Cubesat Deorbiting Using Fenix Multipurpose Propulsion Device

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Introduction

Since the early 2010s the Cubesat market expanded dramatically. According to Space Works Enterprises (2016), historical data shows that the nano/microsatellite CAGR[1] was 39% over the last five years (2010-2015). The same group forecasts that growth will continue, with a CAGR of 13% over the next five years (2016-2020). Such growth has led to the increase in positive externalities to the market, complementing technologies, and has also led to the growth of many business ventures based on Cubesat technology.

The main reasons for the adoption of Cubesats is the easy access to standardized components that reduce the development time and costs for small satellites. Other advantages of standardization are the ease of access to components and parts, who are mostly interchangeable and relatively cheap to find; and the low transaction costs, reducing also the risk of R&D activities and time to market. These reasons apply both to scientific teams, part of research institutes and universities as well as bootstrapped commercial companies wishing to launch their technologies in space as well as profit from easier and low-cost access to space.

For commercial ventures, Cubesats represent a fast and cheap way to reach the market and a user base. Cubesats are mostly used to provide mainstream services such as earth observation and telecommunications. But also, Cubesats are an efficient means for technology demonstration missions and science experiments. Companies such as Planet Labs, Spire, BlackSky, and others are planning constellations of hundreds of small satellites, which will clutter Earth orbits, mostly LEO.

The issue of space debris has already been pointed out by many agencies and institutions, however specific actions and solutions to solve the problem are still insufficient. It is critical to consider the decommissioning phase of the Cubesat in the early stages of mission definition, in order to be able to integrate hardware and software into the spacecraft that can safely and efficiently guarantee a disposal and minimum threat to the remaining spacecraft in orbit.

The Problems of Integrating a Decommissioning Device Onboard a Cubesat

Cubesats have many restrictions, which impose a challenge for engineers when designing the spacecraft and the mission. Besides mass and volume restrictions which are at the base of the Cubesat design, these tiny spacecraft also have pressure and pyrotechnics restrictions, which limit the amount of propellant that can be used, and the propellant types to be used, impacting also the thrust delivered by propulsion systems.

During the initial years of the adoption of the standard, Cubesats missions were mostly used for technology demonstration, where propulsion and orbital maneuvers were not strictly necessary. However, as Cubesat missions expand both in number and in objectives, propulsion has become an important feature to possibly include in the design. The problem being that such low-cost missions are designed to take up very little space and volume, a propulsion system that ensures effective decommissioning of the satellite has not been considered a critical component to add.

Many Cubesats are used for earth observation and are usually equipped with an optical payload. Such cameras leave an empty space between the camera and the inner structure of the satellite, as shown in Figure 1.

[1] CAGR: Compound Annual Growth Rate

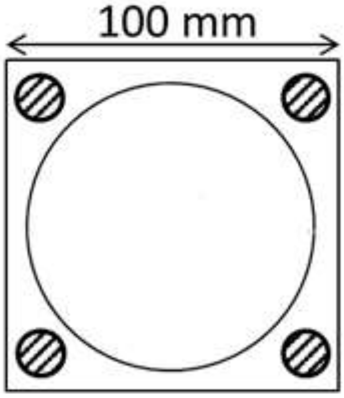

Figure 1 - Cubesat simplified section view

Fenix as a Multipurpose Deorbiting Device

D-Orbit is a satellite systems company specialized in commissioning and decommissioning solutions based on solid rocket propulsion. The company is currently developing Fenix, a miniaturized solid rocket propulsion device for Cubesats and other Micro and Nano satellites with reduced space envelope for payload and instrumentation. Fenix is volume and mass efficient, as it occupies only 6% of the volume and 12% of the mass of a 3U Cubesat.

In order to increase the volume efficiency of Cubesats, Fenix takes advantage of the space left empty on the sides of the payload (hatch sections in Figure 1), introducing propellant cartridges along the payload's length. This means that Cubesat developers don't need to make major design changes in order to incorporate the system into the Cubesat, while also guaranteeing that the Cubesat meets Space Debris Mitigation Requirements.

Most often, in order to be compliant with space debris mitigation requirements, Cubesats have to be released in lower orbits, which makes it fall down after a few months due to aerodynamic drag. By having a decommissioning system, Cubesats can be deployed at higher orbits and rely on the decommissioning device to achieve compliance with debris regulations. This enables an extended mission period, larger revenues for the operator and more launch opportunities.

Solid rocket propulsion is one of the most reliable space propulsion technologies to use, having a wide range of applicability, easy to store, safe and extremely compact. Solid propulsion has an extensive heritage in space missions.

Fenix takes advantage of D-Orbit's experience and heritage on previous missions, such as D-SAT. D-SAT is a 3U Cubesat that will demonstrate D-Orbit capability to design and build successful and efficient decommissioning systems. D-SAT features a miniaturized version of the D-Orbit Decommissioning Device for large satellites, and also sets the technology basis for Fenix, in order to decommission a 3U Cubesats from orbits within the 700 Km range.

