Adjoint Shape Optimization of Fuel Cell Air Intake Duct

Performance Evaluation and Shape Optimization of Air Intake Line of Hydrogen Fuel Cell Aircraft

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In Short

- RANS CFD analysis of a reference intake geometry to set up a benchmark simulation case
- Adjoint shape optimization of the inlet duct to improve pressure recovery for a specific mass flow rate
- Investigating the feasibility of boundary layer suction for increasing the power efficiency of the fuel cell system.

With the vision of decarbonizing the small and medium segments of aircraft, manufacturers are investigating various innovative approaches. One such technology that shows potential is Hydrogen electric fuel cell aircraft. Green hydrogen as a fuel offers the possibility to significantly lower aircraft's greenhouse gas emissions. The current approach to achieve this solution is to develop a hydrogen-propulsive Fuel Cell system as an integral part of a new LH2 aircraft concept. This drives the research away from the current "plug and play" (separate motor development and aircraft architecture) philosophy towards an integrated way of development, which requires a synchronous development of the propulsion system and the aircraft. The EU Horizon project Fuel cell propulsion system for Aircraft Megawatt Engines (FAME) follows this approach by collaborative research and development between on one hand partners involved in development of the needed systems of the fuel cell and on the other hand researchers as well as aircraft manufacturers. This approach ensures that on all levels, from material over component and sub-system up to propulsion system on the aircraft level, an optimization is realized.

The focus of FAME is on developing a complete compact high-efficiency full electric propulsion system based on LH2 as energy source for short to medium range (SMR) aircraft. FAME will develop all the subsystems which are needed and integrate these in a 1MW FC Propulsion System ground demonstrator with the vision to scale it up to aircraft level (sufficient for SMR aircraft). FAME shows the feasibility of a multi-MW FC Propulsion system for hydrogen-powered SMR aircraft. The system will provide the basis for Clean Aviation in phase 2 to undergo a system flight test. To achieve the goal of a complete, compact and lightweight high-efficiency full-electric propulsion system and to show technological capability, a 1MW ground demonstrator of the propulsion system is planned.

The current project aims to investigate the performance of the air intake line suitable for the demonstrator through detailed CFD analysis. The preliminary objective of the present study is to analyze the performance potential of air intake sys- tems through shape optimizations and innovative concepts such as boundary layer suction. As the first part of this study, RANS CFD simulations will be performed on a reference intake and exhaust geometry. The second part of the project involves optimizing the shape of the inlet duct to improve pressure recovery for a specific mass flow rate. Previous literature regarding shape optimization of submerged engine inlets suggests that the surrogate and gradient-free optimization might be expensive due to a large number of design variables[1] . Gradient-based optimization can reach a local optimum in a relatively small number of iterations. Therefore, for the current study, the use of adjoint-based gradient computations is proposed. Minimizing the total pressure loss is considered the main objective for optimization. The mass flow rate and the distortion at the exit of the intake duct need to be monitored during the design evaluations.

The final part of the project involves investigating innovative approaches for increasing the power efficiency of the fuel cell system. The power requirement of the system consists of the power needed to compress the air to a compression ratio of more than 5.2 and the power to overcome the drag of the aircraft. Therefore, increasing the power efficiency means reducing the overall power requirement. An innovative concept that can significantly reduce the drag is the use of boundary layer suction. Boundary layer suction involves removing air from the boundary layer through a micro-perforated outer skin. The boundary layer suction on the fuel cell nacelle can be incorporated using a micro-perforated sheet at the entry of the ASL. Using micro-perforated sheets adds pressure loss that depends on the mass flow of the air through it. Different semi-empirical models for micro-perforated sheets are available in the literature [2] and can be used to determine the pressure loss for a specific mass flow rate

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https://cordis.europa.eu/project/id/101140559

More Information

[1] U. Küçük, I. H. Tuncer, Adjoint Based Aerodynamic Shape Optimization of a Semi- Submerged Inlet Duct and Upstream Inlet Surface *J.Optimization and Engineering* **01**, (2024). doi: 10.1007/s11081-023-09877-x

[2] A. Prasannakumar, J. Wolff, R. Radespiel, L. Boermans, C. Hühne, C. Badrya , Design and Power Calculation of HLFC Suction System for a Subsonic Short-Range Aircraft *CEAS Aeronautical Journal* **09**, (2022). doi: 10.1007/s13272-022-00614-1

Project Partners

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