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ScienceDirect

Transportation Research Procedia 29 (2018) 401–409

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th CEAS AIR & SPACE CONFERENCE AEROSPACE EUROPE 2017, CEAS 2017, 16-20 October 2017, Bucharest, Romania

Development of a software tool for comprehensive flight performance and mission analysis of hybrid-electric aircraft

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Abstract

This paper presents a software tool developed to comprehensively evaluate flight performance and mission analysis of hybrid-electric aircraft. The modelling incorporates conventional propulsion systems as well as an alternative electric propulsion system for flight performance and mission analysis. As part of the overall technology assessment of the Bavarian research project "PowerLab", which aims to develop a hybrid-electric flying platform, this tool is incorporated to assess the reference missions of the project concept. Further analysis on the impact of energy density variation on the transport efficiency using the developed tool was also performed. Finally we present an outlook into the integration of the tool in an overall aircraft fleet system dynamics model to estimate future fleet development for various future scenarios.

Peer-review under responsibility of the scientific committee of the 6th CEAS Air & Space Conference Aerospace Europe 2017.

Keywords: Flight performance analysis; mission analysis; hybrid-electric propulsion

Nomenclature

a	Acceleration
D	Drag
g	Gravity acceleration
L	Lift
m	Aircraft mass
MTOW	Maximum take-off weight
OEI	One engine inoperative
P_{el}	Electric Power

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Peer-review under responsibility of the scientific committee of the 6th CEAS Air & Space Conference Aerospace Europe 2017.
10.1016/j.trpro.2018.02.036

Q	Power density
SEP	Specific excess power
T	Thrust
TSFC	Thrust specific fuel consumption
v_{tas}	True air speed
w	Energy density
μ	Electric thrust faction
η	Efficiency

1. Introduction

Prevailing efforts exploring the potential of hybrid-electric aircraft technology have found application potential for aircraft especially in the commuter category with a seat capacity of less than 20 seats [1] for very short trip distances. Thin-haul range capabilities in the United States have been described to be shorter than approximately 200 nautical miles [2, 3] or 370 kilometres. An analysis of OAG [4] data of the global aircraft fleet operations in 2014 showed, that the aircraft clusters [5] representing “commuter / regional turboprops” and “small propeller aircraft” operate over average trip distances of 360 km and 160 km respectively. The range limitation imposed by current commercial battery technology on electric aircraft, due to the relatively low energy density (<300 Wh/kg) [6] of such batteries, can be seen to be mitigated partially by the very short range requirements of thin-haul aircraft operations.

The Bavarian research project “PowerLab” aims to create a “competence centre […] for hybrid and fully electric aircraft”, as well as to develop “core technologies for electrical propulsion systems for Turboprops […]” [7]. The application case within the project itself is a hybrid-electric propulsion system based on a Do-128-6x-platform with a MTOW of 4350 kg [7]. Depending on the mission, the passenger capacity of the hybrid-electric aircraft is estimated to be in the range of 3 to 10 passengers [7]. The modelling used for this paper adapts the concept of the project to model a slightly larger Do-228-platform.

As a part of the overall technology assessment of the “PowerLab” project, we have developed a tool to evaluate flight performance and mission analysis of hybrid-electric aircraft. The tool developed within this project was based on the ‘Fuel Consumption and Emissions Calculation Tool (FCECT)’, which is an “aircraft performance model being capable of simulating every flight operation […] on the global air transport network […]” [8]. The FCECT “primarily relies on the BADA (Base of Aircraft Data) aircraft performance model” [8, 9]. It is able to evaluate aircraft performance based on conventional propulsion systems with a fidelity level appropriate for the mentioned purpose. The tool developed here similarly relies on a modified BADA aircraft performance model for hybrid-electric propulsion systems.

There are a number of approaches to estimate the flight performance of conventional propelled aircraft. Most commonly the thrust specific fuel consumption (TSFC) is utilized. The TSFC is modelled based on primarily empirical data. This existing approach is, however, not valid for flight performance modelling of hybrid aircraft, since two propeller types, electric and fuel powered, are involved in thrust generation.

1.1. Flight Performance and Mission Analysis of Hybrid-Electric Aircraft

For the civil transport missions considered within this paper, the overall performance is computed solely via the travelled distance. Therefore, the flight dynamics is neglected as we consider a general approach to model the performance of hybrid aircraft. When a quasi-stationary flight condition is given, the performance of the aircraft can be calculated through the specific excess power, SEP, as follows:

$$SEP = (T - D)/(m \cdot g) \cdot v_{tas} \tag{1}$$

When the SEP is calculated, the potential gain in height or acceleration can be obtained directly with the following