deployment mechanism

1.4. Mass and material

The main structure parts of DOM are made of aluminium alloy and stainless steel. The thin film is made of aluminized polyimide. The material of the convex tapes is stainless steel. DOM contains two ceramic resistors, conductive wire, bearings, and a tiny mount (less than 1 g, respectively) of glass-reinforced epoxy plastic, glass cloth tape, polyethylene, lubricant, and adhesive. The mass of DOM1500 is approximately 1000 g. The weight budget of DOM1500 is shown in Table 1.

Table 1. Weight budget

Parts name	Material	Weight [g]
Main structure parts	Aluminium alloy	520
	Stainless steel	70
Thin film	Aluminized polyimide	70
Convex tapes	Stainless steel	220
Electrical Connector and wire	-	30
Bolts	Stainless steel	20
Others	-	10
Margin	-	60
Total		1000

1.5. Switch

DOM has two ceramic resistors as the deployment switch. One is nominal and the other is redundant. The nominal resistor is 6.8 ohm and the redundant is 4.7 ohm. The resistors touch the wires, which keep the contents of DOM stored. Through whichever resistor electric current flows, Joule heat cuts the wires and DOM is deployed. The voltage to be applied is 5 V and the time required to deploy is approximately 30 second. The resistance and the voltage can be changed if the wattage is about 5 W because only the same amount of heat has to be generated.

DOM has a circuit to detect its deployment. This circuit is broken in stored configuration but is made contact after deployment. Figure 3 shows a schematic circuit diagram of DOM connected with an external battery and an external control unit.

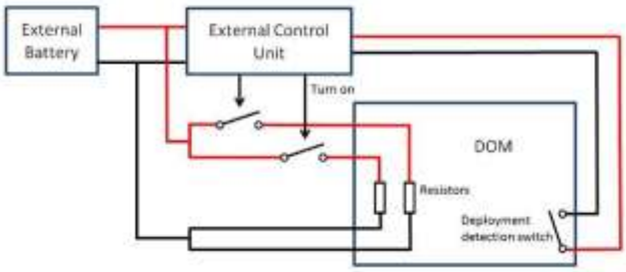

Figure 3. Schematic circuit diagram

1.6. Interface

DOM1500 has a flange as its mechanical interface. The mechanical interface of DOM1500 is shown in Figure 4. DOM1500 is installed in satellites with eight M4 bolts. The bolt circle diameter is 120 mm. Though the standard is that the mounting surface is 39 mm in height above the bottom of DOM1500, this height can be redesigned according to satellite developers' requests.

The electrical interface is Micro-D connector, which is shown in Figure 4.

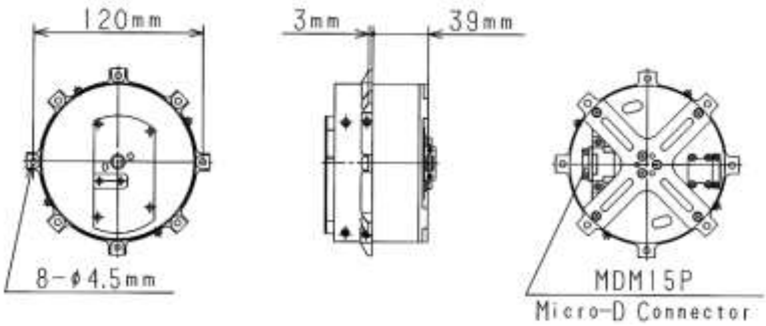

Figure 4. Mechanical interface and electrical interface

1.7. Mechanical vibration tolerance

DOM is designed to withstand the launch environment of H-IIA QT level. Structural analysis is executed with the aid of Finite Element Method (FEM). The FEM software used for the calculation is Femap with NASTRAN. The result of natural frequency analysis is shown in Table 2. X' and Y' are the directions in X-Y Plane as shown in Figure 5. The lowest natural frequency 146.0 Hz is greater than the required minimum frequency in spite of the fact that the analysis model is sufficiently conservative. The results of static load analysis and random vibration analysis are shown in Table 3 and Table 4, respectively. Yield stress margin of safety (*MSy*) and ultimate stress margin of safety (*MSu*) are positive in every direction in both of static load analysis and random vibration analysis. The structure survives the launch static load and random vibration.

