Performance assessment methodology of a commercial aircraft associated with a hybrid propulsion system

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Abstract

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Abstract The present paper synthesizes exploratory studies on hybrid turbofan concept and preliminary design methods developed...
at Snecma. The engine architecture considered here is based on the combination of a conventional dual-shaft high-bypass ratio turbofan with an auxiliary power source. Two different auxiliary energy devices have been taken into consideration: batteries and fuel cell. To assess the benefit of such configurations and to investigate the impact of hybridization on system volume, weight and fuel consumption, an innovative method has been implemented. It couples aircraft and powerplant system preliminary design tools used by Snecma and combined into a design loop taking into account interactions between both aircraft design features and propulsion system. Introduction Future goals on aircraft performances are challenging and will require important improvements on both aircraft and propulsion system sides to enhance efficiency and reduce fuel consumption, emissions and noise. However, such ambitious objectives are unlikely to be achieved by independent incremental improvements of the aircraft and engine characteristics considered as independent subsystems. On the way to the more electric aircraft which is often regarded as a future for commercial aviation, this paper investigates a hybrid propulsion concept. Such concept is based on conventional turbofan engine combined with an electrical secondary energy source to assist the engine during aircraft mission. Two different cases have been considered using batteries or fuel cells as auxiliary energy providers. This study addresses the need for developing a global vision of the aircraft early in the preliminary design phase. To optimize the design phase and enhance reactivity during iterations, each aircraft sub-system shall be no longer separately considered since interactions on other systems and integration issues have reached such a high level of complexity. This is particularly significant in the case of hybrid engine studies where volume, weight and integration effects impact the global aircraft design as well as the required thrust specifications and can drastically reduce the potential fuel savings. A stepped approach has been considered, first aiming at evaluating the impact of an additional power source on the ability to operate and redesign a conventional turbomachinery, then considering the impact of the additional energy required on the aircraft characteristics. In parallel to the assessment of the hybrid turbofan concept, a novel method has been developed to couple design tools used by Snecma (Pacelab APD for aircraft design and PROOSIS for engine modeling and simulation) and therefore implement a design process that takes into account both detailed aircraft and propulsion models. More information about these designs tools and the methods that lay behind them can be found, respectively, in [1] and [2]. Hybrid Turbofan Concept Hybrid turbofan concept consists into combining a thermal energy source (gas turbine engine), with an either fuel cell or batteries electrical energy source, so that the engine can be assisted by the secondary source during the mission (figure 1). The aim is to reduce fuel consumption and emissions by redesigning the turbomachine according to the additional power available through hybridization. The engine architecture chosen to implement this concept is a conventional dual-shaft high-bypass ratio turbofan engine with booster assisted by an electrical motor. Moreover, the engine can also be re-designed taking into account an auxiliary power injection to optimize performance. To convert the electrical energy into mechanical power, and then inject it into the engine’s shaft, a chain composed by several components needs to be installed: secondary energy storage (batteries or fuel cells stack and dedicated equipments), AC/DC convertor, electric motor and gear box. Each one of these components has been modeled for use with the PROOSIS tool and has an associated mass and efficiency penalty. Fig. 1: Hybrid turbofan concept To store electrical energy on board of the aircraft two options were discussed, batteries or fuels cell. Both have a significant impact on the aircrafts structural mass through direct weight impact and snowball effect linked to system volume. On one hand, the battery pack, associated to storage of electrical energy, is the most penalizing with induced additional weight. To model batteries in an aircraft tool, a battery component was implemented in Pacelab APD, enabling battery pack mass estimation based on the total electrical energy used during a mission and the maximum instantaneous power delivered by the pack. On the other hand a fuel cell option dedicated model has been implemented in 1D performance calculation software PROOSIS. In addition a mass model was also implemented on the aircraft design software side. Fuel cell voltage and irreversibilities are calculated to obtain polarization curves representative of fuel cell performances [3] and to design fuel cell and hybridization chain capable of delivering the required system power. In addition the fuel cell combustible was also included in the mass balance of the aircraft. In both case, secondary power source is also used as a power unit for aircraft sub-systems. Indeed, electric power and air conditioning during mission are currently provided by the engine through engine air bleed and power extraction. These so called “installation losses” have a non negligible impact on specific fuel consumption hence fuel burn. This study also emphasizes the possibility of using batteries or fuel cells to supply directly part of the aircraft sub-system