End-Of-Life Disposal Concepts for Lagrange-Point and Highly Elliptical Orbit Missions

Executive summary

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Libration Point Orbits (LPO) and Highly Elliptical Orbits (HEO) are often selected for astrophysics and solar terrestrial missions as they offer vantage points for the observation of the Earth, the Sun and the Universe. No guidelines currently exist for LPO and HEO missions' end-of-life; however, as current and future missions are planned to be placed on these orbits, it is a critical aspect to define a sustainable strategy for their disposal, with the objective to avoid interference with protected regions. Indeed, LPO or HEO lie in a highly perturbed environment; moreover, due to their challenging mission requirements, they are characterised by large-size spacecraft. Therefore, the uncontrolled s/c on manifold trajectories could re-enter to Earth or cross the protected regions.

In the framework of the ESA/ESOC contract No. 4000107624/13/F/MOS "End-Of-Life Disposal Concepts for Lagrange-Point and Highly Elliptical Orbit Missions", a detailed analysis of possible disposal strategies for LPO and HEO missions was performed. The study was done by the consortium led by the University of Southampton in collaboration with SpaceDyS and the University of Strathclyde. In TN1 a list of missions is delivered, covering all the ESA missions currently operating on LPO and HEO and future missions that are currently in post phase-B1. Based on the available debris mitigation requirement documentation and the mission parameters, the requirements and constraints for the disposal are defined.

In TN2 a preliminary analysis of the possible disposal strategies is presented. Five ESA missions currently (or in the future) operating on LPO and HEO are selected as test case scenarios: Herschel, Gaia, SOHO as LPO, and INTEGRAL and XMM-Newton as HEO. In order to keep the general validity of this study to different LPO and HEO, the search for optimal trajectories for disposal is not limited to the on-board propellant; rather, a limit on the delta-v of 150 m/s is considered for LPO, while for HEO 2/3 times the available delta-v on-board is considered. A parametric analysis was performed to define optimal disposal strategies (in terms of time and delta-v) for different starting dates and orbital conditions for the disposal. The manoeuvre is optimised considering the constraints on the available fuel at the end-of-life. For each mission the disposal strategies are analysed, in terms of optimal window for the disposal manoeuvre, manoeuvre sequences, time of flight and disposal characteristics, such as re-entry conditions or the hyperbolic excess velocity at arrival in case of a Moon impact. The disposal strategies proposed and designed are: HEO disposal through Earth re-entry, HEO disposal through injection into a graveyard stable orbit, HEO disposal through transfer to a LPO, HEO disposal through Moon capture, LPO disposal through Earth re-entry, LPO disposal towards a Moon impact, LPO disposal towards the inner or the outer solar system, LPO disposal towards the outer solar system through solar radiation pressure. For each strategy, the mission scenario, the simulation framework and the requirements and constrains for the detailed strategy analysis are defined. On the basis of the operational cost, complexity and demanding delta-v manoeuvres, some disposal options were later discarded via discussion with ESA. Those disposal solutions, namely, HEO disposal through transfer to a LPO, HEO disposal through Moon capture, LPO disposal to another planet, LPO disposal through capture at the Moon, could be anyway considered as starting point for future studies.

As a further step in TN3, the optimal trajectories for each mission scenario and for each disposal strategy are then refined with a high fidelity model of the dynamics and an uncertainty analysis on the initial parameters and the spacecraft parameters is performed. Finally, a trade-off is made considering technical feasibility (in terms of the available on-board resources and delta-v requirements), as well as the future sustainability of the disposal and the collision probability in the protected regions.

General recommendations are drawn in terms of system requirements and mission planning. In light of the objective of sustainability, it appears reasonable to postulate a permanent removal of the hardware from the space environment as a main objective for the end-of-life strategy. For HEO missions this can be achieved by a controlled or semi-controlled re-entry into the Earth atmosphere, when this is allowed by the on-board delta-v. Alternatively, long-term stability orbits should be selected as graveyard. For LPO missions, the feasibility of a controlled re-entry to the Earth depends on the operational orbit and the spacecraft capabilities at the end-of-life. If a re-entry is not possible, a permanent removal from the space environment can be achieved by lunar impact. If such a disposal is performed in line with a sustainable conduct of avoiding heritage sites and sites of high scientific interest, it can be considered more sustainable than the semi-permanent solution of using a parking orbit. In the case a Sun-parking orbit is selected, the zero velocity curves need to be closed with a manoeuvre, considering additional margin to counteract the perturbations due to other bodies and solar radiation pressure.