Feasibility Study of Using Matrix-Stabilized Combustion Technologies to Enable Ultra-low Emission Combustion in Aviation Gas Turbines

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Abstract:

The objective of this multidisciplinary research program is to enable the utilization of matrix stabilized combustion as a low-emission fuel-flexible combustion strategy for gas turbines by developing predictive simulation techniques for the combustion analysis and design optimization, by establishing advanced diagnostics techniques using X-Ray Computed Tomography (CT) for non-intrusive 3D measurements of combustion processes inside the porous matrix, and by conducting experiments to evaluate the durability, stability, and performance at gas-turbine relevant conditions. Matrix-stabilized combustion is an advanced combustion technology, in which combustion is facilitated inside a porous heat-conducting matrix. The internal heat-recirculation is used for preheating the unburned reactants to achieve superadiabatic combustion, thereby providing enormous opportunities for improving emissions, combustion stability, and fuel-flexible operation. The proposed research program directly addresses the research needs on developing innovative concepts for low-carbon and ultra-efficient propulsion systems. To achieve the stated objectives, a closely coordinated research effort will be undertaken, addressing the most critical research issues.

The computational research effort addresses the development of a multi-resolution high-fidelity simulation capability that provides a detailed description of the unsteady heterogeneous combustion and gas/solid interaction inside the porous structure. To this end, a simulation method is developed to accurately model the fluid dynamics and heterogeneous combustion processes inside the porous structure, and heat-exchange processes between gas-phase and solid structure are represented using a conjugate heat-transfer model.

Advanced non-intrusive X-Ray CT diagnostics techniques will be developed to obtain quantitative measurements for examining the 3D flame-structure and temperature field inside the porous structure. Such detailed and volumetric measurements are unprecedented, and will provide quantitative information for model validation and for obtaining fundamental insight about the flame topology in porous media, solid/gas coupling effects, and the construction of regime diagrams for heterogeneous combustion processes.

These computational and diagnostics efforts are complemented by a comprehensive measurement campaign to demonstrate the feasibility of matrix-stabilized combustion at gas-turbine relevant operating conditions. Measurements will be conducted to characterize performance, emissions, and durability for different porous materials.

To accomplish this research plan, a research team is assembled that combines unique expertise on the high-fidelity combustion modeling, numerical methods, and optimization techniques (Ihme, Stanford), the development of advanced X-Ray CT diagnostics techniques (Hinshaw, Stanford), and our industrial partner Alzeta Corporation (Sullivan) brings over 30 years of experience on the development and commercialization of porous burner technologies to this research.