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Title
Integrating Environmental Life Cycle Assessments in the Design Optimization of Electric UAVs

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Abstract
Unmanned Aerial Vehicles (UAVs) have undergone intensive development in recent years. Owing to their cost-effectiveness and high maneuverability, these vehicles are expected to emerge in a wide variety of applications such as package delivery, power line monitoring, and precision agriculture. However, UAVs face regulatory and societal challenges that could slow down their introduction into the markets. Their social acceptance is highly related to environmental concerns, for example, impacts on climate change. The relevance of UAVs will therefore depend on the ability to take stringent environmental limits into account right from the design phase. This requires a rigorous and comprehensive approach to assist manufacturers in sizing and designing eco-efficient UAVs.
Although there are methodologies in the open literature for sizing multirotor [1–4], fixed-wing, and hybrid UAVs [5–8], none of them provides models for analyzing the environmental impacts during the design and sizing process. Environmental considerations for UAVs focus on simplified approaches estimating the in-flight energy consumption [9] or more complex approaches applying Life Cycle Assessment (LCA) methods to analyze the impacts of existing designs associated with different stages of their life cycle [10–12]. In these studies, the evaluation of life-cycle impacts is not linked to the sizing process. Hence, the current state of the art does not provide the capability to evaluate and minimize the environmental impacts of UAVs as of the conceptual design phase. Yet, solutions have already been implemented for conventional aircraft design problems [13], [14]. The present paper provides an approach to integrate LCA in the design optimization of UAVs in order to link design-related issues to environmental casualties.
For this purpose, a numerical tool for the design optimization of electric drones, FAST-UAV, has been developed and implemented in previous work [1], [6], [15]. The methodology enables the sizing and evaluation of various configurations (multirotors, fixed-wings and hybrids) for a wide range of specifications. It relies on a multidisciplinary approach that includes analytical models for the propulsion, aerodynamics and structures, among others. A module for environmental analysis in now being implemented in FAST-UAV. First, the environmental impacts of the components selected in the sizing process are evaluated with LCA methods. This allows determining which components and which life cycle phases are critical with respect to various environmental impact categories. Then, the analysis is integrated in the design optimization problem and different objective functions are compared for minimizing the environmental impacts at the system level. Finally, different designs are compared and sensitivity analyses are carried out for assessing the benefits of future technological improvements such as battery energy density on environmental performances, as well as parameters such as the lifetime of the UAV.
The results will help establish guidelines for the eco-design of UAVs towards a more sustainable market.

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