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ORIGAMI DEPLOYABLE DEORBITING SYSTEM

Cristian Vendittozzi *, Paolo Gessini, Giancarlo Santilli, Alef V. R. Dias, Letícia Barros
Universidade de Brasília (UnB) * vendittozzi@aerospace.unb.br

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Objective

Preliminary design of a Deployable Deorbiting System (DDS) based on an *Origami Deployable Drag Sail* (ODDS), to accelerate the process of Orbital decay of a 3U CubeSat at the end of operations.

Justification

- It is now evident that there is a need for a cleaner space around the Earth to protect lives and reduce risk of current and future space missions (Fig. 1), preserving the chance to explore the universe. Low earth orbit (LEO) covers the entire spherical volume above the Earth up to 2000km altitude and is the most densely populated orbital region (Fig. 2) and also the region that is seeing the fastest growth.

Main requirement
drastic reduction in mission costs
Size reduction of spacecraft

Increase in use of nano-, micro- and mini-satellites
Perspective of lower orbits saturation

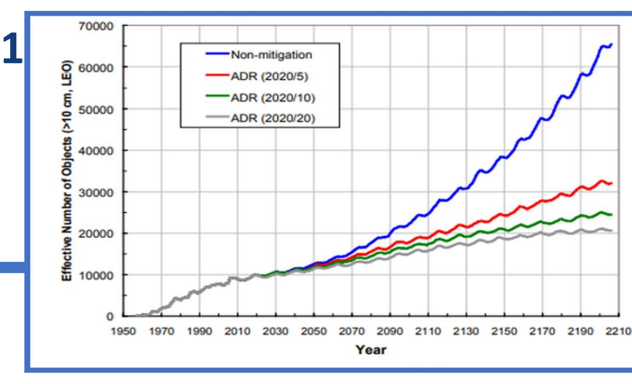
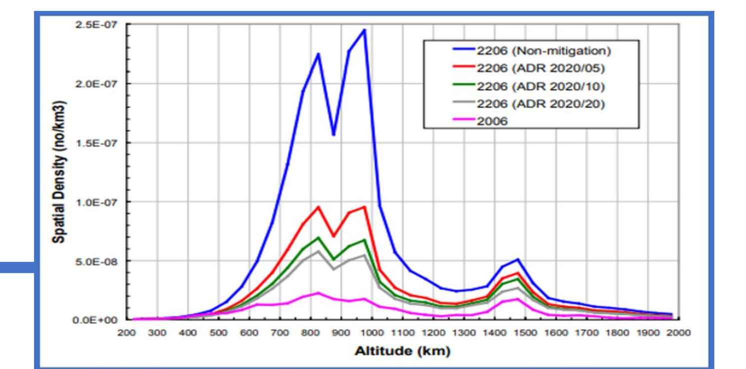
Figure 1


Figure 2


Smaller bus requirement
further optimization of subsystems volumes

Optimization problem
Subsystems storage-space reduction (such as deorbiting systems)

DEPLOYABLE SYSTEMS
reducing the overall dimensions during launch, then extending in orbit.

Increasing of **space debris** production
Demanding ever-more efficient end-of-life de-orbiting systems

CubeSat Low Earth Orbits (LEO)
Residual atmosphere
Deorbiting increasing aerodynamic drag

A light-weight drag sail (tightly packaged in the smallest possible volume)

ORIGAMI
ancient Japanese art/technique of folding paper

Drag Augmentation System (DAS) for CubeSats, developed using Origami folding technique to maximize the Packing Ratio (PR= S/V, where V is the folded stowing volume and S the deployed surface)

Passive de-orbiting method

- Drag augmentation is an effective passive method for de-orbiting in LEO. At altitudes below 1000 km there exists a thin atmosphere that will disturb the orbits of satellites, causing them to spiral towards Earth. Satellites in this orbit region will decay naturally regardless of mitigation strategy, but the time in which the decay completes depends greatly on initial altitude and the area-to-mass ratio of the satellite.

- Drag augmentation will increase the area-to-mass ratio resulting in a shorter decay time. Drag augmentation is achieved by deploying a larger structure at the end of the normal satellite operations - to result in a larger drag surface area.
- The packed volume of the deployable sail can be folded using origami technique (elaborate Origami folding patterns are ever more employed to minimize the packed volume).

Mission target: Maximizing the Packing Ratio (S/V) to de-orbit 3U-CubeSat (4 kg) from a 400 km Sun-synchronous Orbit (SSO) to the Karman line.

