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Sizing Considerations of an Electric Ducted Fan for Hybrid Energy Aircraft

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Abstract

Hybrid and universally-electric aircraft are promising configurations to potentially handle the ambitious emission reduction targets set for example by the Advisory Council of Aviation Research in Europe with the Strategic Research and Innovation Agenda. Those concepts are confronted usually with high mass impacts caused by the electric system architecture design. In this paper a closer look is taken on the sizing of the electric power train components and sizing options of the electric motor powering a ducted fan for a discrete parallel hybrid-electric aircraft concept. In such a configuration, the electric system is used as an assistance system to enable a downsizing of the gas turbine and to increase the overall power train efficiency. The studies include considerations concerning geared versus direct drive systems and its implications on overall aircraft level. Furthermore, using the electric system as assistance system different motorization options are discussed to identify the sizing point offering the best utilization of the electric system during the entire mission. As baseline an A320 class aircraft is used for an entry into service year of 2035+ and a 1300nm design range. Finally, for this aircraft concept trade-factors will be provided to cover the impact of a changed electric system mass and efficiency on the overall aircraft mass.

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Keywords: electric ducted fan; electric architecture; hybrid-electric aircraft; thrust envelope

1. Introduction

Electro-mobility in the aeronautical sector seems to be one potential solution to cope with the ambitious emission reduction goals unveiled by the Advisory Council of Aviation Research in Europe (ACARE)(2012) with the Strategic Research and Innovation Agenda (SRIA). Those targets specify a reduction of 60% carbon dioxide, 84%

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nitrogen oxides and 55% perceived noise level based on a year 2000 datum for future transport aircraft with an entry-into-service of 2035. A main focus to fulfil those targets can be performed with an optimization of the energy and power system (EPS). A promising solution seems to be an electric transmission system, which allows for a decoupling of the power sources and the power consumers. For fixed wing aircraft several studies were already performed to cover such new transmission systems for example with turboelectric concepts performed by the NASA N+3X concept of Felder et al. (2009), even universally-electric aircraft (UEA) like the Bauhaus Luftfahrt Ce-Liner of Hornung et al. (2013) or the Airbus VoltAir given by Stückl et al. (2012) and also hybrid-electric aircraft like the Boeing SUGAR Volt of Bradley et al. (2017) with the different topology options like serial, parallel or serial-parallel. The previous studies have already identified that short to medium range aircraft applications utilizing a hybrid-electric EPS enabling block fuel saving potentials of up to 20% shown by Pornet et al (2014a). A major challenge is the high system mass impact of the new power train, which all different kinds of electric propulsion systems for transport aircraft have currently in common. One mass driver is caused by the take-off sizing case of the electric system. The air-density dependent propulsors (ducted fans or propellers) normally show a power lapse over the flight envelope, which an electric motor system does not represent. For example a ducted fan requires only a third of the take-off power during cruise mainly caused by the aircraft top level requirements (ATLeRs) of a typical transport aircraft as presented by Seitz et al. (2012a). This means that the electric system is sized for a power demand, which is only required for a short time during the mission and implies that this system is running in relative deep part load during cruise. Several design studies identifying an optimal design point of electrically powered propellers and ducted fans have been investigated by Seitz et al. (2012a) and Seitz et al. (2013). The focus of those papers was to identify optimal propulsor diameters and tip speeds for an efficient and mass optimized propulsor system. The electric system components were considered as black boxes with constant efficiencies. The included electric motor performance limit was only covered by the maximum installed power.

The main scope of the present paper is to deepen the understanding of electric component designs when linking them with a ducted fan for different sizing cases, using more detailed models. First a brief overview of current concepts of electric propulsion systems including important assessment parameters will be given, followed by the modelling approach of the involved components and subsystems. In the next step different motorization options are presented on a system level without aircraft impact (uninstalled performance). After the identification of the best system parameters for an electric powered ducted fan concept the sensitivities of the system are assessed on overall aircraft level with the help of trade factors. The aim of this study is to identify the impact on overall aircraft level when trading overall system mass versus system efficiency.

Nomenclature

ACARE	Advisory Council of Aviation Research in Europe
ATLeR	Aircraft Top Level Requirements
b	Wing Span
BCU	Battery Control Unit
EDF	Electric Ducted Fan
EPS	Energy and Power Supply
GTF	Geared Turbofan
H_E	Degree of Energy Hybridization
H_P	Degree of Power Hybridization
HTS	High-Temperature Superconducting
MTOW	Maximum Take-Off Weight
PMAD	Power Management and Distribution
OEI	One-Engine Inoperative
OMI	One-Motor Inoperative
SRIA	Strategic Research and Innovation Agenda
SOC	State-of-Charge
SSPC	Solid State Power Controller