Flight Testing of a Low Cost De-Orbiting Device for Small Satellites

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Abstract

Use of small and very small spacecraft is rapidly becoming more common. Methods to intentionally de-orbit these spacecraft at the end of useful satellite life are required. A family of mass efficient Roll-Out De-Orbiting devices (RODEO™) was developed by Composite Technology Development, Inc. (CTD). RODEO™ consists of lightweight film attached to a simple, ultra-lightweight, roll-out composite boom structure. This system is rolled to stow within a lightweight launch canister, allowing easy integration to the small satellite bus. The device is released at the end of useful lifetime and the RODEO™ composite boom unrolls the drag sail in a matter of seconds. This dramatically increases the deployed surface area, resulting in the higher aerodynamic drag that significantly reduces the time until reentry. A RODEO™ flight demonstration was recently conducted as part of the Colorado Space Grant Consortium's (COSGC) RocketSat-8 program, a program to provide students hands-on experience in developing experiments for space flight. The experiment was ultimately a success and RODEO™ is now ready for future CubeSat missions.

Introduction

Operational satellites are at risk from a growing threat of orbital debris generated by satellite explosions and collisions. There are currently 19,000 objects larger than 10 cm being tracked by the U.S. Space Surveillance Network and an estimated 500,000 particles between 1 and 10 cm in diameter that are hazardous to satellites but are too small to be tracked.[1] The risk of orbital debris is also self-propagating, as the recent collision of the Iridium 33 communications satellite and the derelict Russian Cosmos 2251 satellite demonstrated by generating more than 500 pieces of debris large enough to be tracked.[2]

Addressing this concern, NASA has created a specification that requires all new satellites to launch with a known reentry plan. According to NASA technical standard NASA-STD-8719.14, "Process for Limiting Orbital Debris", one of the three options for disposal includes atmospheric reentry where 1) the space structure is left in an orbit in which natural forces will lead to atmospheric reentry within 25 years after completion of the mission; or 2) the space structure is maneuvered into a controlled de-orbit trajectory as soon as practical after completion of mission.[3]

However, the challenge faced by many small satellite mission teams is that small satellites are often designed for rideshare opportunities without full knowledge of the final orbit where they will be placed. In this case, the mission team must assume the highest possible orbit for calculation of the de-orbit time. Also, many small satellites have high mass-to-area ratios because they are designed with body-mounted solar arrays and minimal other deployable structures, such as a whip antenna. This lack of deployed area combined with a high possible orbit can lead to de-orbit times in excess of the NASA standard.

To enable small satellites to meet the 25-year requirement, CTD has developed a family of highly mass efficient Roll-Out De-Orbiting devices (RODEO™). Depicted in Figure 1 is a 3U CubeSat version of the RODEO™ de-orbit system. RODEO™ consists of lightweight film deployed and supported by a simple roll-out composite boom. RODEO's dramatic increase in the deployed surface area significantly reduces the time until reentry for satellites within low earth and elliptical orbits.

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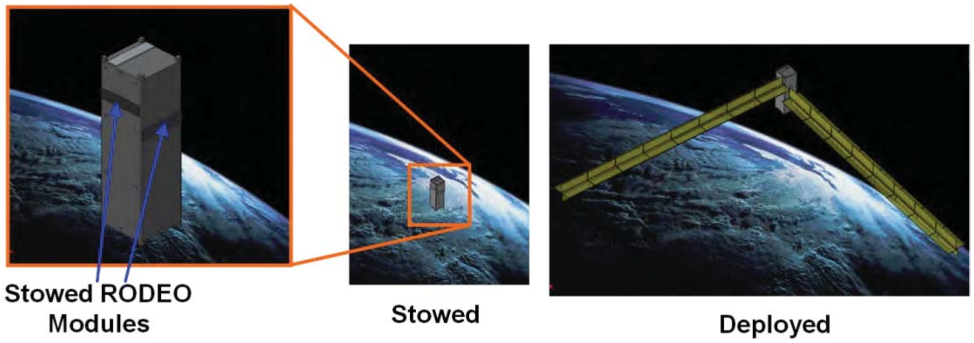

Figure 1. 3U CubeSat with two Roll-Out De-Orbiting modules (RODEO™)

RODEO™ Overview

RODEO™ is a "turn-key" self contained de-orbiting system with everything required to operate the system included within each RODEO™ canister. This includes the composite roll-out boom fitted with robust thin film drag sail material, and the operational electronics with a built-in timing system and batteries. The mechanical system is extremely simple with a very low mechanical part count and complexity. The use of a high specific stiffness carbon fiber reinforced composite boom minimizes system mass yet provides a very robust deployed structure. The electronic system is also simple, providing an intentional release circuit and a timed release circuit. The timed release will execute if end-of-life is detected by a lack of power to the charging circuit for a preset amount of time.

