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A deorbiter CubeSat for active orbital debris removal

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Abstract

This paper introduces a mission concept for active removal of orbital debris based on the utilization of the CubeSat form factor. The CubeSat is deployed from a carrier spacecraft, known as a mothership, and is equipped with orbital and attitude control actuators to attach to the target debris, stabilize its attitude, and subsequently move the debris to a lower orbit where atmospheric drag is high enough for the bodies to burn up. The mass and orbit altitude of debris objects that are within the realms of the CubeSat's propulsion capabilities are identified. The attitude control schemes for the detumbling and deorbiting phases of the mission are specified. The objective of the deorbiting maneuver is to decrease the semi-major axis of the debris orbit, at the fastest rate, from its initial value to a final value of about 6471 km (i.e., 100 km above Earth considering a circular orbit) via a continuous low-thrust orbital transfer. Two case studies are investigated to verify the performance of the deorbiter CubeSat during the detumbling and deorbiting phases of the mission. The baseline target debris used in the study are the decommissioned KOMPSAT-1 satellite and the Pegasus rocket body. The results show that the deorbiting times for the target debris are reduced significantly, from several decades to one or two years.

Keywords: Active debris removal; CubeSat; Detumbling; Deorbiting

1. Introduction

Space debris are generally considered to be man-made objects in Earth orbit, which no longer serve useful purposes. A large number of such objects are currently in orbit, as a result of the space development that has been ongoing since the mid-20th century. The number of space debris has increased in recent years due to intentional or accidental explosion and collision of orbital objects. The accumulation of space debris has been particularly evident in the low Earth orbit (LEO) region that extends to an altitude of about 2000 km, as shown in Fig. 1. Consequently, the problem of space debris has become a major concern in the space community. The collision between Iridium 33 (operational) and Cosmos 2251 (debris) in 2009 exposed the real threat that orbital debris can pose to space assets. The collision resulted in the creation of an additional 2000 items of debris that are now tracked from the ground using radars (NASA, 2017, 2016). These events, in addition to numerous near-miss events, have reasserted the need for mandatory disposal of decommissioned satellites. With increased awareness of the space debris issue, space agencies in major space-faring countries are conducting studies of methods to eliminate space debris, and some agencies have already announced plans to perform technology demonstration missions in the near future, e.g., e.Deorbit by the European Space Agency (ESA) in 2023 (Clean Space, 2015; Bastida Virgili et al., 2014) and CleanSpace One by the Swiss Federal Institute of Technology in Lausanne in 2018 (Richard et al., 2013).

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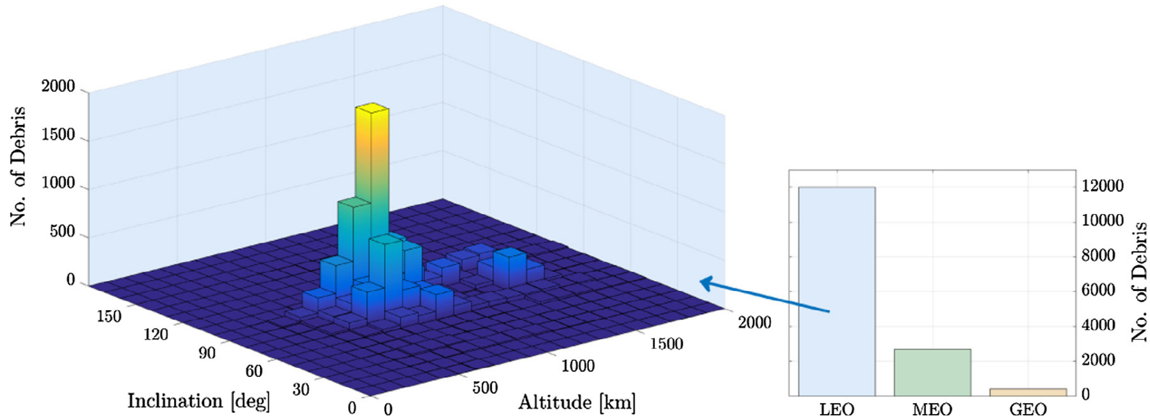

Fig. 1. Distribution of debris objects in geocentric orbits (as of Feb. 2017 Kelso, 2017).