Design Steps

a) Orbit definition.
b) Estimation of the minimum area necessary to guarantee the decay of the 3U-CubeSat.
c) Design of the most suitable geometry (sail configuration) to reach the required surface extension with the minimum stowing volume (maximization of packing ratio, PR)
d) Selection of the Origami pattern that make the deployment phase faster and safer for the whole ODDS.
e) Selection of the sail material.
f) Design of the most suitable actuator to free the sail at the unfolding beginning.

a) Orbital elements: a = 400 km; i = 97°; e = 0; Ω = 0° and C_d = 2 (Drag Coef.); C_r = 1 (Solar radiation pressure coef.).
b) To guarantee the decay from the selected orbit, a minimum required area of 0.29 m^2 was estimated. In this way the decay from the SSO of 400 km is estimated in 50 days. The deorbiting system shown in Fig.3 allows expansion of retractable booms up to 1 m in length, allowing sail expansion up to 2.3 m^2, this would allow even faster decay, estimated in 15 days.
c) The selected geometry has the shape of a racing boat mainsail, is composed of a rectangular sector, which extends along the BOOM and a triangular sector, placed laterally (shown in Fig. 4). THE ODDS consists of four wings of this type that open simultaneously on the 4 sides of the CubeSat front face.
d) Origami patterns: *Miura-Ori* for the rectangular section and *Rabbit ears* for the triangular section..
e) The same material commonly used for solar sails, i.e., a multilayer of Mylar and Kapton.
f) The deploying system, shown in Fig.s 4-5, uses a Shape Memory Material (SMA) based actuator.

