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Estimation of mission fuel savings potential using thermoelectric recuperation in aero-engines

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Abstract

The reduction of fuel consumption represents a major challenge on the way to an environmentally friendly air transport system. Thermoelectric generators (TEG) can offer a robust solution for direct conversion of lost heat from an aero-engine to electricity, reducing the fuel burn fraction of engine offtake and thereby required mission fuel. The overarching goal of the TERA-project (Thermoelectric Energy Recuperation for Aviation) within Germanys fifth Aeronautical Research Program (LuFo-V) is thus to evaluate the potentials of TEG on engine and aircraft level. To that effect, integration between the hot section of the engine and the cooler bypass flow is considered to quantify achievable output power. Fundamentally, two aspects determine the success of the concept: Firstly, the gravimetric power density of the TEG, which depends on thermoelectric material properties and thermal conditions, determines whether a break-even performance can be reached. Beyond break-even, mission fuel is saved. Secondly, the total generated power, limited by the TEG size and available area, determines the overall fuel savings potential. In this contribution, a trade-study approach is presented. In order to evaluate the fuel savings potentials, an aircraft with entry-into-service in 2035 was defined and sized for future requirements as a baseline. Mission fuel is calculated as function of TEG power and weight of the TEG system. Two models are used: a simple model based on the Breguet range equation considering cruise phase only, and a more elaborate mission-based model, in which the aircraft is sized according to engine offtake and weight modifications. Results are presented for design and off-design missions and collated to expected TEG performance. From the trade studies, break-even power density is determined, and the fuel savings potential evaluated. Preliminary studies, based on a TEG integrated into the engine nozzle, indicate a fuel savings potential of one tenth of a percent.

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Keywords: Aero-engine; Energy Recuperation; Fuel Savings; Thermoelectric Generator; Waste Heat Recovery

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1. Introduction

It is well-known that the fuel efficiency of transport aircraft and especially the propulsive efficiency of jet engines have improved remarkably since the beginning of the jet age (Lee et al. (2001)). Major contributors toward the achieved efficiency potentials of aero-engines come from advancements in materials, engine sizing, overall pressure ratio, burn temperature, mechanics, aerodynamics, and control. There are numerous approaches to exploit untapped potentials e.g., considering optimized engine-airframe integration, distributed propulsion concepts, or electrification and hybridization. However, it seems clear that the stated goals of EU ACARE Flightpath 2050 (ACARE (2017)) of a 75% decrease in fuel consumption require a strong and combined effort of optimizing both technological and operational potentials, and that a need for near-term solutions is evident. As it is becoming increasingly difficult to further improve fuel burn of conventional aero-engines, different avenues have already been explored, including thermodynamic recuperation concepts. These concepts typically require bulky components, such as heat exchangers for efficient operation, adding weight and drag to the engines, so that the achievable potentials must be carefully evaluated. In this contribution, another possibility is explored. As a fraction of fuel burn is used for electricity generation, the direct generation of electric energy from waste heat in the exhaust gas flow is an attractive option to improve the thrust-specific fuel consumption of aero-engines. As thermoelectric modules generate electrical energy from heat directly via the Seebeck effect, thermoelectric generators (TEG) may in principle be placed downstream the burn chamber between core and bypass flow and relieve, or even replace, the mechanical generators, thus reducing mechanical shaft load. Thermoelectric modules are flat, solid-state devices, promising favorable integration opportunities and a low maintenance requirement. Therefore, in this contribution we present results of the TERA-project (Thermoelectric Energy Recuperation for Aviation) within Germanys fifth Aeronautical Research Program (LuFo-V), in which the potentials of TEG in aero-engines are explored (Bode et al. (2017)). To this end, a future, 180 PAX class airliner with entry-into-service 2035 was defined as a reference aircraft model to evaluate the fuel savings potentials of TEG integration on the basis of a) a Breguet-based performance estimation and b) mission performance modeling of an optimized aircraft in the Pacelab APD modeling environment (Pace GmbH (2011)). The design aircraft, performance metrics and TEG integration are discussed in the following sections, before the presentation of methods and results.

Nomenclature

ACARE	Advisory Council for Aviation Research and Innovation in Europe
APD	Aircraft Preliminary Design
ECS	Environmental Control System
EIS	Entry Into Service
FHV	Fuel Heating Value
ICAO	International Civil Aviation Organization
ISA	International Standard Atmosphere
KCAS	Knots Calibrated Airspeed
L/D	Lift-to-Drag ratio
MLW	Maximum Landing Weight
(M)TOW	(Maximum) Take-Off Weight
OEW	Operating Empty Weight
PAX	Passengers
p	Power density
Q	Heat flux
RANS	Reynolds-averaged NavierStokes
RF	Reserve Fuel
R	Resistance
s	Range
SFC	Specific Fuel Consumption
SL	Sea Level