Satellite Shape Optimization for Maximum Lift over Drag ratio in LEO and VLEO

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Introduction

Low Earth orbit (LEO) and very low Earth orbit (VLEO) are attracting considerable interest. These orbits have several advantages: a relative low launch cost, the ability to intrinsically respect space-debris reentry guidelines and provide better conditions for remote sensing missions. However, because the high density of the residual atmosphere, perturbation caused by atmospheric drag are significant for both their orbital and attitude effects.

Nevertheless, the aerodynamic forces, properly controlled, can also be exploited to benefit specific missions. In particular, by modulating aerodynamic drag and lift, it is possible to obtain control forces by which orbital or satellite attitude corrections can be made without using propellant. The purpose of this study is to analyze and optimize the geometry of a satellite to maximize its Lift-to-Drag ratio in a rarefied environment, so that the effectiveness of purely aerodynamic control can be maximized.

Methods

The geometry optimization is performed using the software CADO (Computer Aided Design Optimization). This software allows the integration of optimization algorithms with Computational Fluid Dynamics (CFD) so that optimal geometries can be designed [1].

The software used for CFD are chosen so that both transient and free molecular flow regimes can be simulated.

SMARTA is a software based on view-factor methods, which can be used to compute internal and external collisionless gas flows when surface reflections are fully diffuse [2]. This software is particularly versatile because it allows changing boundary conditions with a low computational cost (Fig. 1).

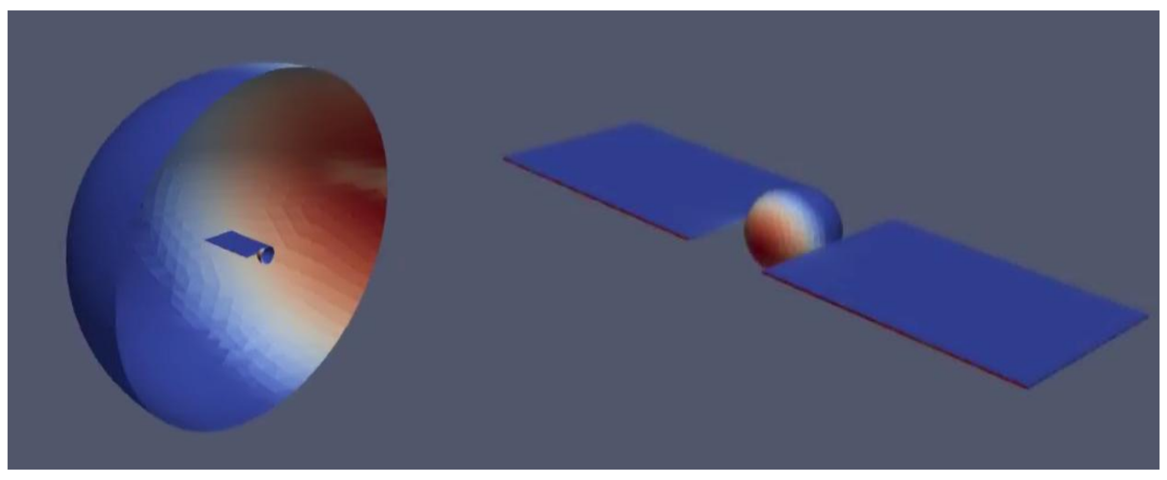

Fig. 1 Example of simulation obtained with SMARTA on a simplified satellite model with aerodynamic surfaces.

In order to consider collisions in the transient regime and the effect of accommodation coefficients in the case of not fully diffuse collisions, the software SPARTA is used. This is based on Direct Simulation Monte Carlo [3].

The effects of the accommodation coefficient (σ_t, σ_n) have a great importance on the calculation of the optimal lift over drag ratio. Fig. 2 shows how these affect the maximum lift over drag ratio (L/D) and the angle of attack (α) at which this is obtained for a flat plate in free molecular flow.