required energy instead of extracting it from the engine. Removal of auxiliary power unit (APU) and introduction of an in-wheel electric taxiing systems [4] was also considered in other studies. Coupling Aircraft and Engine design tools Nowadays, typical commercial aircraft models and conventional engines architectures are well mastered. These concepts have been optimized to reach a mature state, and dedicated and efficient tools for aircraft or engine design simulation have been developed. Nevertheless design process could be improved by integrating aircraft model earlier into engine design’s loop. As stated by D. Raymer [5], global sizing effects need to be taken into account to enhance aircraft design. Therefore implementing an interconnection between aircraft and engine design tools appears as a major interest in modeling. On one hand, it enables a more refined engine optimization taking into account mission characteristics and actual aircraft flight performances. On the other hand, it allows a better and faster prediction of engine impact on mission performances or aircraft design. In most aircraft design and mission analysis tools, engines are represented by engine performance dataset (EPDS) referred as Engine Decks. EPDS data matrices contain all available relevant engine performance’s data including net thrust FN and specific fuel consumption SFC and this for all flight conditions (altitude, Mach and International Standard Atmosphere temperature deviation). During design process, EPDS matrices must be updated with new performances data from an engine modeling tool to include performance’s modification within the aircraft model. Fig. 2: Aircraft and Engine design coupling chain However, rewriting completely new EPDs to substitute an updated one into the aircraft tool when design cycle implies several aircraft resizing leads to considerable iterations simulation efforts and can become very time consuming. In order to enable quick redesign and optimization studies, other options to update an EPDS were...
investigated. A new multi-point calibration method (MPC) has been developed. The MPC method is based on applying local correction factors that are estimated by comparing the new engine performances with the outdated EPDS at specific carefully sampled points with a mesh covering the whole flight domain. It is then possible to keep simulations costs low while improving the accuracy of EPDS updates (figure 2). Assessment of the hybrid concept. After battery and fuel cell models validation in PROOSIS, a hybrid turbofan concept has first been assessed without any mass consideration and aircraft coupling. Then, the aforementioned coupling method has been implemented between modern aircraft design software Pacelab APD and engine modeling tool PROOSIS to consider engine weight system impact on main fuel consumption and performances while maintaining top level aircraft requirements. For each iteration, EPDS is updated to reflect resulting hybridization modifications on engine performances and fuel burn. The baseline aircraft model used for this study was of short/medium range commercial aircraft type such as Airbus A320 or Boeing B737. A progressive approach, summarized on figure 3, has been followed to reach a global design that fulfills the initial payload and overall performance (design range, take-off field length and time to climb) targets. Fig. 3: Approach logic for the hybrid electrical aircraft study. First, the main aircraft characteristics were unchanged (fixed MTOW) and mass penalties due to the incorporation of the electrical systems were exchanged against payload, at fixed design range, or fuel then range at fixed payload. In a second phase, the aircraft and the engine has been redesigned for an increased MTOW in order to respect the initial payload and overall performance (design range, take-off field length and time to climb). Reduction of fuel consumption has been assessed and a parametric study on battery and fuel cell technologies has been conducted to estimate the breakeven point to reach so that the hybrid concept can become competitive in relation to modern day aircraft performances. Concerning power source design, total electrical energy stored and maximum instantaneous required power are the two main parameters used to size battery pack. During mission energy supplied to other aircraft subsystems such as customer bleed and power extraction is taken into account. Generally battery pack design is based on total electrical energy consumed during a mission. Fuel cell design differs from batteries pack one since it is not energy related but based on maximum delivered power. According to power profile considered for hybridization, a balanced design point can be chosen on the polarization curve to mitigate between cells number (directly impacting fuel cell system mass) and efficiency. Further studies are currently carried out for this case. Conclusions Hybridization studies shall consider the entire global aircraft system from airframes to engine components and interactions between them. Any gains or penalties shown in calculation could be overcome by judicious whole architecture (re)design at aircraft level. Thought some results can be cumbersome others within the scope of aircraft architecture changes and technologies improvements are an encouraging path to a more electrical aircraft future. References 1 PACE Aerospace Engineering and Information Technology GmbH, Pacelab APD: User's Guide, Release 3.5, 2014. 2 Empresarios Agrupados, PROOSIS User manual, Release 3.2, 2013. 3 J. Larminie et al, Fuel cell systems explained, Wiley & Sons, 2009. 4 Safran/Messier-Bugatti-Dowty, Honeywell Aerospace, Electric Green Taxing System Brochure, 2014 5 D. Raymer, Advanced Technology Subsonic Transport Study, Conceptual Research Corporation, Los Angeles CA, 2011

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