Table 2. Result of natural frequency analysis

Axis	Natural frequency [Hz]
X'	146.0
Y'	146.4
Z	339.0

Table 3. Result of static load analysis

Axis	Calculated stress [MPa]	*MSy*	*MSu*
X	37.83	7.4	6.0
Y	34.87	8.1	6.6
Z	9.52	32.3	26.9

Table 4. Result of random vibration analysis

Axis	Calculated stress [MPa]	*MSy*	*MSu*
X'	168.5	0.67	0.57
Y'	149.7	0.88	0.77
Z	66.2	3.2	3.0

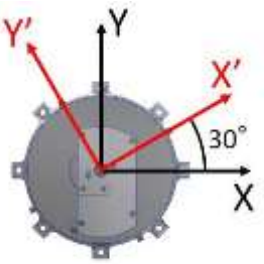

Figure 5. X' and Y' direction

1.8. Operation and storage temperature

The temperature range from -25 degC to +80 degC is specified as the storage temperature of DOM. The allowable temperature of materials are as shown in Table 5. The storage temperature is determined with consideration for the narrowest temperature range from -25 degC to 100 degC of materials.

The temperature range from -20 degC to +70 degC is specified as the operation temperature of DOM. The lower limit of the operation temperature range depends on the heating ability of the resistors. The range is determined because it was verified that the wires can be cut in -20 degC air by a power source of 5 V.

Table 5. Allowable temperature of materials

Material	Lower limit [degC]	Upper limit [degC]
Aluminium alloy	Very low temperature	200
Stainless steel	-200	800
Polyimide	-180	200
Polyethylene	-60	100
Bearing	-25	100
Ceramic resistor	-55	275
lubricant	-80	200

2. Suitability for evaluation Criteria

2.1. Effectiveness

The lifetime of a satellite is calculated in the case with and without deploying DOM1500. Newtonian equation of motion including spherically symmetric gravitation, atmospheric drag, and J_2 term is numerically integrated with the aid of Runge-Kutta method. The mass and the effective cross-sectional area for the calculation are shown in Table 6. The initial semi-major axis, orbital inclination, and eccentricity are 6930 km, 97.6°, and 0.002, respectively. The drag coefficient is assumed to be 2.2. The reference[1] is used as the atmosphere model. The result of the lifetime calculation is shown in Figure 6.

Table 6. Mass and effective cross-sectional area used in lifetime calculation

		Effective cross-sectional area [m^2]	
Satellite size	Mass [kg]	with thin film	without thin film
1U CubeSat	1.33	1.125	0.015
2U CubeSat	2.66	1.125	0.025
3U CubeSat	4	1.125	0.035
10kg-class	10	1.165	0.06
50kg-class	50	1.25	0.375

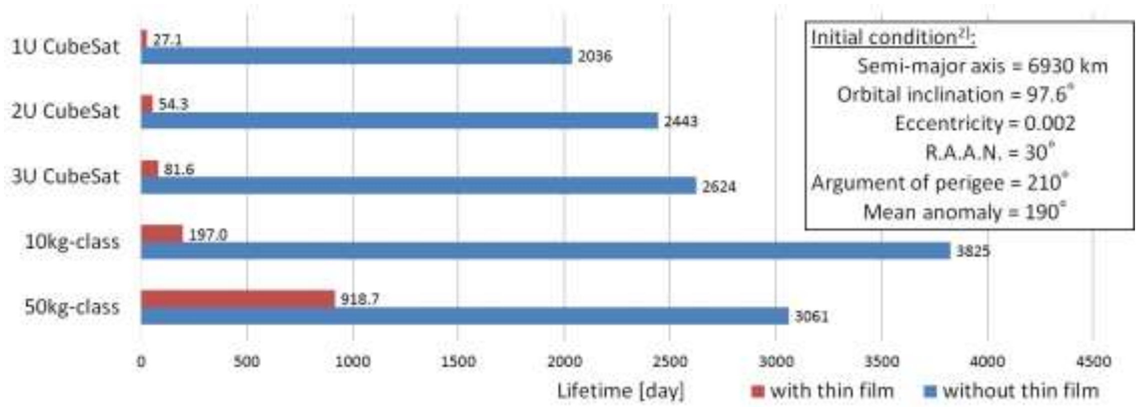

Figure 6. Result of lifetime calculation

2.2. Mass and envelop

External views and the mass of DOM1500 are mentioned in Section 1.2 and Section 1.4, respectively. DOM1500 fits into a single unit CubeSat[3]. Actually, a single unit CubeSat FREEDOM carrying DOM1500 was already developed. When DOM1500 is installed in a 50kg-class microsatellite, it can be mounted inside the rocket interface cylinder (PAF239M) as shown in Figure 7 and is therefore likely to be a standard deorbit device for 50kg-class microsatellites.

