Progress in Aerospace Sciences 85 (2016) 51–64

Contents lists available at ScienceDirect

Progress in Aerospace Sciences

journal homepage: www.elsevier.com/locate/paerosci

A comparison of low-pressure and supercharged operation of polymer electrolyte membrane fuel cell systems for aircraft applications

C. Werner [a,1,*], G. Preiß [a,1], F. Gores [a], M. Griebenow [b], S. Heitmann [b]

[a] German Aerospace Center, Institute of Engineering Thermodynamics, Hein-Saß-Weg 38, 21129 Hamburg, Germany
[b] Hamburg University, Lothar Collatz Center for Computing in Science, Bundesstraße 55, 20146 Hamburg, Germany

A R T I C L E I N F O

Article history:
Received 3 June 2016
Received in revised form
13 July 2016
Accepted 15 July 2016
Available online 25 July 2016

Keywords:
Multifunctional fuel cell system
Polymer electrolyte membrane fuel cell
Operating pressure
Balance of plant
System efficiency
Aircraft auxiliary power

A B S T R A C T

Multifunctional fuel cell systems are competitive solutions aboard future generations of civil aircraft concerning energy consumption, environmental issues, and safety reasons. The present study compares low-pressure and supercharged operation of polymer electrolyte membrane fuel cells with respect to performance and efficiency criteria. This is motivated by the challenge of pressure-dependent fuel cell operation aboard aircraft with cabin pressure varying with operating altitude. Experimental investigations of low-pressure fuel cell operation use model-based design of experiments and are complemented by numerical investigations concerning supercharged fuel cell operation. It is demonstrated that a low-pressure operation is feasible with the fuel cell device under test, but that its range of stable operation changes between both operating modes. Including an external compressor, it can be shown that the power demand for supercharging the fuel cell is about the same as the loss in power output of the fuel cell due to low-pressure operation. Furthermore, the supercharged fuel cell operation appears to be more sensitive with respect to variations in the considered independent operating parameters load requirement, cathode stoichiometric ratio, and cooling temperature. The results indicate that a pressure-dependent self-humidification control might be able to exploit the potential of low-pressure fuel cell operation for aircraft applications to the best advantage.

Contents

1. Introduction

Multifunctional system integration of polymer electrolyte membrane fuel cells (PEMFC) offers the potential to completely

* Corresponding author.
E-mail address: Claudia.Werner@DLR.de (C. Werner).
[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.paerosci.2016.07.005
0376-0421/

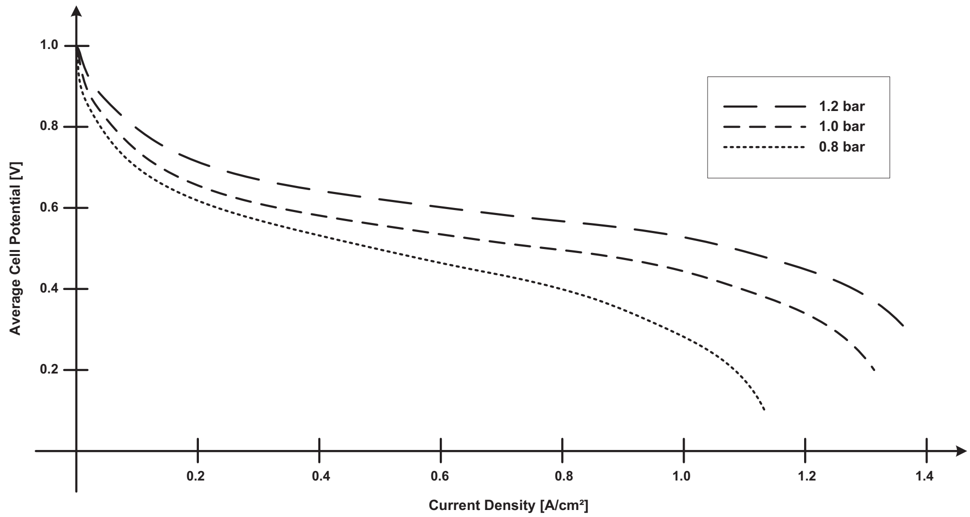

Fig. 1. Characteristic electrochemical fuel cell potential at various operating pressures.

replace gas-turbine powered auxiliary power units (APU), on-board inert gas generation systems (OBIGGS) and other aircraft subsystems [1,2]. To make use of this potential both the operating and state conditions of PEMFC, influencing their dynamical behavior and degradation process, respectively, need to be optimized with respect to the environmental conditions aboard civil aircraft [3].

