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The many futures of active debris removal

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ABSTRACT

In the last decade, space debris modelling studies have suggested that the long-term low Earth orbit (LEO) debris population will continue to grow even with the widespread adoption of mitigation measures recommended by the Inter-Agency Space Debris Coordination Committee. More recently, studies have shown that it is possible to prevent the expected growth of debris in LEO with the additional removal of a small number of selected debris objects, through a process of active debris removal (ADR). In order to constrain the many degrees of freedom within these studies, some reasonable assumptions were made concerning parameters describing future launch, explosion, solar and mitigation activities. There remains uncertainty about how the values of these parameters will change in the future. As a result, the effectiveness of ADR has only been established and quantified for a narrow range of possible future cases. There is, therefore, a need to broaden the values of these parameters to investigate further the potential benefits of ADR.

A study was completed to model and quantify the influence of four key parameters describing launch and explosion rates, the magnitude of solar activity and the level of post-mission disposal compliance on the effectiveness of ADR to reduce the LEO debris population. Each parameter's value was drawn from a realistic range, based upon historical data of the last 50 years and, in the case of post-mission disposal, a current estimate of the level of compliance and a second optimistic value. Using the University of Southampton's Debris Analysis and Monitoring Architecture to the Geosynchronous Environment (DAMAGE) model, the influence of each parameter was modelled in Monte Carlo projections of the ≥ 5 cm LEO debris environment from 2009 to 2209. In addition, two ADR rates were investigated: five and ten removals per year.

The results showed an increase in the variance of the size of the LEO population at the 2209 epoch compared with previous ADR modelling studies. In some cases, the number of LEO debris objects in the population varied by a factor greater than ten. Ten removals per year were not sufficient to prevent the long-term growth of the population in some cases, whilst ADR was not required to prevent population growth in others.

1. Introduction

It is well known that space debris represents a significant collision risk to operational satellites as well as a threat to the long-term sustainability of outer space activities. Several responses outlining mitigation procedures, including the Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines [1], the United Nations Committee on the Peaceful Uses of Outer Space Mitigation Guidelines [2], the International Organization for Standardization Space Debris Mitigation standards [3], the ESA Space Debris Mitigation Handbook [4], and a multitude of other national and international

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documents have been, and continue to be, developed to limit the expected future growth of the debris population. Whilst the widespread adoption of mitigation measures has been shown to be effective at reducing this predicted growth [5–7], these are unlikely to stop the long-term debris population in low Earth orbit (LEO) from increasing in size [8–10]. In 2009, the IADC initiated an action item (A.I. 27.1) [11] to determine the stability of the future LEO environment. Using six agencies' modelling capabilities, a consensus was reached that confirmed, even with high levels of mitigation (90% future compliance with a 25-year post-mission disposal (PMD) rule and no future explosions), the current LEO debris population is likely to grow. As such, one of the key conclusions of this action item was that more aggressive measures, such as active debris removal (ADR), should be considered.

Active debris removal studies performed by the National Aeronautics and Space Administration (NASA) Orbital Debris Program Office [12], the International Academy of Astronautics [13], the University of Southampton [14] and many others, have demonstrated the effectiveness of ADR in reducing the predicted LEO population. Results have shown that it may be possible to reduce the growth of the ≥ 10 cm LEO population by removing a number of target debris objects alongside widespread compliance with IADC mitigation guidelines. These studies have demonstrated that removal rates in the order of five objects per year may be sufficient to address the growth of the LEO population ≥ 10 cm over a 200-year period [12].

To constrain the many degrees of freedom in these ADR studies some reasonable assumptions were made that confined parameters including the future launch, explosion and mitigation activity to a limited number of cases. The values of these parameters remained unchanged throughout the studies, for example eight-year launch traffic cycles, repeating solar cycle projections, a fixed level of PMD compliance and no explosions. In recognition of this, some authors of these studies have stated that calculated removal rates are only intended to serve as a guide, in particular.

> “The ‘removing five objects per year can stabilize the LEO environment conclusion’ is somewhat notional. It is intended to serve as a benchmark for ADR planning.” (J.C. Liou, June 2012, Presentation at the 2nd European Workshop on Active Debris Removal, CNES HQ, France, slide 19) [15].

Consequently, because of the restricted range of these parameters, the effectiveness of ADR has only been investigated for a narrow range of possible future cases. Several previous modelling studies [16–19] have shown that adjusting the values of these parameters, such as increasing or decreasing launch rates or modifying solar cycle projections, can significantly influence the size of the future debris population. Whilst these previous studies have investigated variations in individual parameters, they have not considered the effects of their variations in conjunction with ADR activities. There remains a need to model a broader range of values for these parameters to help establish ADR removal rates in a wider context.

In this work, four key modelling parameters were varied; these were launch and explosion rate, magnitude of solar activity and compliance with PMD. To investigate these parameters, with respect to the effectiveness of ADR, the University of Southampton's evolutionary model, DAMAGE (the Debris Analysis and Monitoring Architecture for the Geosynchronous Environment) was used to simulate the future ≥ 5 cm LEO debris population over 200 years.

At the beginning of each Monte Carlo (MC) projection, four uniformly distributed random numbers were generated. These numbers dictated the future launch rate, magnitude of solar activity, level of compliance with PMD and explosion rate for that particular projection. The range of each parameter's value, excluding PMD compliance, was derived from the maximum and minimum values of the last 50 complete years of historical data. The range of PMD compliance was between an estimate of the current level of PMD and an optimistic level that may be achievable in the future. Throughout the projection, the value of each parameter remained fixed. Thus, each projection contained a different set of future conditions throughout its projection period.

To demonstrate the effect these parameters had on ADR activities, two ADR scenarios and a baseline scenario with no ADR were investigated. To capture a wide variety of possible cases, 200 MC projections were conducted for each scenario.

2. Method

A 200-year future projection from 1 May 2009 to 1 May 2209 for the effective LEO debris population was used by DAMAGE. The description of this study is shown in Table 1. Three scenarios were investigated using Monte Carlo (MC) simulation technique that comprised of 200 future

Table 1
Summary description of the study.

Parameter	Value
Initial population	Meteoroid and space debris terrestrial environment reference (MASTER) population ≥ 5 cm residing in or passing through the LEO regime on 1 May 2009
Sources included	Satellites, rocket bodies, mission-related debris, explosion and collision fragments
Sources excluded	Reusable launch systems, space stations, new solid rocket motor slag (Al_2O_3), sodium potassium droplets (NaK), ejecta and paint flakes
Satellite properties	The operational lifetime of satellites was set to eight years, no station keeping or collision avoidance manoeuvres occurred
Post-mission disposal	Spacecraft and rocket bodies were moved to orbits that decay within 25 years (with a one-year tolerance) or re-orbited above LEO and taken out of the simulation