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MINIMUM-TIME SPACECRAFT COLLISION AVOIDANCE USING AERODYNAMIC LIFT AND DRAG VIA REACHABLE SETS

Abstract

The increasing number of satellites and debris in low Earth orbit poses a growing risk of collision for operational spacecraft, requiring efficient collision avoidance manoeuvres (CAMs) that can handle short warning times and multiple encounters while minimising impact on the mission. Conventional approaches rely on propulsive manoeuvres, but alternative methods are required for satellites without active propulsion or those on a stringent propellant budget. Aerodynamic CAMs provide a propellant-free alternative, and their development has been identified by the Zero Debris Community as a key enabling factor in improving spacecraft manoeuvrability.

We demonstrate that Very Low Earth Orbit (VLEO) satellites, operating at altitudes of 450 km and below, can effectively use aerodynamic forces for collision avoidance. While VLEO benefits from rapid natural de-orbiting in line with space debris mitigation policies, collision risks remain relevant and must be addressed, particularly as the overall satellite and debris populations grow. Previous research has employed drag-based CAMs that are initiated several orbits prior to a projected collision. However, challenges remain in managing short warning times and complex conjunction scenarios. Our work explores the potential of out-of-plane aerodynamic forces, or lift, as a means to improve control authority and the ability to reduce orbital decay.

Starting from the conjunction point, the spacecraft performing the manoeuvre is propagated back in time. The spacecraft attitude profile and the resulting aerodynamic accelerations can then be related to their effect on the conjunction geometry. Uncertainties in parameters affecting the control effort, such as thermospheric mass density and gas-surface interactions are taken into account. The optimal attitude profile results from a nonlinear program and minimises the required reaction time prior to the collision while satisfying operational constraints.

Drawing on advances in materials science and spacecraft designed to exploit aerodynamic forces, we show that lift-based manoeuvres can reduce orbital decay compared to purely drag-based approaches. Applied to test datasets and past encounters, the presented work demonstrates the feasibility and effectiveness

of aerodynamic CAMs in multi-conjunction scenarios. These findings contribute to the development of manoeuvre strategies that enhance spacecraft autonomy and enable sustainable operations in increasingly congested orbital environments.