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Large-Eddy Simulations for the Design Optimization of a Rich burn – Quick mix – Lean burn Lab-Scale Combustor Operating in High-Pressure and High-Temperature Conditions

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The Rich Burn - Quick Mix - Lean Burn (RQL) concept is a staged combustion technology that provides an excellent alternative to Lean Burn technology, which is more sensitive to the constraints imposed by combustion instabilities and in-flight flame extinction. It consists in the establishment of a fuel-rich primary region at the injection system outlet to ensure a stable flame at all operating conditions. This rich flame which promotes soot, unburned hydrocarbons (UHCs) and CO formation, but low NOx, is then quickly fed by an injection of a large quantity of dilution air in order to prevent any region of large thermal NOx production near the stoichiometry and to finally generate a lean combustion providing an efficient soot oxidation and a lower temperature that minimizes the NOx production.

The aim of the current work is to detail a design optimization by Large-Eddy Simulations (LES) of a RQL lab-scale combustor equipped with a new-generation fuel injection system elaborated by the French engine manufacturer Safran Helicopter Engines and large optical windows for investigating simultaneously the Rich-burn, Quick-mix and Lean-burn regions by means of advanced laser-based diagnostics. It is intended to study the soot oxidation and NOx reduction chemical processes under high-pressure / high-temperature operating conditions with two types of liquid fuels, kerosene (Jet A-1) and a HEFA-type Sustainable Aviation Fuel (SAF), which will constitute a reference base for validating numerical models of these pollutants.

The design of the RQL combustion module is first ensured by performing LES simulations by the AVBP solver of the reactive flow produced by a kerosene-vapor/air mixture. Various geometric architectures of this module were tested at the nominal regime to gradually improve its performance while seeking a relevant and efficient design optimizing the flow, mechanical and thermal constraints. The main versions will be presented to illustrate progresses made to well isolate the different RQL regions of the combustor, while preserving the ability to perform a detailed analysis by advanced laser-based diagnostics. The optimized configuration was further validated by a reactive two-phase flow LES simulation using an injection of a kerosene spray. The results revealed efficient dilution and mixing properties, distinct RQL regions, well-defined swirling flame structure, high combustion efficiency, as well as optimal pressure drop and air mass flow rate distributions.

After integrating the manufactured optimized RQL combustion module into the visualization block of the HERON (High prEssuRe facility for aerO-eNgines combustion) test bench of the CORIA Research laboratory, the efficiency of the dilution jets ensuring well-separated RQL regions, as well as the thermal resistance of the metallic walls and optical windows were assured, confirming the reliability of the design optimization process performed by LES simulations. The extension of this study will consist in the application of advanced coupled 2D laser-based diagnostics (PIV, OH-PLIF, fuel-PLIF, NO-PLIF and PLII) for performing a simultaneous probe of the different RQL regions, which will provide a better understanding of aerodynamics, flame structure, fuel consumption, as well as NOx and soot pollutant formation.