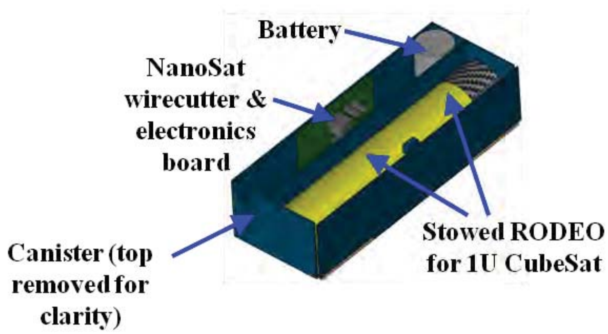

Figure 2. Stowed CubeSat RODEO™

Fundamentally the RODEO™ structure is easily scaled in length and width and has an extremely high packaging efficiency (greater than 100:1) allowing for integration upon "under-utilized" portions of the spacecraft, such as behind deployable solar panels.

<u>Multifunctional Composite Slit-Tube Boom</u>

The key technology for RODEO™ is the rolled composite boom. CTD has developed a wide variety of deployable composite slit-tube booms that range from 12.7 mm (0.5 in) to 127 mm (5.0 in) diameter (see Figure 3) and up to 23 meters (75 ft) in length. Common to all of these structures (including the RODEO boom) are robust composite slit-tube booms that can be flattened and rolled for storage (see Figure 4). This method of stowage and deployment is highly efficient, allowing large structures, in comparison to the spacecraft, to be stored within very small volumes. The material and composite laminate properties of rollable composite booms are highly tailorable and can be optimized to meet the specific requirements for a given application. Additionally, because the boom and drag sail are rolled together in one piece, the mechanical system has a very low part count with minimal complexity.

The RODEO™ boom is self deploying, meaning the stored strain energy of the packaged boom provides the necessary deployment force. The design of such a boom is challenging since the composite must survive the mechanical strain of being stowed within a very small volume, while also having adequate deployment torque and significant axial stiffness upon deployment. The multi-functionality of the boom results in minimal parasitic mass, stowed footprint, and cost, making these booms attractive for a variety of applications, including within roll-out de-orbit devices.

Figure 3. Wide range of deployable slit-tube booms developed by CTD

Figure 4. Deployable composite slit-tube boom used for RODEO™

Concept of Operations

Inside the RODEO™ housing, CTD has included a very simple electronic circuit board and battery. The board only has two inputs and a ground wire. The first input is to initiate a commanded release by supplying spacecraft voltage. The second input supplies a very small trickle charge to the battery and resets a timer circuit so that RODEO™ will remain stowed. However, if the spacecraft loses functionality and stops supplying the trickle charge, the timer circuit initiates and begins counting. After a pre-determined period of time with no trickle charge supplied, the timer circuit executes an automatic command to deploy the RODEO™ drag sail. Once the command to deploy is sent (either manually or via the timer circuit) an internal hot wire will release the spring-loaded hinged door, and the RODEO™ de-orbit wing will deploy. Deployment occurs via the single-degree of freedom composite roll-out boom that is restrained by the hinged door of the RODEO™ canister.

RODEO Sizing

To demonstrate the benefits of RODEO™, CTD ran an orbital decay analysis using NASA's DAS 2.0 software in order to identify the minimum surface area required to de-orbit each size of satellite. This RODEO™ sizing analysis has been summarized in Table 1 for a 25-year reentry timeframe, and is based on a 700-km circular orbit. Table 2 provides estimates for volume and mass for the three RODEO™ systems assessed.

