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Ultra-Wet Operation of a Hydrogen Fueled GT Combustor: Large Eddy Simulation Employing Detailed Chemistry

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Abstract: Operating gas turbines under ultra-wet conditions (i.e., adding steam to the combustion process) offers the attractive possibility of increasing the plant efficiency and reducing NO_x emissions significantly, due to altered formation pathways. Since steam increases the specific heat capacity, it reduces the peak temperatures and, thus, allows for the usage of hydrogen and hydrogen-rich fuels. The present study focuses on the effect of steam on the combustion process by using detailed chemistry, one-dimensional kinetic assessments and Large Eddy Simulations. The steam-air ratio ($\Omega = \dot{m}_{steam}/\dot{m}_{air}$) was varied from 0% to 50%.

Keywords: Reactive Flows, Hydrogen Combustion, Diluted Flames, Large Eddy Simulation, Implicit LES, Thickened Flame Model.

1 Introduction

Operating gas turbines with hydrogen is a challenging task. Hydrogen gas is highly flammable, has a low autoignition temperature and due to high burning velocities, a high risk of flashback. Moreover, hydrogen oxidation is a highly exothermic reaction, leading to high peak temperatures and, hence, to high NO_x emissions. A promising way to overcome this, is to add steam to the combustion process at near stoichiometric conditions. It lowers the temperature peak by increasing the specific heat capacity and reduces oxygen concentration. Supplementary to the thermodynamic influence of the steam on the combustion process, it reduces NO_x emissions.

One aim of this study is to identify an adequate detailed reaction mechanism. Therefore, several candidates are compared and their performance is assessed based on laminar premixed flame calculations under dry and wet conditions, for which experimentally determined flame speeds are available. In a second step, the best suited mechanism is used for Large Eddy Simulations (LES) of a turbulent flame in a generic swirl burner operated with hydrogen and air at different steam levels. The simulations are compared with experimental data (PIV and OH* chemiluminescence). In order to compare the simulations with OH* recordings, the mechanism is extended by OH* formation pathways according to [1]. An moderate-wet case with an steam-air ratio of $\Omega = 20\%$, a ultra-wet case ($\Omega = 50\%$) and, for comparison, a dry case are provided.

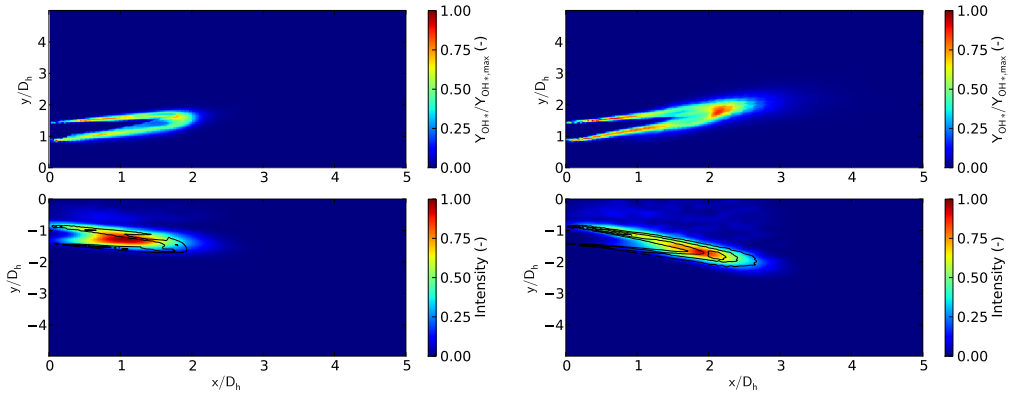
2 Reaction Modeling

Incorporating combustion chemistry into LES involves finding a suitable reaction mechanism and solving the filtered species equations, which contain the filtered reaction rates. These rates are non-linear functions of species concentration and temperature. The investigated flame in the present paper is characterized by a relatively high Karlovitz number as a large amount of steam is added to the reactants, which spreads the heat release peak. Thus, the turbulent integral scale is larger than the chemical time scale and the flame

is definitely subject to strong finite rate chemistry effects. A suitable candidate for resolving this effects is the Thickened Flame Model and the Implicit Large Eddy Simlation, which offer the attractive feature of handling complex chemistry naturally, since the reaction rate is obtained from an Arrhenius expression of reasonable extra cost.

3 Preliminary Results and Discussion

A flame is approximately represented by the concentration of active OH radicals. Figure 1 shows the experimentally obtained deconvoluted OH* chemiluminescence recordings as well as a streamwise slice of the computed OH* concentration for the dry and the wet case. For better comparison, contour lines of the computations are superimposed on the measurements. The burner exit is located at $x/D_h = 0.0$. For the



(a) Dry case ($\Omega = 0.0$, $\Phi = 0.5$, $T_u = 293$K) (b) Wet case ($\Omega = 0.5$, $\Phi = 0.75$, $T_u = 633$K)

Figure 1: Comparison of the LES (top) with experimental OH* chemiluminescence measurements (bottom).

dry case, a non-reacting jet surrounded by a thin reaction layer with a steep gradient is predicted. The flame shape and dimension is well represented by the computations. For the wet case the flame extends further downstream and shows a larger spatial distributed reaction zone with a less steep gradient. Moreover, the computations of the flame shape and distribution are well in line with the measurements.

References

[1] Gregory P. Smith, Chung Park, and Jorge Luque. A note on chemiluminescence in low-pressure hydrogen and methane-nitrous oxide flames. *Combustion and Flame*, 140(4):385–389, March 2005.