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Drag sails for space debris mitigation

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ABSTRACT

The prudence for satellites to have a mitigation or deorbiting strategy has been brought about by the ever increasing amount of debris in Earth orbit. Drag augmentation is a potentially passive method for de-orbiting in LEO but its collision risk mitigation efficiency is sometimes underestimated by not taking all the relevant factors into account. This paper shows that using drag augmentation from a deployable drag-sail to de-orbit a satellite in LEO will lead to a reduction in collision risk. In order to support this finding, the models that are needed in order to evaluate the collision risk of a decaying object under drag conditions are presented. A comparison is performed between the simpler Area-Time-Product (ATP) and more precise collision risk analysis, and the effects that are overlooked in the simple ATP calculation are explained.

1. Introduction

The prudence for satellites to have a mitigation or deorbiting strategy has been brought about by the ever increasing amount of debris in Earth orbit. Satellites and rocket upper stages in the past were left abandoned once the particular mission ended. With increased access to space this has evolved into a potentially hazardous population of objects in Earth orbit. Active and operational satellites currently share space with numerous inactive and uncontrolled objects ranging from intact but non-operational satellites and upper stages, to explosion and collision fragments.

1.1. Mitigation guidelines

Studies have been used to formulate space debris mitigation guidelines, and adherence to these guidelines would theoretically lead to a sustainable environment for future satellite launches and operations. The guidelines make specific mention of two orbital regions: low-Earth orbit (LEO) and geosynchronous Earth orbit (GEO) [1].

The desire for mitigation of debris in GEO comes as a result of the strategic importance of the GEO orbit region for providing communication services. The GEO region is defined by the circular equatorial orbit with angular rate equal to the Earth's rotation rate and occurs at 35,768 km. GEO satellites are assigned a specific longitude and thus the narrow geostationary band is already tightly controlled and satellites in GEO require station-keeping abilities to remain in a geostationary position.

LEO in contrast is not defined by such a specific orbit since it covers the entire spherical volume above the Earth up to 2000 km altitude. Satellites in this region come in all shapes and sizes and can have any possible orbital orientation and shape, although there is a preference for specific altitudes and inclinations (see Figs. 1 and 2). LEO is also currently the most densely populated orbital region and also the region that is seeing the largest growth. Studies have theorized the instability of the region, fueled by an anti-satellite weapons test and accidental collision that occurred in the past decade. This is also the region to which the

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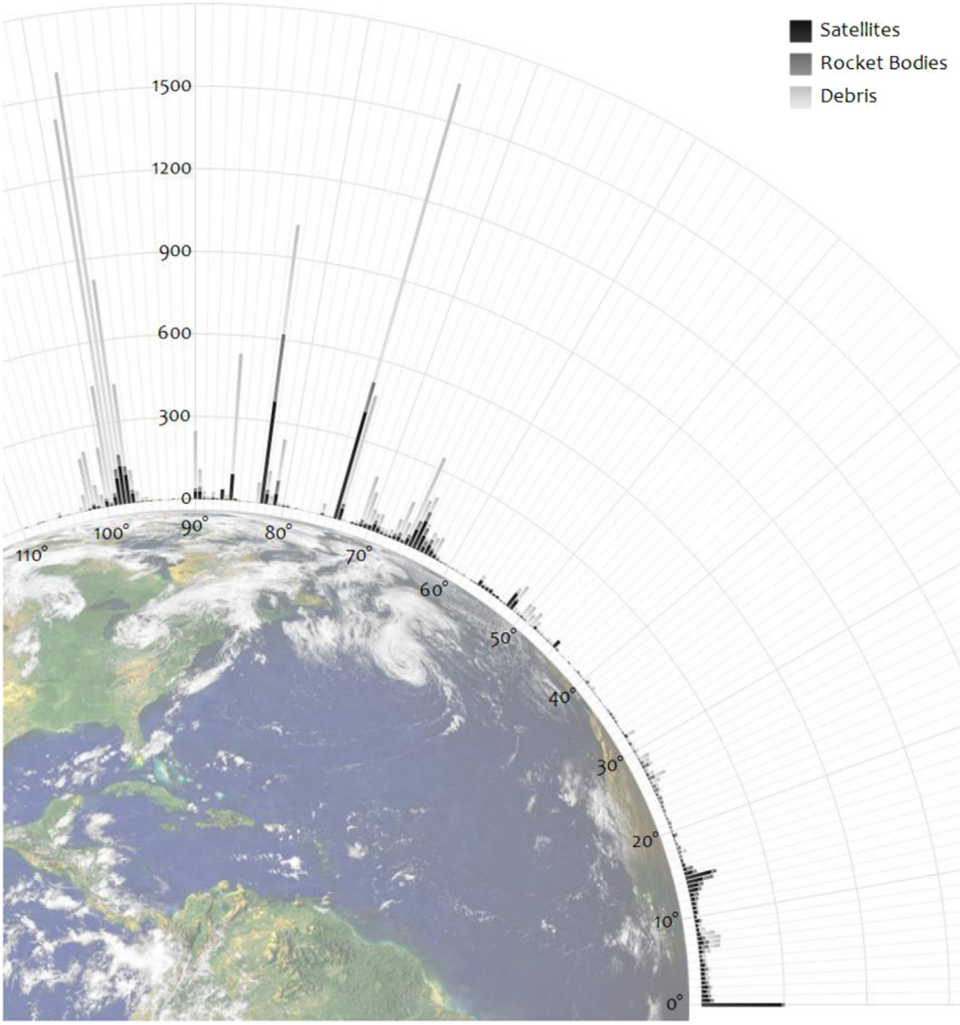

Fig. 1. Distribution of LEO objects per orbit inclination (compiled from Space Situation Report on 6 Jan 2014 [3]).

so-called Kessler Syndrome would theoretically apply. The major source of new debris could be in-orbit collisions, between both intact satellites and already existing debris [2].

The mitigation guidelines for the LEO region suggests disposal by destructive re-entry in the Earth atmosphere. The time in which such a disposal maneuver should occur is 25 years after the mission has ended [1]. The guidelines also state that uncontrolled re-entry should only be allowed if there is no undue risk to people or property. Large satellites have the potential to survive atmospheric re-entry (at least in part) and re-entry fragments pose a risk when they impact habited areas on the Earth surface. Controlled re-entry by means of high-thrust propulsion should be used in such cases to make sure the debris reaches uninhabited or oceanic areas on the Earth surface.

1.2. Drag augmentation

Drag augmentation is a potentially 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, satellite mass and drag surface area. Drag augmentation increases the drag surface area with minimal increase to the satellite mass, resulting in a shorter decay time.

Deployable sail designs that have traditionally been studied and used for solar sails are increasingly being considered for de-orbit applications. Solar sails also have a low mass, large surface area design requirement to achieve efficient thrust. Examples of recent advances in deployable sail technologies can be found in [4–6].There are already missions that specifically make use of sails for deorbiting either as the main objective [7] or to comply with mitigation guidelines [8].

Orbital decay due to drag has been studied extensively and varying degrees of detail can be applied to the models. One of the pitfalls of combining orbital decay calculations to debris mitigation analysis is to oversimplify. When considering drag augmentation this can lead to an unfavorable evaluation compared to other alternatives in terms of risk reduction.