Electrodynamic Tether as a Propulsion System for Station-Keeping at Low Orbits

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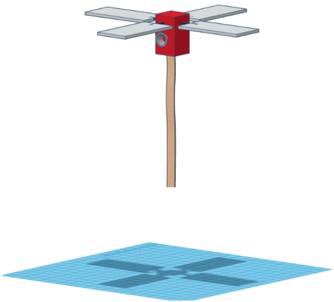
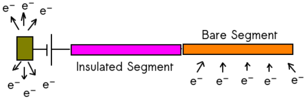
Context:

We performed this work on the framework of E.T.PACK, an H2020 FET OPEN project aiming to develop a de-orbit kit and related software based on low work-function tether technology (828902) [1]. It was hosted at Universidad Carlos II de Madrid.

Goal:

This study aims to evaluate the viability of using Electrodynamic Tethers (EDT) as a propulsion system to keep S/Cs in low orbits. In other words, we intend to oppose the air drag effect with the Lorentz force that arose from an EDT device.



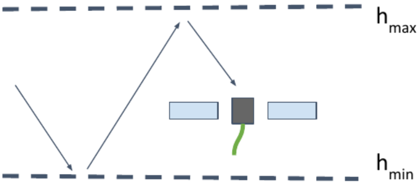


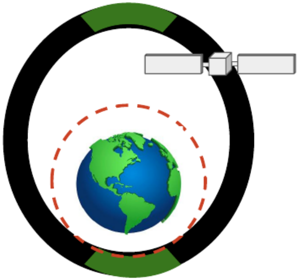
Electrodynamic Tether

EDTs are a promising technology to provide propulsion to S/C with low mass required for its function as a propellantless technology. One of the most prominent EDT types is the Bare EDT [2] that captures electrons from ionosphere by a bare segment and deliver them back by an active electron emitter(e.g. hollow-cathode). The electric current created in this process interacts with the magnetosphere giving rise to Lorentz force. There are two main EDT's operational modes:

- Passive: The EDT take advantage of the motional electric field to create the electric current. The Lorentz force de-orbit the S/C.
- Active: On-board power feeds the EDT to create the electric current in opposed direction of the motional electric field. The Lorentz force re-boost the S/C.

In this work we use a Bare EDT in active mode to perform station-keep maneuvers. To do this, we introduce 3 different strategies for EDT function





ZIG-ZAG

A simple manner of performing station-keeping against the air drag is re-boosting it whenever the S/C falls below a certain altitude, selected as a threshold during the design of the mission. To avoid ground command, we design a technique for the tether operation considering the satellite's position. In this work, we call this strategy as zig-zag. Note that this strategy needs a low eccentricity, since in this configuration the EDT will be more active in pericenter than in apocenter. If the altitude difference of them are huge, this potentially increase the eccentricity even more breaking the station-keeping condition.

Air Drag Compensation

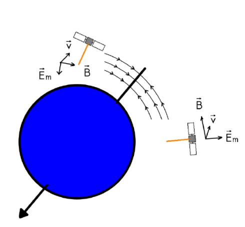
In the Air Drag Compensation Strategy we focus on the air drag and Lorentz forces. This technique aims to neutralize the resulting power. We make the component of the Lorentz force in opposed direction of the air drag force to be equal in module. By substituting the general expressions of the Lorenz's and drag force, in the equilibrium expression of the forces, we compute the average electric current needed along the EDT.

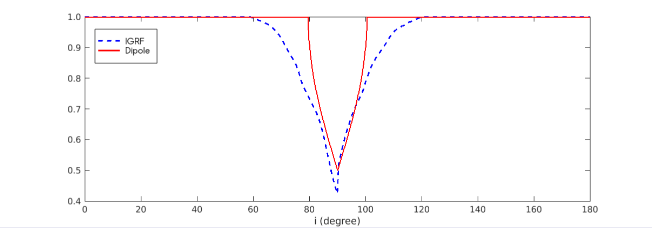
$$\boldsymbol{F}_{air} \cdot \boldsymbol{v}_{rel} + \boldsymbol{F}_{L} \cdot \boldsymbol{v}_{rel} = 0$$

$$I_{av} = \frac{P_{air}}{L\left[\vec{u}_t \cdot \left(\vec{v} \times \vec{B}\right)\right]}$$