The Fenix propulsion system is composed by four independent 19 mm diameter solid propulsion cartridges that can be assembled in two different configurations. In the first configuration, the system fits into one unit Cubesat structure, keeping the central area of the unit completely free and available for a payload with a complete circular cross-section, like an optical payload with a 90 mm diameter lens. In the second configuration, the four cartridges are assembled side by side, giving the standard Cubesat footprint to the payload.

The propulsion system consists of 4 cylindrically shaped cases, with a default diameter of 19 mm and a default length of 95 mm. At the aft end, a nozzle is integrated in the case. The case is filled with a circular, centrally perforated solid propellant charge, whose formulation can be selected by the client based on mission performance requirements. The four rocket motors can be ignited one at a time for maximum manoeuvring flexibility, or in full or partial combination to avoid generating momentum and turn around the pitch or yaw flight directions. Each motor has a reversible, electro-mechanical safe and arm device, which separates the firing line between the forward end of the motor and an igniter screw (electro-explosive subsystem, or EED). The safe and arm device is compliant with all applicable pyrotechnical subsystems safety standards to prevent inadvertent initiation of the motor during assembly, transportation, handling, and launch. There is also a manual arming and safing system, composed by an eccentric rotating disk with two different positions, enabling or blocking the connection between the igniter and the motor propellant.

Lifetime Extension and Added Features of Fenix

With four independent motors, Fenix can also be used to perform other important orbital manoeuvres while still ensuring the Cubesat's decommission ate the end-of-mission. Other possible manoeuvres include dispersion, re-orbit, and collision avoidance. Using Fenix, constellation operators can quickly deploy the constellation, reducing the initial orbit acquisition time and enhancing orbital accuracy by compensating launch altitude dispersions caused by the launch vehicle. The motors can also be used to increase the service life of the satellite by compensating drag forces. And finally, Fenix can be used to perform collision avoidance manoeuvres and change the satellite's trajectory, inhibiting the satellite from colliding with another satellite or space debris.

The propulsion system burns 65 grams of propellant, enough to rise the orbit of a 4.5 kg three-unit Cubesat from 300 km to 410 km, resulting in about one-year orbital life increase, depending on solar flux and satellite geometry.

Performance Criteria

Fenix has been designed with a special focus on its modular approach, which allows for greater flexibility when it comes to customization depending on the Cubesat configuration. Also, although the device is a particular fit to earth observation mission, it is also suitable for other mission types, such as communications and technology demonstration. The device's performances according to the evaluation criteria are as follows:

- Effectiveness. Depending on the altitude of the satellite, Fenix can ensure decommissioning through either controlled or uncontrolled atmospheric re-entry. At 550 Km altitude, Fenix can decommission a 3U Cubesat within a few days, ensuring a debris-safe trajectory for atmospheric re-entry.
- Mass and envelope at launch. Fenix fits into a 1U Cubesat, either placed in the four corners of the Cubesat, or using the Cubesat standard component format (e.g. electronic board shape format). These two configurations guarantee that the propellant case can be scaled to become larger as necessary, being able to extend along two or more Cubesat units for larger satellites. The system's total mass fitted into 1U Cubesat will be 500g, respecting the Cubesat Design Specification.
- Cost. As Cubesats were developed as a low-cost solution to access space, so should components follow the same principles. Fenix's design is optimized in order to ensure affordability to cash-restricted researchers and universities as well as commercial ventures.
- Technical feasibility – mechanical and electrical design. Fenix acquires the expertise from D-Orbit previous mission, where a larger Cubesat decommissioning device was built and will be launched by the end of 2016.
- Impact on the satellite. In order to minimize the impact for the developer, Fenix will be able to be assembled into a Cubesat and connected using RS-232 serial port in order to approach as much as possible a plug-and-play feeling for the developer.
- Reliability. The safe and arm device ensures that the device is has an extremely low probability of failure. Also, software is designed with a safety critical approach and in compliance with ECSS standard.
- Safety. The device is designed to be compliant with MIL 1576 safety standard. It has a safe and arm mechanism in order to ensure a safe operation. Impact on the launcher or on neighbouring satellites is expected to be non-existent.
- Maintenance and testability. The motor technology has been tested on ground, for the specific case of Fenix, ground tests are planned for 2016, with the first complete prototype ready by late 2017.

Provided that solid propulsion is a well-known technology and D-Orbit's expertise on that is large, maintenance of the system shall not demand extensive resources from the operator.

- User friendliness. Satellite interface will be made through an RS-232 serial port, which is one of the most common and standard interfaces. Also, software provided will allow almost full customization by the operator in order to ensure the user interface to be according to the customer's requirements.
- Debris risk. Fenix is designed in order to avoid release of particles larger than 1 mm. Also, depending on the configuration selected, a fully-redundant device can be installed in order to achieve a single point of failure free design. As a standard feature most of these options are not available as they would require a larger share of the satellite's mass and envelope.

References

Space Works Enterprises, 2016 Nano/Microsatellite Market Forecast. Space Works Enterprises, 2016. Available online.