Innovative thermal management systems for fuel cell electric aircraft applications

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Abstract

Introduction: The topics of product sustainability and pollutant emission reduction have all become increasingly relevant factors in the design and approval of the latest generations of engineering devices, especially in the transport field. Total or partial electrification of propulsion systems emerged as the most promising solution to the problem, with the automotive industry already proposing a relatively wide selection of products.
The aerospace sector, however, is still struggling to present designs suitable for competitive mass transport, with the currently available models being mostly single-seat aircrafts. The main hindrance to the introduction of significant on-board electrification relies in the very low energy-to-weight ratios offered by currently available electric energy storage solutions. Amongst them, hydrogen powered fuel cells, and their associated storage devices, represent a more promising candidate, when compared to batteries and supercapacitors. However, despite providing favourable energy-to-weight ratios, the significantly lower efficiency of the fuel cell stacks (about 50% of the total hydrogen stored power), introduces important amounts of waste heat that needs to be effectively dissipated. Therefore, optimal design of aircraft-based Thermal Management System (TMS) is to be considered a crucial asset in the development of the next generation of more electric, medium to big scale aircraft.

Objectives: Taking into consideration all previously presented issues, the intended purpose of this paper is the investigation, analysis, and description of the various TMS solutions currently available in the aerospace literature, with the purpose to identify the models and methods most suited specifically for the development of hybrid-electric aircrafts.

Furthermore, a deepening about fuel tank-heat sink solutions is specifically carried out, while a preliminary proposal of requirements analysis is conducted for said architecture.

Material and methods: Deep investigation of the available literature was the starting point of this study. Prosecuted by the means of Scopus library and other relevant texts, this research led to an ample collection of related articles. Upon completing a bibliographic and bibliometric study of the results, acquired knowledge is applied in a preliminary evaluation of a possible TMS for medium sized aircraft by the means of MBSE approach.

Results: Advantages and disadvantages of each proposed cooling system are presented. Examples of applications are proposed for each architecture, when available, and possible enhancement solutions and challenges are also be described. Particular attention is placed on the conceptualization of systems suitable for a fuel cell, hybrid-electric, medium scale aircraft. Consequently, designs exploiting the potential heat capacity of the stored kerosene are taken into greater consideration, with a brief confront amongst the various possible fuel heat sink architectures being presented. Finally, a preliminary study of the system requirements associated with such solution is proposed, via the exploitation of Model Based System Engineering (MBSE) methodologies.

Conclusions: The investigation of all currently available aviation based TMS offers a wide selection of possibilities when it comes to the selection of components, architectures, and systems. Amongst them, solutions capable of exploiting the heat capacity of stored jet-fuel to absorb hydrogen fuel cell generated waste heat, appear as a most favourable proposal for hybrid aircraft applications.

References

[1] Kellermann, H., Habermann, A.L., Vratny, P.C., Hornung, M., 2020. Assessment of fuel as alternative heat sink for future aircraft. Applied Thermal Engineering 170, 114985. https://doi.org/10.1016/j.applthermaleng.2020.114985

[2] Liu, Y., Lin, G., Guo, J., Zhu, J., 2022. Dynamic prediction of fuel temperature in aircraft fuel tanks based on surrogate. Applied Thermal Engineering 215, 118926. https://doi.org/10.1016/j.applthermaleng.2022.118926

[3] Manna, R., Ravikumar, N., Harrison, S., Goni Boulama, K., 2022. Aircraft fuel thermal management system and flight thermal endurance. Trans. Can. Soc. Mech. Eng. 46, 308–328. https://doi.org/10.1139/tcsme-2021-0146

[4] Van Heerden, A.S.J., Judt, D.M., Jafari, S., Lawson, C.P., Nikolaidis, T., Bosak, D., 2022. Aircraft thermal management: Practices, technology, system architectures, future challenges, and opportunities. Progress in Aerospace Sciences 128, 100767. https://doi.org/10.1016/j.paerosci.2021.100767