**Paper title: Fundamentals of Innovative Aircraft Heat Exchanger Integration for Hydrogen-Electric Propulsion**

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For an efficient application of hydrogen proton exchange membrane fuel cell (PEMFC) based propulsion systems in aviation, a sophisticated cooling system is required. Despite their high efficiency, hydrogen PEMFCs are operated at low temperatures, resulting in high shares of low quality heat that demand large heat exchanger surface areas to dissipate this heat. A thoughtful installation of the heat exchanger allows to minimize the drag due to the heat exchanger, and even the generation of additional thrust is possible, as already demonstrated in the 1940's. The fundamentals of the heat exchanger design are based on coolers of piston engine aircraft, like the P-51 Mustang. In order to reduce the drag caused by the heat exchanger installation apparent as pressure losses, the flow speed of the air passing through the heat exchanger needs to be reduced by diffusion. A subsequent temperature increase of the air flow due to the heat exchanger increases the volumetric flow rate and allows to increase thrust. This concept is known as the Ram Jet or Meredith effect.

To further improve the efficiency of the recuperation process, the heat exchanger is integrated into the propulsion system, as seen in Fig. 1. A ducted fan propulsor is combined with a heat exchanger. The fan located upstream of the heat exchanger allows to increase the pressure ratio of the system and improves the performance of the propulsor, compared to a through-flow design, see Fig. 2. This can be deduced by applying the principle of the Brayton cycle to this process that states an increase of the pressure ratio resulting in enhanced efficiency. Additionally, Fig. 2 shows the process with a ducted fan without heat exchanger, indicated by the green dotted lines.

This paper aims to give an insight into the fundamental principles to harness waste heat generated by fuel cells for additional thrust due to the ramjet effect that may enhance the overall propulsion system efficiency. The integration of the heat exchanger and the fan stage for the combined benefit of dissipating excess heat and thrust generation is a promising approach to improve the performance of hydrogen fuel cell aircraft that offsets some of the disadvantages of such a system like the increased system mass.

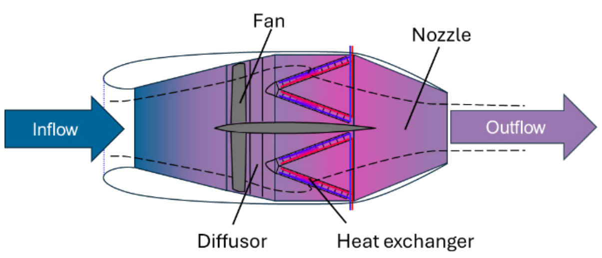


Fig. 1: Layout of the propulsion system combining fan stage and heat exchanger

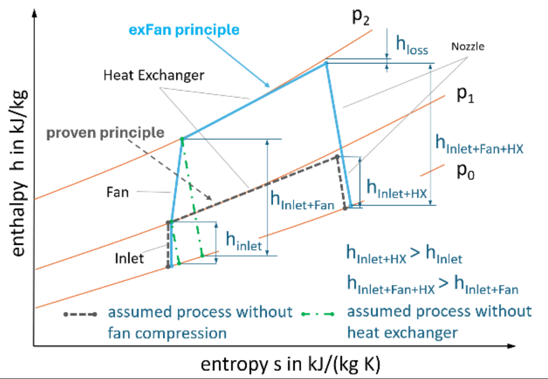


Fig. 2: Comparison of the recuperation systems brayton cycle with and without a fan stage