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ORIGINAL ARTICLE

# CFD based exploration of the dry-low-$NO_x$ hydrogen micromix combustion technology at increased energy densities

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**Abstract** Combined with the use of renewable energy sources for its production, hydrogen represents a possible alternative gas turbine fuel within future low emission power generation. Due to the large difference in the physical properties of hydrogen compared to other fuels such as natural gas, well established gas turbine combustion systems cannot be directly applied for dry-low-$NO_x$ (DLN) hydrogen combustion. Thus, the development of DLN combustion technologies is an essential and challenging task for the future of hydrogen fuelled gas turbines.

The DLN micromix combustion principle for hydrogen fuel has been developed to significantly reduce $NO_x$-emissions. This combustion principle is based on cross-flow mixing of air and gaseous hydrogen which reacts in multiple miniaturized diffusion-type flames. The major advantages of this combustion principle are the inherent safety against flash-back and the low $NO_x$-emissions due to a very short residence time of reactants in the flame region of the micro-flames.

The micromix combustion technology has been already proven experimentally and numerically for pure hydrogen fuel operation at different energy density levels. The aim of the present study is to analyze the influence of different geometry parameter variations on the flame structure and the $NO_x$ emission and to identify the most relevant design parameters, aiming to provide a physical understanding of the micromix flame sensitivity to the burner design and identify further optimization potential of this innovative combustion technology while increasing its energy density and making it mature enough for real gas turbine application.

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The study reveals great optimization potential of the micromix combustion technology with respect to the DLN characteristics and gives insight into the impact of geometry modifications on flame structure and $NO_x$ emission. This allows to further increase the energy density of the micromix burners and to integrate this technology in industrial gas turbines.



## 1. Introduction

Aviation and power generation industry has need of efficient, reliable, safe and low-pollution energy conversion systems in the future. Gas turbines will play a decisive role in long-term high power application scenarios, and hydrogen has great potential as renewable and sustainable energy source derived from wind- or solar power and gasification of biomass substituting the limited resources of fossil fuels [1]. Hydrogen impacts the operation of common gas turbine systems due to its high reactivity requiring combustion chamber modifications to guarantee efficient, stable, safe and low $NO_x$ combustion. Besides optimized combustion technology and related exhaust gas emissions, modifications of the gas turbine control and fuel metering system have to be applied to guarantee safe, rapid and precise changes of the engine power settings [2–7]. Against this background the Gas Turbine Section of the Department of Aerospace Engineering at Aachen University of Applied Sciences (AcUAS) and B&B-AGEMA GmbH work in the research field of low-emission combustion chamber technologies for hydrogen gas turbines and related topics investigating the complete system integration of combustion chamber, fuel system, engine control software and emission reduction technologies. The hydrogen gas turbine research at AcUAS started during the European projects EQHHPP [8] and CRYOPLANE [9] where the low $NO_x$ micromix hydrogen combustion principle was invented. When hydrogen is burned as fuel with air, only $NO_x$ emissions occur, but Refs. [2,3,10] and [11] have shown that the combustion process has to be modified and optimized in order to achieve low $NO_x$ emissions. Because of the large difference in the physical properties of hydrogen compared to other fuels such as kerosene and natural gas, well established gas turbine combustion systems cannot be directly applied for dry-low-$NO_x$ (DLN) combustion. Thus, the development of DLN hydrogen combustion technologies is an essential and challenging task. The DLN micromix combustion principle for hydrogen is being developed and optimized for years to significantly reduce $NO_x$-emissions by miniaturizing the combustion zone, reducing the residence time of reactants in the combustion zone, and enhancing the mixing process using a jet in cross-flow design. A review of the previous research activities at AcUAS is presented in Ref. [12].

Especially the flame anchoring – mostly dominated by the resulting recirculation zones and vortices within the micromix burner geometry [10] and by the momentum flux ratio of the jet in cross-flow [11] – is most essential to the micromix low $NO_x$ characteristics. Based on previous investigations a micromix combustion chamber with about 1600 miniature injectors (Fig. 1) was designed for a small size Auxiliary Power Unit APU GTCP 36-300 and successfully tested [13].

The GTCP 36-300 requires about 1.6 MW thermal energy converted to shaft power generating electrical and pneumatic power up to 335 kW. The combustion section consists of an annular reverse flow combustion chamber in which the micromix combustor is to be integrated.

The micromix hydrogen combustion research is done using an interactive optimization cycle including experimental and numerical studies on test burners, full scale combustion

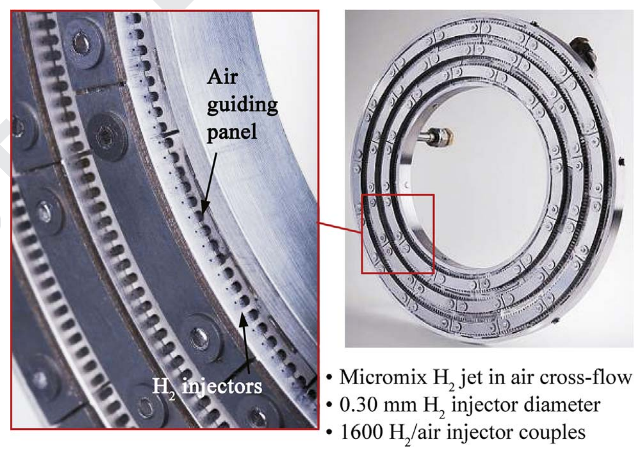


**Fig. 1** Micromix prototype combustor for gas turbine Honeywell/Garrett Auxiliary Power Unit APU GTCP 36-300.

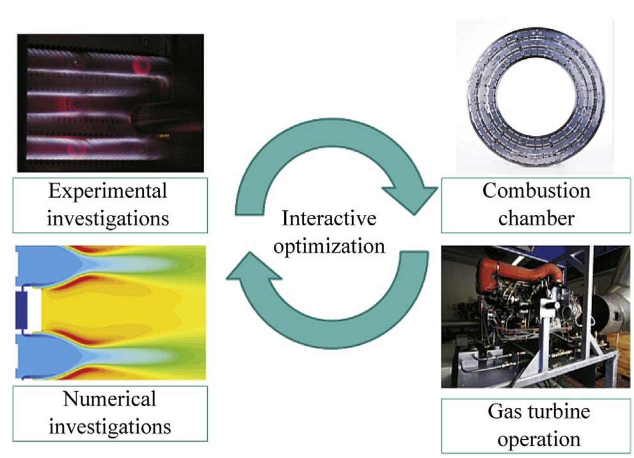


**Fig. 2** Interactive optimization cycle of micromix combustor research and development for APU GTCP 36-300.



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