# Orbit Aspects of End-Of-Life Disposal from Highly Eccentric Orbits

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Abstract

International space debris mitigation standards request a permanent clearance of the Low Earth Orbit (LEO) and Geostationary Orbit (GEO) protected regions. Furthermore, the risk on-ground, following a potential atmospheric re-entry, shall be constrained by clear safety limits. Corresponding disposal options are well established for missions in GEO and LEO, and consist of near circular graveyard orbits or atmospheric decay. Science missions, however, sometimes operate on highly-eccentric orbits (HEO) to achieve their mission goals, such as astronomical observations or measurements of the Earth's environment. HEOs describe a group of orbits with perigees in or close to the LEO region and eccentricities above those of Geostationary Transfer Orbits (GTOs) (approximately 0.73). The dominant perturbation forces on these orbits are typically caused by the gravity fields of Sun and Moon.

ESA's Cluster-II mission investigates the interaction between cosmic plasma and weak magnetic fields. Flying in a tetrahedral formation, four spacecraft collect the most detailed data yet on small-scale changes in near-Earth space and the physical processes between the charged particles of the solar wind and Earth's magnetosphere. The remaining delta-v constraints do not allow for a controlled de-orbit (i.e. direct re-entry boost). Instead, without dedicated disposal action, the combination of the perturbing accelerations will force the re-entry of all four spacecraft. The first re-entry will occur in 2024, followed by two re-entries in 2026 and the last one in 2038.

ESA's Integral mission is dedicated to the fine spectroscopy and fine imaging of celestial gamma ray sources in various energy bands. The spacecraft, with 3.3 ton dry mass, will not re-enter naturally within 200 years, however it will repeatedly drift into the LEO region and cross the GEO protected region. Similarly to Cluster-II, delta-v constraints do not permit a controlled re-entry.

This paper highlights ESA's investigations on orbit manoeuvres to change the long-term evolution and to finally influence the orbital lifetime, re-entry epoch, and re-entry location for the Cluster-II and Integral spacecraft. Manoeuvres, years before the end of the mission, to target a natural re-entry driven by third body perturbations several years after the end of mission, were analysed and implemented. The manoeuvre options considered are presented with a view to their cost in delta-v and therefore maximum post-manoeuvre operational lifetime and their effect on orbital lifetime and re-entry location.

A large parameter space was analysed varying time and size of manoeuvre, on-orbit location, and direction. Once a baseline approach had been selected a fine strategy was devised taking further operational constraints into account, such as ground station coverage during manoeuvres and post-manoeuvre orbit requirements. In case of Integral a repeat pattern was chosen which allows the continued use of the ground segment with minimum changes with respect to the pre-manoeuver 3-day orbit. In case of Cluster only one of the 4 spacecraft (Cluster-1) was manoeuvred maintaining its orbital position relative to the other satellites, while shifting its inclination and increasing the eccentricity.

Both Integral and Cluster-1 performed their manoeuvres successfully during the first quarter of 2015. For both missions the manoeuvres entail three major burns – the largest since several years of operations. Details of the manoeuvre sequence and execution are reported as well as post-manoeuvre orbit assessment results. An outlook on on-going work covering options for further fine-tuning of the re-entry scenarios via final touch-up manoeuvres at the end of operations is also presented. Such fine-tuning may allow some limited control of the final break-up process during re-entry potentially constraining further the location of fragments reaching ground.