Debris removal strategies can be broadly classified into two categories (Seong et al., 2017): (a) *active* removal methods, and (b) *passive* removal methods. In the case of active methods, an external agent applies force to space debris that has no control authority over its position or attitude, and thus is incapable of deorbiting itself. Many such methods are currently under study, such as the use of space tug (net (Starke et al., 2010; Guang and Zhang Jing-rui, 2012) or robotic manipulator (Reintsema et al., 2010; Nishida and Kawamoto, 2011)), ion-beam shepherd (Bombardelli and Pelaez, 2011), and ground-based and space-based high-power lasers (Phipps et al., 1996; Yang et al., 2016). In the case of passive methods, an object to be cleared remains capable of operating its internal actuators, for instance to deploy a drag sail (Visagie et al., 2015). Alternatively, the object may activate its thrusters to deorbit itself. Passive removal methods cannot be applied to the great majority of objects currently in orbit (Seong et al., 2017), but could be applied in future space missions.

Several researchers have investigated the concept of space debris removal using a chaser vehicle, known as a "mothership," that captures a sizable target debris, nullifies its angular rates (a process known as a detumbling maneuver), and then attaches deorbiting devices to the debris. The devices then independently proceed to deorbit the debris using a form of propulsion system. Many studies (Castronuovo, 2011; Tadini et al., 2014; DeLuca et al., 2013; Astroscale, 2016) have considered chemical propulsion systems as the deorbiting devices. Electrodynamic tether (EDT) capabilities have also been investigated in deorbiting space debris (William Barbee et al., 2011; Nishida et al., 2009). An alternative approach is based on the utilization of detumbling devices that are deployed by a mothership. A number of these devices dock with a target debris and detumble it, after which the mothership captures the stabilized debris and deorbits it. For example, in Udrea and Nayak (2015) the detumbling devices are considered to be in the form of CubeSats that cooperatively detumble the debris using their chemical thrusters. The mothership captures the debris once the debris attitude is stabilized, and uses its propulsion system to deorbit the system in a controlled manner. Also, Savioli et al. (2013) propose a mission concept in which a large mothership carries several modular, microsatellite-sized remover units of different kinds (namely, EDT, electric thruster, and hybrid rocket modules) in orbit, which are then attached to a 50-kg main bus (also carried by the mothership), and the whole compound system is then attached to the debris by the mothership. The type and number of deorbiting units depend on the orbit and characteristics of the target debris object to be removed.

In this paper, the proposed approach is based on the utilization of CubeSats, similarly to Udrea and Nayak (2015). But in our approach, a single CubeSat (called *deorbiter CubeSat*) is used for the removal of a target debris, unlike in Udrea and Nayak (2015) where several CubeSats in addition to the mothership are expended for the removal of a single debris. Further, the deorbiter CubeSat makes use of its onboard reaction wheels to detumble the debris, instead of using expendable propellants. Lastly, and most importantly, the deorbiter CubeSat uses its low-thrust propulsion system to deorbit the debris over time; hence, the mothership will not need to be involved during the deorbiting maneuver, and can move on to the next target debris.

Therefore, the objectives of this paper are to:

1. introduce the concept of active removal of sizable space debris based on the utilization of CubeSats;
2. determine the feasible range of debris masses and orbits, given the amount of propellant on the deorbiter CubeSat;
3. investigate the detumbling of the debris using the CubeSat's attitude control system;
4. investigate the deorbiting of the debris using the CubeSat's low-thrust propulsion system; and
5. verify the performance of the deorbiter CubeSat in active debris removal missions through two case studies.