Other sizes of DOM were already developed. DOM500 has a square thin film with edge length of 500 mm and is 80 mm in diameter by 45.5 mm high in the stored configuration. DOM2500 has a 2500 mm square thin film and is 150 mm in diameter by 75 mm high.

2.3. Cost

Nakashimada Engineering Works, Ltd. sells DOM1500 at a price of approximately 5 million yen, which is 44 thousand dollars if the price is converted at 115 yen to a dollar.

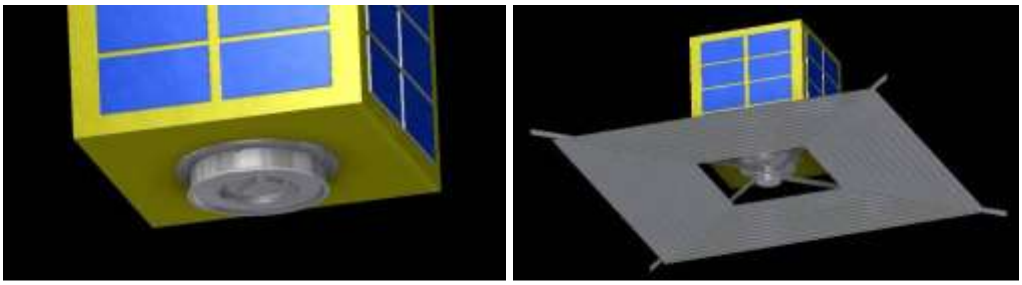

Figure 7. DOM1500 mounted inside PAF239M (left: stored, right: deployed)

2.4. Technical feasibility

DOM mechanism is mentioned in Section 1.3. The wires are first cut by Joule heat, the elastic energy of the compression coil spring and the convex tapes is released, and DOM is deployed. The mechanism contains neither a motor nor gas, therefor is considered one of the simplest designs mechanically and electrically.

2.5. Impact on satellite

The mass of DOM1500 is approximately 1000 g. The power consumption is 5.3 W and the time required to deploy is approximately 30 second.

2.6. Reliability

DOM has two switches for improvement in reliability. DOM is deployed whichever switch turns on.
DOM mechanism is designed as simple as possible to enhance the certainty of DOM deployment action.

2.7. Safety

The wires keeping DOM components stored are made of ultra high molecular weight polyethylene. It is at the highest level of organic fibers in strength per line density and elastic modulus. Because DOM has two wires and a wire alone is strong enough to bear the launch environment, DOM will not be deployed even if one of two wires is cut for some unexpected reason.
The mechanical vibration tolerance is mentioned in Section 1.7.

2.8. Maintenance and testability

It is recommended that DOM is stored in a clean room at room temperature away from sunlight when DOM is on earth. Condensation is never allowable though relative humidity is not defined.
To confirm that there is no defect with DOM, two inspections can be implemented. These inspections are shown in Figure 8. One inspection is touching wires with a thin rod and confirming that the wires are strained (this inspection is qualitative). The other inspection is measuring the distance between chucks (this inspection is quantitative). If the distance is less than 1.0 mm, it is permissible.
DOM can be tested on ground repeatedly. Consumables is wires, which are cut on every test. Deployment tests using the resistors for flight should be limited to ten times for fear of the resistors degrading.

2.9. User friendliness

The mechanical interface and the electrical interface are mentioned in Section 1.6. Users have only to tighten eight bolts and join electrical connectors to mount DOM1500 on to their satellite.

2.10. Debris risk

Increased probability of collisions with spacecraft, debris, or meteoroids caused by the large cross-sectional area of deployed DOM and splits caused by breakage of the thin film are identified as risks in producing additional debris.
If the satellite does not supply DOM with electric power, DOM does not function because DOM has no battery and no control system.

Figure 8. Inspections

References

1) Toshio Han'you: Fundamentals of Mission Analysis and Trajectory Design, Gendai-Sugakusha, 2014 (in Japanese).
2) UNISEC-Global: Call for Papers, Deorbit Device Competition during the 4th UNISEC-Global Meeting, November 2015.
3) The CubeSat Program, Cal Poly SLO: CubeSat Design Specification rev.13, 2014.