Operating pressure is one of those conditions demanding special attention. From a fuel cell point of view the electrochemical cell potential is directly proportional to the natural logarithm of pressure ratio. Hence, fuel cell power output benefits from increasing the operating pressure (cp. Fig. 1). However, pressurizing reactant gases requires more power for auxiliary equipment, for instance, an external compressor. Furthermore, pressurized reactant gases involve additional stress for fuel cell components and affect the water management of PEMFC [4]. From an aircraft point of view a highly alternating pressure ratio exists between inside and outside an aircraft due to independent decrease of external pressure and conditions within the pressurized cabin, both related to the flight altitude (cp. Fig. 2). Since the pressure dependencies of fuel cells as well as the pressure curve for aircraft operation show non-linear behavior, an analysis is necessary to identify the most efficient PEMFC operating points for aircraft applications.

In the present study, the low-pressure operation of PEMFC driven by characteristic pressure ratios of aircraft flight conditions and supercharged PEMFC operation using an electrically operated compressor are compared with respect to operating ranges, output power and system efficiency with respect to aircraft operation.

Within this study, an experimental investigation is performed to verify feasibility and stability of low-pressure PEMFC operation in suction mode. The corresponding test plan uses an underlying (model-based) design of the experiment. The experimental results are used to validate numerical studies visualizing gross and net efficiencies of low-pressure and supercharged PEMFC operation, respectively. Experimental and numerical results of both PEMFC operating modes are compared to each other and evaluated with respect to performance and efficiency criteria. Furthermore, a sensitivity analysis of low-pressure as well as supercharged PEMFC operation is performed with respect to variations in operating parameters. Finally, a summary of the results is provided along with an outlook for further investigations. Besides pressure, the operating parameters cooling temperature, cathode stoichiometric ratio and load requirement are varied during experiments.

2. Experimental investigation of low-pressure PEMFC operation

In this section the PEMFC device under test is introduced and the test facility for low-pressure PEMFC operation in suction mode is illustrated.

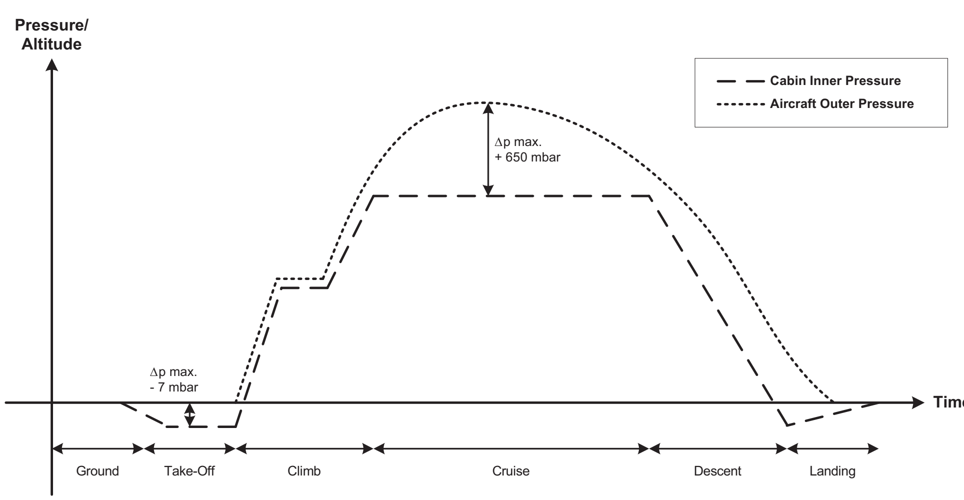

Fig. 2. Typical pressurization flight profile of a civil aircraft.