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Life Cycle Assessment of Primary Distribution Systems in Modern Aircraft

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Introduction

The aviation sector must transition to hybrid-electric regional aircraft to achieve the European Green Deal objectives, aiming for Europe to become climate-neutral by 2050. To reach this target, transport emissions need to be reduced by 90% by mid-century, compared to 1990 levels. This transformation necessitates power distribution networks capable of safely managing high power and voltage levels, reaching several megawatts.
The EU-funded HECATE project aims to tackle challenges related to system weight and power density, high voltage phenomena such as lightning arcs and electromagnetic interference, and optimized thermal management. HECATE will develop a suite of enabling technologies and outline a scalability roadmap for CAJU Phase 2 flight demonstration and the deployment of hybrid-electric regional aircraft by 2035.

Methodology

The Life Cycle Assessment is a science-based approach to assessing the potential environmental impacts of products or services during the entire life cycle. The methodology consists in carrying out an assessment of natural resources and raw material consumption, energy consumption and emissions into the environment (emissions to air, water, and ground), for each life-cycle phase of the system under study.In this study, a Cradle-to-Gate approach was employed to evaluate the primary electrical power distribution system. This method covers the life cycle from raw material extraction ("cradle") to the point at which the product exits the manufacturing facility ("gate"). The system boundaries include raw material acquisition and processing, manufacturing (including energy and material use), and transport between production sites up to final assembly. Excluded from the scope are: waste disposal during production , downstream transportation, end-of-life (EoL) treatment, and the production, maintenance, and decommissioning of supporting infrastructure.

The functional unit (FU) used in this analysis is one primary distribution system capable of supplying power to a 500 kW electric motor.

Abstract

REDUCING CARBON EMISSIONS FROM AVIATION IS ESSENTIAL FOR ADDRESSING CLIMATE CHANGE, GIVEN THE SECTOR'S SUBSTANTIAL CONTRIBUTION TO GLOBAL GREENHOUSE GAS EMISSIONS. HYBRID ELECTRIC AIRCRAFT (HEA) OFFER A PROMISING PATHWAY TO LOWERING AVIATION'S ENVIRONMENTAL FOOTPRINT.
THIS WORK PRESENTS A COMPREHENSIVE ANALYSIS OF THE PRIMARY DISTRIBUTION SYSTEM IN MODERN AIRCRAFT, WITH A PARTICULAR FOCUS ON ITS LIFE CYCLE ASSESSMENT (LCA). THE PRIMARY DISTRIBUTION SYSTEM IS CRUCIAL FOR THE EFFICIENT AND RELIABLE DELIVERY OF ELECTRICAL POWER THROUGHOUT THE AIRCRAFT. THIS STUDY EVALUATES THE SYSTEM'S DESIGN, IMPLEMENTATION, AND OPERATIONAL PERFORMANCE, HIGHLIGHTING ITS ADVANTAGES IN TERMS OF WEIGHT REDUCTION, IMPROVED LOAD MANAGEMENT, AND ENHANCED OVERALL EFFICIENCY. ADDITIONALLY, THE LCA METHODOLOGY IS EMPLOYED TO ASSESS THE ENVIRONMENTAL IMPACTS ASSOCIATED WITH THE PRIMARY DISTRIBUTION SYSTEM THROUGHOUT ITS LIFECYCLE, FROM MATERIAL EXTRACTION AND MANUFACTURING TO END-OF-LIFE DISPOSAL. THE FINDINGS INDICATE THAT WHILE THE ADVANCED ELECTRICAL POWER SYSTEMS OFFER SIGNIFICANT OPERATIONAL BENEFITS, THEY ALSO POSE CHALLENGES RELATED TO INCREASED POWER DEMAND, SUSCEPTIBILITY TO ELECTRICAL FAILURES, AND POTENTIAL ENVIRONMENTAL IMPACTS. THE WORK CONCLUDES WITH RECOMMENDATIONS FOR OPTIMIZING THE PRIMARY DISTRIBUTION SYSTEM TO BALANCE PERFORMANCE AND SUSTAINABILITY.

Key words:

Life Cycle Assessment, carbon footprint, sustainable aviation, primary distribution system, environmental impact, aviation emissions, sustainability analysis

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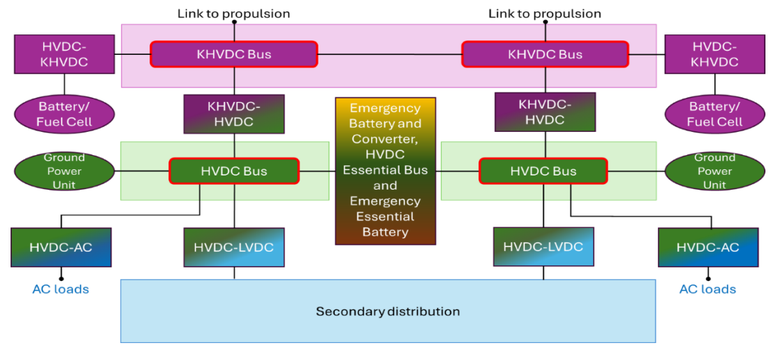
Results

The electrical architecture of the HECATE system is organized into three dedicated subsystems (Fig.1):

- **Primary Distribution for Propulsive Loads**
- **Primary Distribution for Non-Propulsive Loads**
- **Secondary Distribution and Energy Conditioning Subsystem**



The results indicate that printed circuit boards (PCBs), magnets, precious metals (gold and silver), and copper are the primary contributors to environmental impact, with PCBs alone accounting for over 50% of material-related emissions. Although precious metals constitute only 0.014% of the product's mass, they account for nearly 9% of total emissions due to the energy-intensive nature of their mining and refining. The findings underscore the necessity of optimizing both material selection and manufacturing processes in the development of high-performance aircraft electrical systems. Specific attention should be directed toward reducing the use of high-emission materials and implementing low-energy alternatives or recycling strategies. Moreover, transportation, while generally a minor contributor, can become significant when globalized supply chains involve long-haul air freight, as observed in the chamber sub -assembly.

By quantifying the environmental impact of each component and process, this study provides a robust foundation for future design improvements and sustainability-focused decision-making in the aerospace sector. The methodological framework applied here may be extended to other subsystems within the aircraft power architecture to support a system-wide approach to emission reduction according to the regulations.

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