Development of a solid-state inflation balloon for aerodynamic drag assisted deorbit of CubeSats

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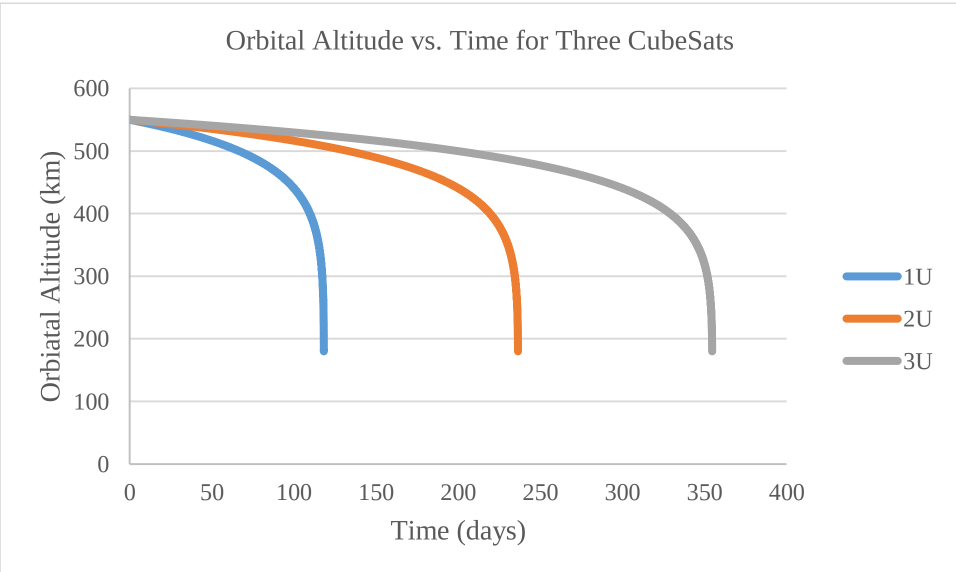
Abstract

We have proposed and are currently developing a deorbit system for small satellites in collaboration with NASA Ames Research Center (ARC) under a Small Satellite Technology Partnership (SSTP) Grant. In this report we will describe the current development of the Solid State Inflation Balloon (SSIB), a simple, reliable, low-cost, non-propulsive deorbit mechanism for the full range of small satellites (<180kg). Small satellites typically rely on aerodynamic drag to deorbit within the FAA's 25 year requirements. The SSIB will enhance aerodynamic drag by inflating a balloon at the end-of-life of a satellite mission. This technology will provide a scalable and non-existing capability, low-cost deorbit, for applications in the full-range of smallsats, from CubeSats to MicroSats. The proposed SSIB system is composed of three major components: a Micro-Electro-Mechanical Systems (MEMS) Solid-State Gas Generator (SSGG) chip, a balloon structure made of thin metallized polyimide films such as Kapton® HN composed of multiple lenticular gores which will form a spherical balloon, and a sub-system package suitable for spacecraft integration. The SSGG is composed of a 2D addressable array of Sodium Azide (NaN_3) crystals on a glass substrate. The crystals are contained in wells formed by a thick-film of polyimide (SU-8). Under each well is a resistive heater that is selectively addressed using Metal-Insulator-Metal (MIM) diode networks. When heated to above 350 °C, the NaN_3 spontaneously decomposes to generate N_2 gas in time scales on the order of 10 milliseconds. Each well can be designed with a typical volume of 10-15 m3 to 10-6 m3 of NaN_3. The effectiveness of the system has been numerically evaluated for 1U, 2U and 3U CubeSats. The deorbit time for these three spacecraft from a 550km altitude has been calculated to be 118, 236, and 355 days respectively, and is independent of initial inclination. This analysis assumed a 1m diameter balloon, spacecraft mass of 1.3kg/U, a circular orbit, and deorbit criteria of 180km altitude (the orbital lifetime of a CubeSat at 180km altitude is on the order of 5 orbits). Figure 1 shows the orbital altitude over time for these three example cases.

Figure 1. Altitude verses Time for three CubeSats with a 1m diameter SSIB



The system mass for a SSIB with a 1m balloon, primarily composed of balloon material, would be ~150g and can easily be integrated into a CubeSat bus. The total system cost is relatively low, a batch of flight hardware and spares could be produced for less than $1000 in materials. The technical feasibility of the

SSGG has already been demonstrated and has been shown to be able to generate ~10µg of N_2 gas per well. The SSIB system will be low power and low energy (< 1W and << 1 J per well). The SSIB system has inherently built-in redundancy due to the fact that the SSGG is a scalable chip design and can incorporate as many gas generating wells as a mission may dictate. Additionally, the SSIB can mitigate balloon leaks by sequential deployment of additional gas wells and can thereby maintain the inflated state of the balloon. The SSIB is safe and would not pose a risk to the CubeSat mission or any primary payload on a launch vehicle due to the stable nature of NaN_3 in operational environments. The SSIB will be easy to integrate because it requires no attitude control for operation or deployment (unlike electrodynamic tethers or solar sails) and can integrated on any face of the spacecraft. The SSIB would not introduce significant additional debris risk in operation or in the event of failure since the balloon material has a very low weight to drag ratio and would naturally deorbit very rapidly. The SSIB is a scalable system that could be sized to deorbit the full range of small satellites (<180kg) from orbits as a high as 1000km in altitude within 25 years. A summary of the deorbit time for three CubeSats with various SSIB balloon diameters is shown in Table.

Table 1. Deorbit times in days for three CubeSats with various SSIB balloon diameters

Deorbit Time in Days for Spacecraft with Different Balloon Diameters					
	Balloon Diameter				
Spacecraft	0.5m	0.75m	1.0m	1.25m	1.5m
1U	473	210	118	76	53
2U	946	420	236	151	105
3U	1419	631	355	227	158