Aircraft Conceptual Design Including Powertrain System Architecture and Distributed Propulsion

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The paper presents a thorough conceptual design approach for a generic aircraft with conventional, hybrid-electric, or full-electric powertrain. It follows the steps of classic aircraft design methods, including the main aspects related to the hybridization of an aircraft: powertrain architectures, energy sources, aerodynamic-propulsive interactions, stability and control effects. Such aircraft is designed considering design and regulations requirements. Three are the main steps of the conceptual design approach presented: preliminary design, sizing, and analysis. The first step provides a statistical baseline, including both geometry and weight breakdown, moving from top-level requirements. The sizing activity provides the energetic requirements and the mass breakdown, by combining the free choice of the designer with aviation regulations and requirements. The subsequent analysis aims to choose the baseline for high-fidelity optimization. The first application of the presented workflow deals with regional turboprop aircraft and it is based on the ATR-42 design mission. However, in the present work, a further investigation of the possible concepts, based on different design missions, highlights that the competitiveness of hybrid-electric aircrafts cannot be based on the same mission profiles on which nowadays aircrafts have been designed.

I. Nomenclature

$(\cdot)_1$	=	subscript for primary propulsive system
$(\cdot)_2$	=	subscript for secondary propulsive system
$C_{(\cdot)}$	=	aerodynamic coefficient
E	=	energy
P	=	power
S	=	wing planform area
W	=	weight
A_s	=	cross-sectional area of the slipstream
A_p	=	area of the disk propeller
T	=	thrust
$V_{(\cdot)}$	=	velocity at the location $(\cdot)$
$a_{(\cdot)}$	=	axial induction at the location $(\cdot)$
φ	=	shaft power ratio
Φ	=	supplied power ratio
η	=	efficiency
χ	=	thrust hybridization factor
DEP	=	Distributed Electric Propulsion
DOC	=	Direct Operative Costs
PMAD	=	Power Management And Distribution
TLAR	=	Top Level Aircraft Requirements

II. Challenges to the conceptual design process of a (hybrid) electric aircraft

The present work aims to define a single conceptual design process for conventional, hybrid-electric, and full-electric aircraft, developing a dedicated tool, also underlying the critical points and the major advantages resulting from different powertrain architectures. Attention is given to the regional turboprop aircraft (ATR-42) category, as main example of this conceptual design process. Comparisons will be made in order to point out differences in fuel consumption, propulsive and aerodynamic efficiencies, as well as weight breakdown among conventional, turboelectric, and hybrid-electric architectures. The importance of hybrid-

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