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Design methodologies and CFD methods for the development of low emission combustion systems in aero-engines

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ABSTRACT

State-of-the-art gas turbine combustion chamber design requires a wide range of design rules and parameters using a multitude of empirical correlations. In order to allow for a more effective use of this knowledge, Knowledge Based Engineering (KBE) tools are developed in the framework of the European research project INTELLECT D.M. (INTEgrated Lean Low Emission CombusTor Design Methodology). The developed tools strengthen European competitiveness by reducing the development costs and time of new low emission aero-engine combustion chambers. An overview of the current status of these tools is given subsequently.

Overview of the developed KBE tools providing advanced capabilities for the preliminary design of state-of-the-art combustion chambers:

- Automatic preliminary combustor layout including sizing, flow split analyses and advanced cooling requirement calculations.
- Automatic generation of the respective combustor geometry utilizing a parametric CAD model.
- 1-D network modeling of the complex combustor flow splits including injector flow, mixing holes and a representation of all cooling features.
- Automatic mesh generation and CFD combustor analyses based on the generated parametric CAD model.
- Capability for multi-objective CFD optimisation of low NOx injection systems.

To account for the lean low NOx combustion chambers, which are currently under development, new design rules and guidelines are developed to be incorporated in the system. Reliability and safe operation of lean low NOx combustors have been investigated based on the numerical analyses and experimental work carried out in the fields of ignition, lean blow out, extinction, external aerodynamics and advanced cooling design in the framework of this project.

RESULTS

A number of results obtained during the aforementioned studies are already captured, formalised and the derived knowledge has been incorporated in the newly developed KBE system in the form of correlations and design rules. In the following an overview of the generated knowledge and its incorporation in the design system is given:

- Geometry parameters have been determined to characterise lean low NOx fuel injectors. Based on these, a parametric definition of the injector has been incorporated in the KBE tool, providing the user with a parametric CAD model and automatic mesh generation for CFD analyses.

- Advanced integrated OGV pre-diffuser design rules characterising the length and area ratio have been captured, formalised and included in the KBE system, to account for the reduced system length, which can be achieved due to the application of the integrated design.
- Based on the experimental and numerical studies of the combustor cooling design, improved models were included in the KBE system, resulting in a significantly improved predictability of the wall temperatures and cooling flow requirements.

The developed low emission rich burn combustor design methodology could be used for the design of new combustion chambers and has proven to reduce the time required for the definition of the preliminary combustor design. Due to the automation of the design process the time required to set up a new preliminary combustion chamber design is reduced from weeks to hours. In addition the sophisticated layout of the combustor including advanced cooling methods, parametric CAD modelling and CFD methods enables the user to already perform detailed analyses during the preliminary combustor design phase.

OUTLOOK

Although valuable data have been obtained during the aforementioned studies further work in the field of lean low NOx combustion systems is still required to improve the understanding of the complex combustion process especially at the lean operating points. Additional experimental and numerical studies have to be carried out aiming to find a way of predicting and simulating the weak extinction of the combustor flame, as this is not fully understood yet. Moreover LES simulations using the volume-of-fluid (VOF) method could help to improve the simulation of the fuel preparation in lean systems, as it has a significant effect on the overall combustion process and emissions. Based on more advanced simulation techniques improved analyses of the ignition and relight performance of lean low emission combustors could be carried out resulting in a better combustion stability of those systems.

The external aerodynamics studies have shown to offer a great potential of improvement. Further studies in this field are required for validation purposes and to lead to even more advanced concepts. The same applies to alternative fuels. Detailed studies of the fuel properties will have to be carried out to confirm the trends obtained during the performed tests. All these studies will contribute to the definition of lean low emission combustor design rules and parameters to be integrated in the current knowledge based engineering system.

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