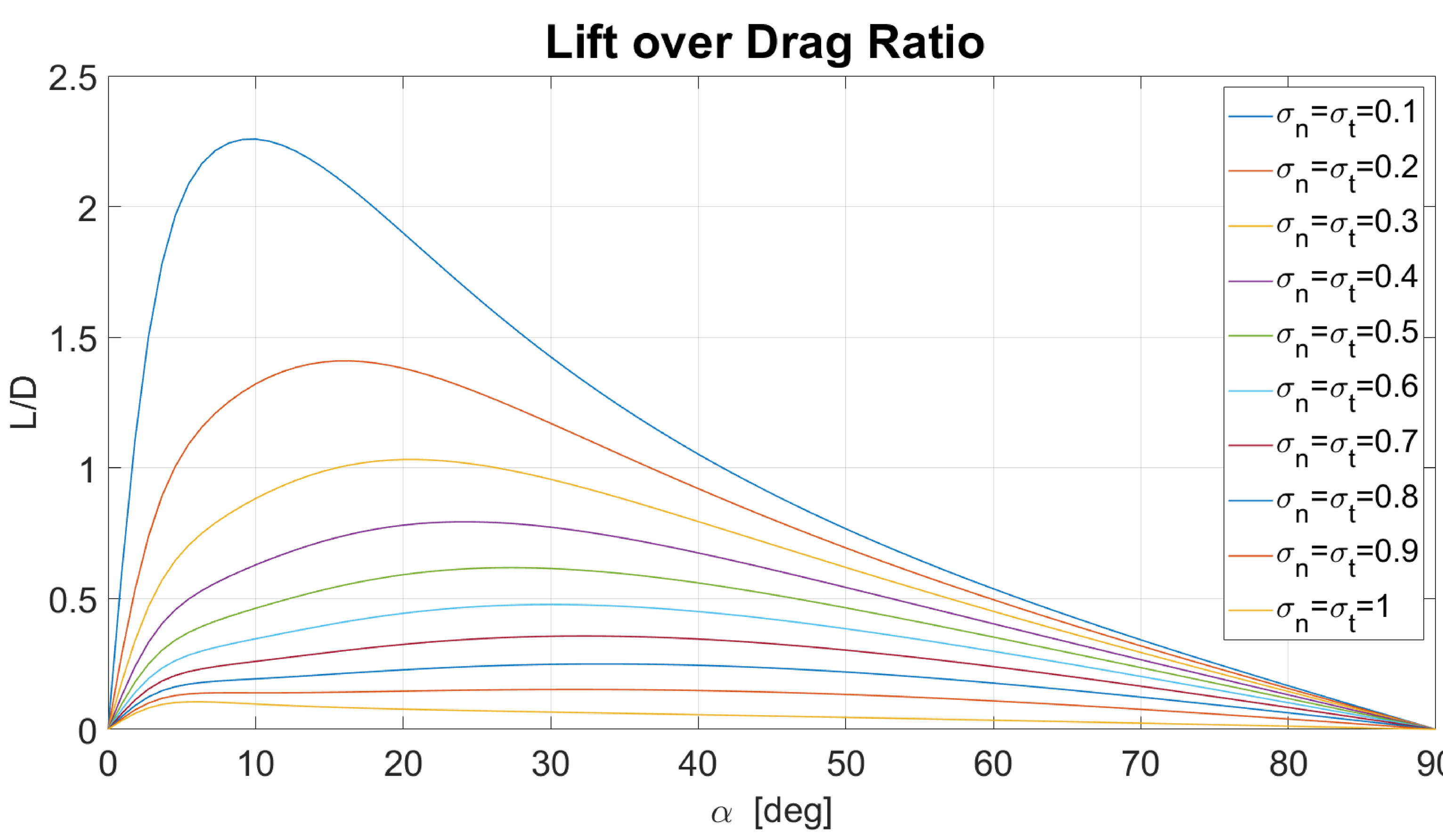

Fig. 1 Effect of accommodation coefficients on lift over drag ratio. The plot represents the trend for a flat plate as a function of angle of attack.

Applications

The main application of this study is the control of satellites in LEO and VLEO. Properly optimized geometries could take full advantage of the Earth's atmosphere to achieve orbit and attitude aerodynamic control without the use of propellant.

These methodologies have already been investigated in previous studies, exploiting the effect of atmospheric drag alone to perform rendezvous between two satellites or to control their attitude [4, 5]. By introducing geometry to generate a suitably large lift, aerodynamic control would be even more versatile and effective in various possible mission scenarios.

An example might be the combination of aerodynamic effects with air-breathing electric propulsion in VLEO. In this architecture, the propulsion system would provide the thrust needed to counteract the atmospheric drag, while the lift force could supply control in the direction perpendicular to the motion.