INCLINATION FACTOR

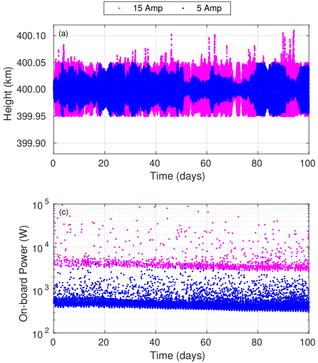
For high inclined orbits, the EDT designed for just one sense function can not operate after crossing the earths magnetic pole. This happens because the motional electric field is in opposite direction in a such configuration. To operate in this context, we extend the previous technique introducing a coefficient to compensate the period when the Lorenz's force must be off. This factor is shown in the plot below for two different Earth's magnetic field models.

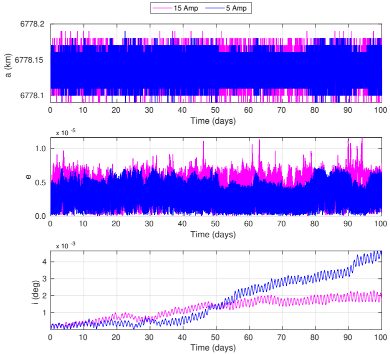




Result: ZIG-ZAG

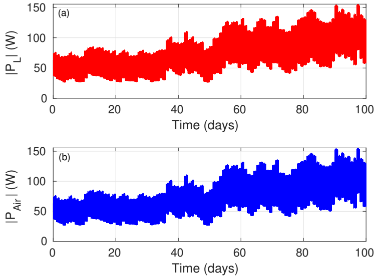
We used the software BETsMA v2 [3] to simulate the described techniques. We set an EDT with a bare tape of $1km \times 2cm \times 50\mu m$ in a S/C in 400 km altitude circular orbit. Two case were simulated, in the first one the EDT performs a 5 Amps electric current when active, and the other 15 Amps.

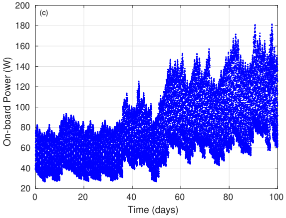


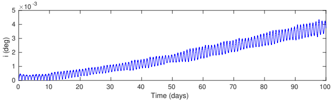


Result: Air Drag Compensation

The air drag compensation strategy in a equatorial orbit (using the same orbital parameters and tether configuration) avoids any change in semi-major axis and eccentricity. The inclination varies slowly.

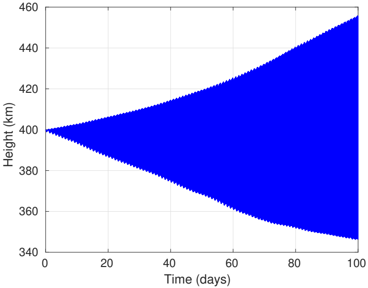


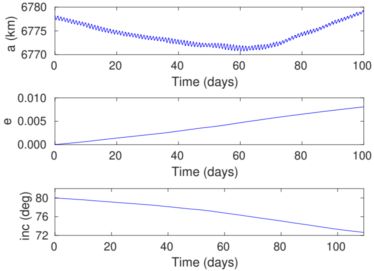




Result: INCLINATION FACTOR

Even by the compensation of the difference between Lorentz power by the inclination factor, the perturbations due to both forces change gradually the orbital elements.





Final coments

In summary, our work shows that a S/C equipped with an EDT can make station-keeping using an autonomous system that controls the tether current based on the environment and the orbital parameters of such S/C. However, each mission must be projected to reach the goal, considering the spacecraft dimensions, and the availability of on-board power.

Next

We intend to publish a paper soon with an extension of this work.

Reference

[1] https://etpack.eu/
[2] Sanmartin, et al. Bare wire anodes for electrodynamic tethers, Journal of Propulsion and Power (1993)
[3] Sanchez-Arriaga, et al. A code for the analysis of missions with electrodynamic tethers, Acta Astronautica (2022)