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SUSTAINABLE DEVELOPMENT OF SMALL SATELLITES USING LIFE CYCLE ASSESSMENT (LCA): A SYSTEMS ENGINEERING APPROACH

Abstract

In the wake of ambitious plans by companies like SpaceX and Amazon to deploy numerous satellites, the global space industry stands at the threshold of a 'SmallSat revolution'. Studies predict that roughly 18,500 SmallSats (i.e., satellites weighing under 500 kg) will be launched into Earth orbits between 2022 and 2031, representing a fourfold increase over the previous decade.

While lower launch costs are driving innovations in SmallSat applications, they also raise concerns about sustainability and potential dangers such as satellite conjunction, orbital debris and even the Kessler Syndrome. These issues reflect the urgent need for responsible development of SmallSats and adherence to sustainability principles.

This paper presents a Life Cycle Assessment (LCA) of SmallSats, analysing their environmental impact across design, manufacturing, operation, and end-of-life stages. We analyse all the lessons learnt from past SmallSat missions and apply these learnings to perform LCA to study how SmallSats can be developed more sustainably.

The paper explores different aspects in the SmallSat lifecycle, including material selection for subsystems, energy consumption throughout its operational lifespan, power requirements, waste generation during manufacturing, launch and operations, and active and passive satellite disposal methods. Furthermore, the research covers the design parameters of the satellite's structure, electronics, power system, attitude determination and orientation control system, onboard propulsion system, and communication and data handling system. A top-down systems engineering approach is followed to perform the analysis for the SmallSat LCA.

Based on the LCA findings, we develop actionable recommendations for sustainable practices within the SmallSat industry, emphasising design principles that minimise resource consumption and consider safe decommissioning practices. We identify and recommend alternatives to currently used materials and processes in SmallSat development and operations. We explore strategies for reducing energy consumption during SmallSat operations, such as optimising orbital manoeuvres and communication protocols. Various disposal methods, such as controlled deorbiting or active debris removal, are also analysed and compared for environmental impact, and the best practices are presented.