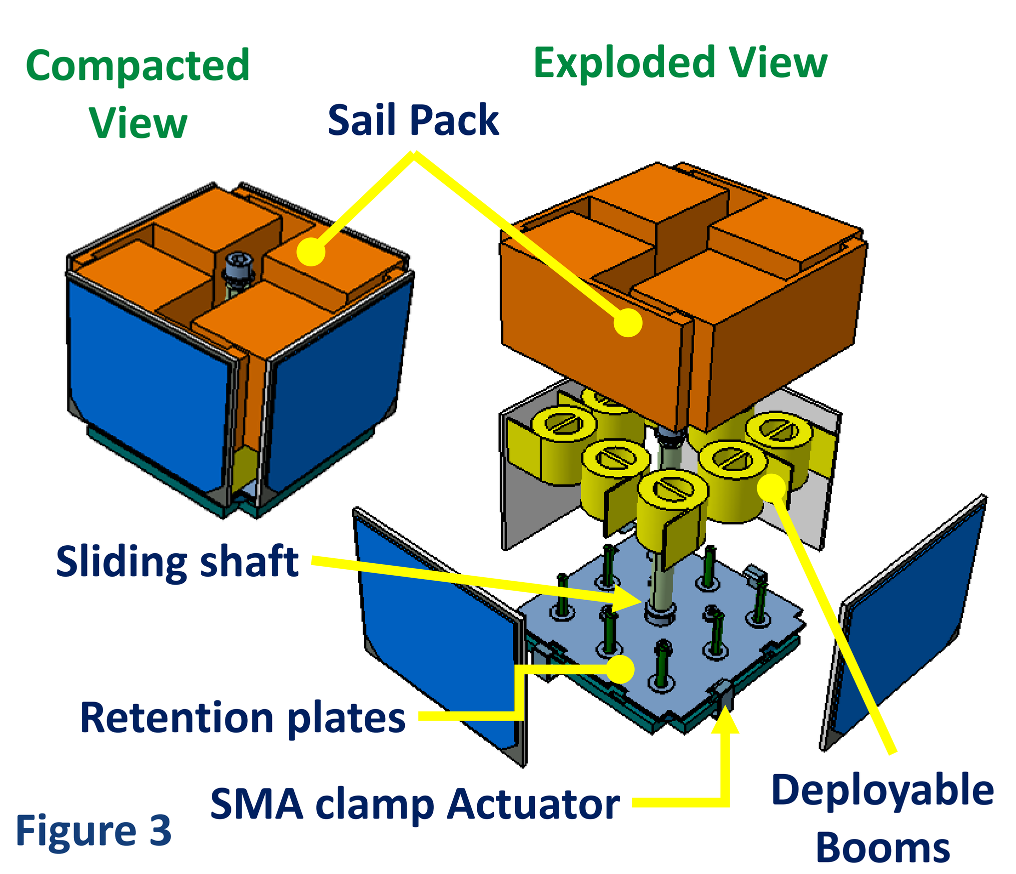


Figure 3

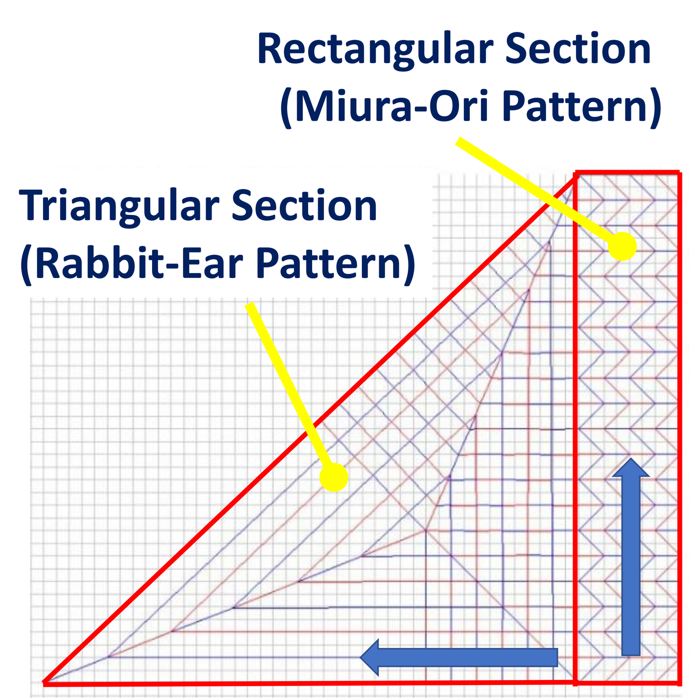


Figure 4

Opening Mechanism: it consists of two retention plates (RP) in which 8 torsion springs are "braked", which allow the opening of 8 folded tape-strings BOOMs (2 for sail). Deployment occurs by an electrical pulse that open 4 SMA clamp actuators, letting the RP slide away from each other along the Sliding Shaft, freeing the torsion springs and, thus, unrolling the booms from the coils (boom gains stiffness once it has been unrolled by having a non-flat cross section).

Each boom-pair drags the rectangular section of the corresponding sail and the tail of the triangular section of the adjacent sail.

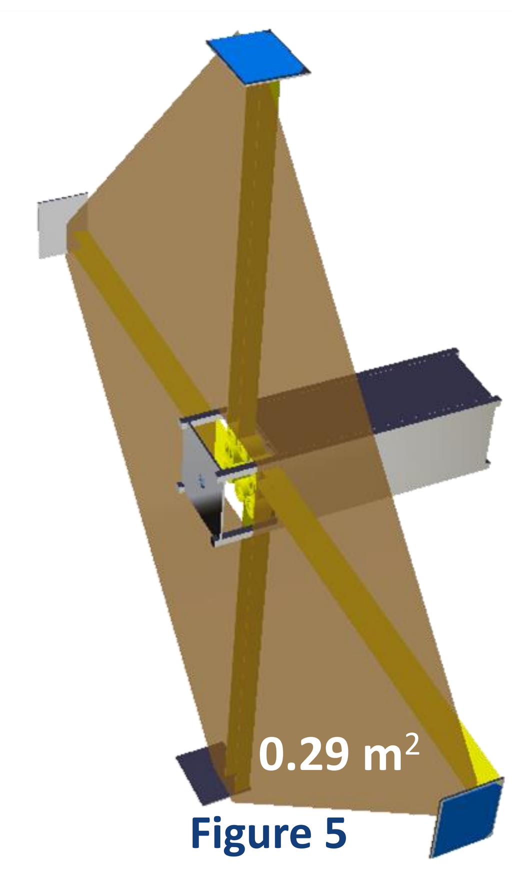


Figure 5

CONCLUSIONS

The aim of this work has been to:

- define the minimum sail surface area to decay from the selected orbit (Drag augmentation)
- to select the geometry of the sail
- to select the origami patterns that would optimize the sail folding/unfolding, maximizing the packing ratio
- to design the concept model of the deployment mechanism.

The proposed Sail Pack has an estimated volume of about 2.5 10^{-5}m^3 for an area of about 2.3 m^2, (allowing a 15 days decay from a 400 km SSO), the packing ratio (S/V) is therefore of 9.3 10^3 m.
A sail-based deorbiting system seems to be best choice for LEO. It might be more efficient at reducing collision risk, weighs less, and has less operational requirements than other solutions (electrodynamic tethers and conventional propulsion).
The research will continue by means of in-depth analysis, starting from the production of a 1: 1 deployment mechanism prototype to verify its theoretical efficiency. Among the things still to be evaluated are: the behavior of sail materials, for long-duration missions, and the effective behavior of an SMA alloy used as an actuator (i.e., actual estimate of the power required to actuate the SMA clamp).

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