# RESPONSE OF ACOUSTICALLY EXITED LEAN LAMINAR HYDROGEN FLAMES

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**Abstract**

The adoption of hydrogen as a fuel for gas turbines represents a promising pathway toward reducing greenhouse gas emissions and fostering the development of sustainable energy systems. Nonetheless, the unique chemical and physical characteristics of hydrogen introduce significant challenges, particularly within lean premixed combustion regimes, which are widely employed to mitigate $NO_x$ emissions. Thermo-acoustic instabilities may also arise, threatening combustion stability and potentially causing structural damage. This study explores the dynamic response of laminar premixed lean hydrogen flames under the combined influence of externally induced thermo-acoustic instabilities and intrinsic thermo-diffusive instabilities. The analysis is conducted using two-dimensional Direct Numerical Simulations, where sinusoidal velocity perturbations are applied at the inlet to reproduce the external forcing characteristic of thermoacoustic phenomena. Simulations are conducted across a range of excitation amplitudes and frequencies, with the flame's dynamic response quantitatively characterized via the Flame Describing Function (FDF). The results reveal the presence of three distinct response regimes. At low perturbation amplitudes, the flame remains largely unaffected. As the amplitude increases, the system transitions into a second regime in which thermo-diffusive instabilities emerge, producing a wrinkled flame front and a flame response which features multiple characteristic frequencies. At sufficiently high amplitudes, the third regime is observed, where the flame dynamics become dominated by the imposed oscillations. To disentangle the different phenomena involved, a comparative analysis is carried out between the time evolution of the integrated fuel reaction rate and that of the flame surface area. This comparison shows that in the first and second regime, the reaction rate is not directly linked to the flame surface area, whereas in the third regime, a strong correlation is observed between the two. Moreover, the study demonstrates that the relative contribution of thermo-acoustic and thermo-diffusive instabilities depends on the forcing frequency, with different behaviors prevailing over specific ranges of perturbation amplitude. These results emphasize the intricate interaction between perturbation and flame dynamics, offering valuable insight into the complex behavior of hydrogen flames under the combined influence of thermo-acoustic and thermo-diffusive instabilities.