RocketSat-8 X Flight Experiment

RocketSat-8 was the eighth RocketSat student project at the Colorado Space Grant Consortium (COSGC) since the program began in 2006. RocketSat-8 flew as part of the national program called RockSat-X. This program allows university-level students to fly experiments on board a sub-orbital rocket launched out Wallops Flight Facility each August. The flight reaches an altitude of approximately 160 km and provides experiments with full access to the space environment including 30 to 180 seconds of stable microgravity. Experiments also have access to power and telemetry. There is a fee to fly on the flight, which helps foster partnerships with industry, universities, and students. CTD partnered with COSGC to develop the RODEO™ experiment, enabling the students to cover their required fee to fly. Students worked side by side with engineers from CTD in the development of RODEO™. The experience in developing RODEO™ with CTD enriched the experience for each of the students involved.

Table 1. Required RODEO sizes for 25-year reentry

System	Satellite Mass (kg)	RODEO Area
3U CubeSat (0.10, 0.10, 0.34)	6.00	**0.150 m²**
Nanosatellite (0.204, 0.204, 0.204)	15.0	**0.526 m²**
ESPA-Class Small Satellite (0.464, 0.464, 0.464)	100	**3.74 m²**

Table 2. Estimated volume and mass for three RODEO™ configurations

Satellite	RODEO Performance Metrics	
	Stowed Volume	System Mass
3U CubeSat (6kg)	140 cm^3	96 g
Nanosatellite (15kg)	175 cm^3	131 g
Small Satellite (100kg)	270 cm^3	472 g

Flight Configuration

For the flight design, CTD selected a RODEO™ that would provide approximately 0.15 m^2 deployed surface area, enough area to de-orbit a 3U CubeSat in a period of 25 years (see Table 1). This area is achieved using three pop-out "wings" from a central 127-cm diameter boom as pictured in Figure 5. The wings are formed 120° apart to provide area in multiple planes. Structural "battens" bonded to the backbone of the boom and extending out to the edge of the Mylar are used to support the wings and enforce the deployed position. These battens are flexible and allow the three wings to be wrapped around to one side of the boom and stacked for stowage, as can be seen in Figure 6.

