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Design Methods for Axial Flux Machines in E-Aircraft Applications

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Declaration

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2026

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The transition toward sustainable transportation systems presents both significant challenges and opportunities, particularly in the integration of electric architectures. International organizations and governments have established ambitious targets for the reduction of greenhouse gas emissions, with the transportation sector accounting for more than 20% of global emissions. Within this sector, aviation plays a critical role, making the electrification of aircraft powertrains and onboard systems a key enabler for achieving these sustainability goals.

In this context, different levels of aircraft electrification have been proposed, with the More Electric Aircraft (MEA) and All Electric Aircraft (AEA) concepts representing the most promising approaches. The MEA paradigm focuses on replacing conventional hydraulic, pneumatic, and mechanical systems with electrically powered alternatives, thereby improving efficiency, reliability, and operational flexibility. This approach has already been adopted in modern large-scale aircraft, contributing to reduced operating costs. In contrast, the AEA concept aims at the complete electrification of the propulsion system. While currently feasible only for small-scale aircraft, its extension to regional and commercial aviation remains limited by the performance of existing technologies.

Achieving full electrification requires substantial advancements across all powertrain subsystems, including energy storage, power electronics, power distribution, and electromechanical energy conversion. In particular, electric machine technology still presents considerable opportunities for improvement in terms of topology, materials, and thermal management.

Among the various machine topologies, axial flux permanent magnet machines (AFMs) appear as strong candidates for aerospace applications due to their high specific torque and compact geometry. These advantages are primarily attributed to the higher number of magnetic poles that can be accommodated for PM configurations, as well as the feasibility of multi-stage and coreless topologies. Furthermore, synchronous AFMs are well suited for concentrated winding arrangements, which

offer reduced copper usage, lower Joule losses, and enhanced fault tolerance, features that are particularly attractive for aircraft propulsion systems.

The development of fully electrified aircraft architectures involves long research and development cycles, making the availability of simple and accurate design strategies essential for optimizing electric machines. Within this context, this thesis presents a set of methodologies for the fast sizing and analysis of axial flux machines, aimed at facilitating their integration into design workflows, accelerating prototyping, and reducing time-to-market for electrified propulsion systems.

First, an analytical sizing procedure is developed based on self-consistent electromagnetic formulations to determine the main machine dimensions. The approach also estimates circuit parameters, enabling the calculation of the number of conductors per phase required to meet performance targets. The methodology is validated through finite element simulations and experimental measurements, showing good agreement between predicted and measured results.

Second, an electromagnetic analysis method based on magnetic equivalent circuit (MEC) modeling is introduced. The proposed approach accounts for nonlinear material behavior, rotor motion, leakage fluxes, and multi-stage configurations. Detailed formulations of the reluctance network and the nonlinear solution procedure are provided. The model is validated against finite element simulations and experimental data from axial flux prototypes, demonstrating high accuracy in predicting machine performance.

Finally, a thermal analysis methodology based on a lumped parameter thermal network is presented to estimate temperature distribution within axial flux machines. The model is specifically tailored for early-stage design, requiring limited input data while maintaining sufficient accuracy. Analytical formulations are developed for conduction and convection elements, including correlations adapted to disk-type geometries. Validation against thermal simulations and experimental measurements confirms the capability of the model to predict both steady-state and transient thermal behavior with satisfactory accuracy.

Overall, the proposed methodologies provide a comprehensive and computationally efficient framework for the design and analysis of axial flux machines, supporting the development of high-performance electric propulsion systems for future sustainable aircraft.