Another possible application is based on a study done by the ASTRADORS team on tethered space systems: by introducing appropriate aerodynamic surfaces, it is possible to stabilize a tethered system in a cross-track (naturally unstable) configuration, making it optimal for remote sensing applications [6].

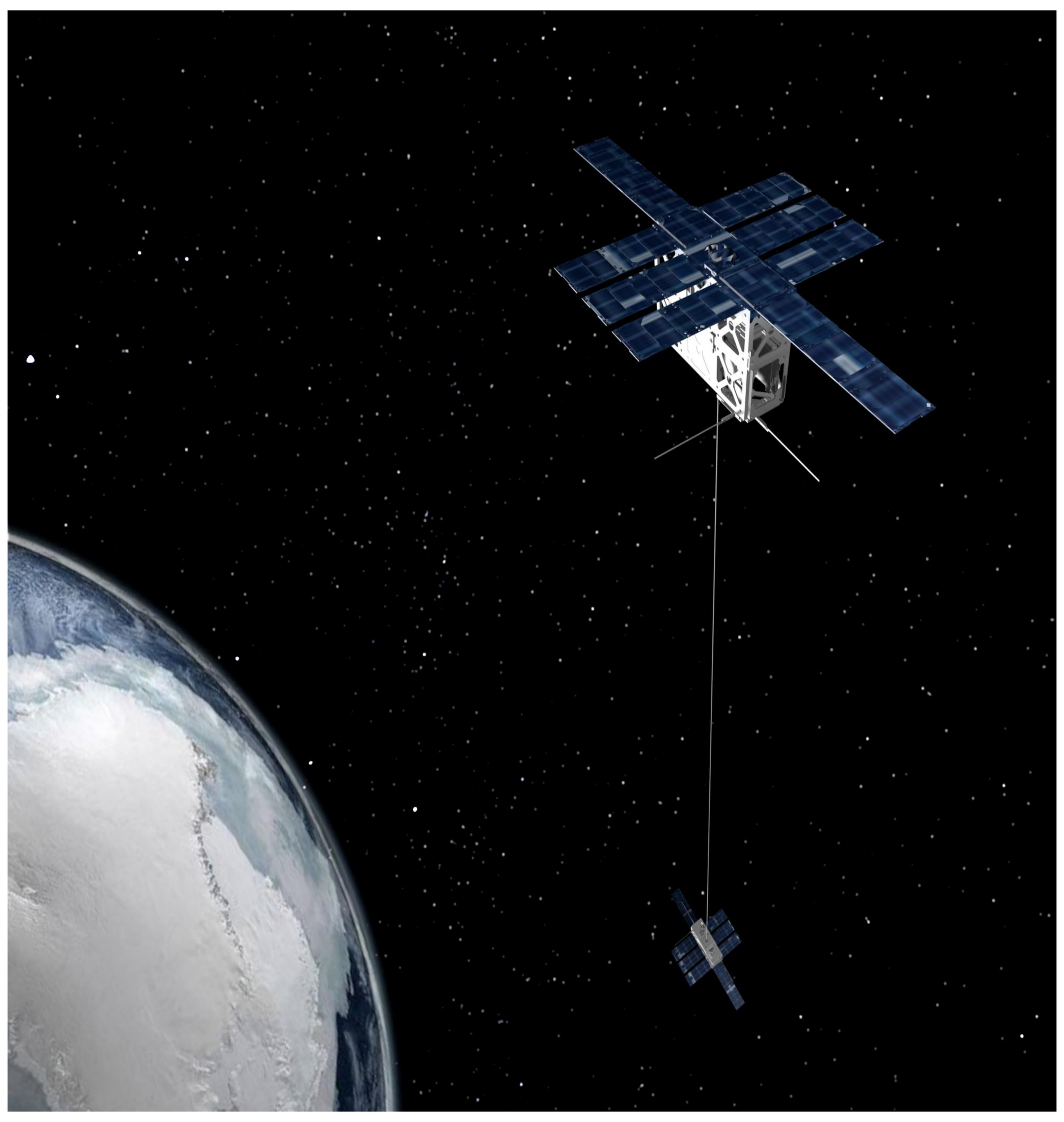

Fig. 3 Tethered system stabilized in the cross-track direction by aerodynamic forces. Credit. ASTRADORS lab

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