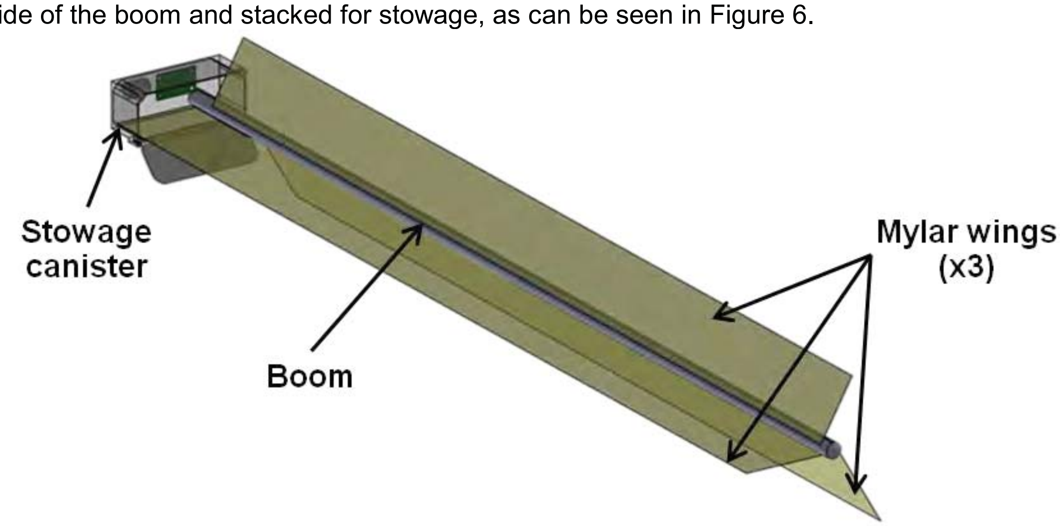

Figure 5. 3U CubeSat RODEO™ configuration

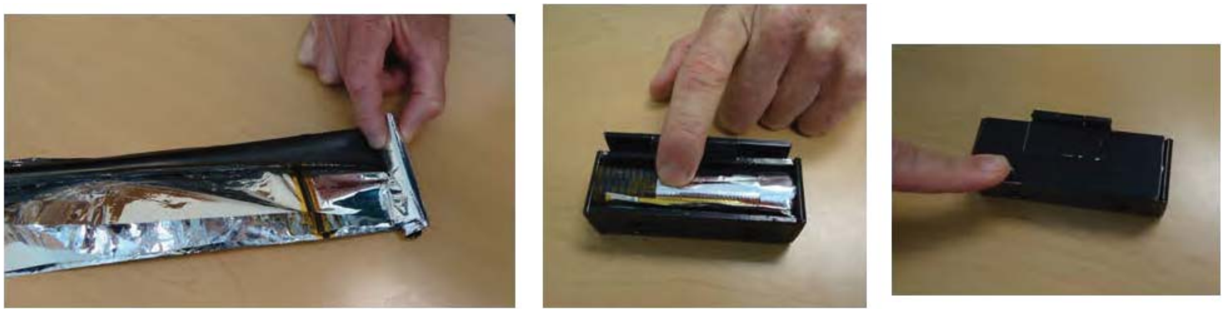

Figure 6. Stowage of 3U CubeSat RODEO™ model

Figure 7. Deployment progression for 3U CubeSat RODEO

The stowed RODEO™ is held constrained within an aluminum box with a hinged door (see Figure 6). When the door is released, RODEO™ deploys in less than 1 second (see Figure 7). The flight hardware was fabricated using space-qualified materials. Multiple stowage/deployment cycles were completed in CTD's laboratory. The RODEO™ was found to deploy reliably without any deployment snags, or stalls.

<u>Flight Testing</u>
On August 13, 2012 RockSat-8 was lofted to an altitude of approximately 160 km above the Atlantic Ocean before landing via parachute about 145 km from the Wallops Flight Facility. The payload was recovered and high definition video of the RODEO™ experiment was retrieved from the payload. The video showed a complete, but off-nominal deployment. The deployment was slower than expected but continued in short bursts until reaching full deployment. Images from the RODEO™ flight experiment are pictured in Figure 8.

Beginning of Deployment | **Mid-Deployment** | **Fully Deployed**

Figure 8. Images from RODEO™ flight experiment

This anomalous deployment was shown to be caused by moisture saturation in the composite boom. In the dry environment of Colorado, the boom always deployed nominally. When the students from the COSGC took their 2012 RockSat-8 payload, including RODEO™, to Wallops, located on the very humid coastal region of Virginia, they found that the RODEO™ boom did not deploy properly in final system tests and checks prior to integrating the payload into the rocket. CTD determined that the high humidity caused the composite to absorb moisture, plasticizing the resin and significantly reducing the stiffness and stored strain energy of the boom. The effect was duplicated in laboratory conditions and is completely reversible. The boom would deploy as expected after drying out.

The moisture issue was discovered two weeks before payload integration. To mitigate the issue, desiccant was packed within the RODEO™ canister to keep it dry for several days during launch preparation. Unfortunately, the launch was delayed by several weeks and the desiccant became saturated, allowing RODEO™ to also become saturated with moisture. As a result, the boom did not immediately deploy. However, the multiple starts and stops observed indicated that as the outer layers of the boom dried out, the boom was gradually able to reach full deployment.

Moisture would not be an issue for a CubeSat or small satellite mission since the boom would have ample time (months to years) to completely dry out in the hard vacuum of space prior to deployment. In addition, CTD has since incorporated a different moisture-resistant polymer matrix into the boom and has shown that deployment is no longer affected by moisture.

Conclusions

The most responsible and proactive method of mitigating orbital debris caused by small and very small spacecraft is to incorporate an effective de-orbit device. To this end, CTD has developed RODEO™; a family of ultra-lightweight de-orbiting devices. All RODEO™ devices are capable of de-orbiting both functional and non-responsive satellites within NASA's required timeframe. RODEO™ modules utilize extremely lightweight, mass efficient composite slit-tube boom elements to deploy the drag film in a controlled, reliable fashion.

CTD recently worked with the Colorado Space Grant Consortium to demonstrate a RODEO™ deployment on a suborbital platform as part of the RocketSat-8 experiment. While high-definition video taken during the experiment showed that RODEO™ did eventually deploy, the deployment was off nominal. Moisture contamination was found to be the cause, which was only an issue for the sub-orbital demonstration due to the very short duration of the flight. At this point, RODEO™ is ready for future CubeSat missions.

References

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