International Conference on Numerical Combustion
Rome, Italy, October 14-17, 2025
www.icnc2025.com

Investigation of ignition and flame propagation mechanisms in turbulent jet ignition of lean hydrogen mixtures using a super-rich pre-chamber

Haoming GU[1], Fangsi REN[1]*, Shinji NAKAYA[1], Mitsuhiro TSUE[1]
*lead presenter: ren-fangsi@g.ecc.u-tokyo.ac.jp
1 Department of Aeronautics and Astronautics, The University of Tokyo, Japan

In this study, a numerical investigation was conducted to analyze the combustion mechanism of a super-rich-burn, quick-mix, lean-burn combustion strategy for hydrogen internal combustion engines equipped with an active pre-chamber. This strategy aims to achieve stable ignition under lean-burn conditions while mitigating nitrogen oxide (NOx) emissions resulting from high combustion temperatures inherent to hydrogen turbulent jet ignition (TJI). Large Eddy Simulation (LES) using OpenFOAM [1] was employed to model the combustion behaviors of the super-rich transient TJI process in globally lean mixtures, integrating a dynamic sub-grid model and the Partially Stirred Reactor (PaSR) combustion model. For experimental validation, a series of tests were conducted using a rapid compression machine with a diaphragm-isolated pre-chamber filled with uniformly super-rich mixtures, with an equivalence ratio of 3.0. The simulation results accurately captured key phenomena, including the auto-ignition of the hot jet and flame lift-off behavior, exhibiting strong agreement with experimental data. From the numerical results, the flame structure was found to consist of an outer lean premixed zone and an inner non-premixed core, with the stoichiometric mixture fraction located within the non-premixed region, where high heat release rates and temperatures were observed. Regarding NOx emissions, despite the occurrence of stoichiometric combustion in the non-premixed region, the mixture was significantly diluted by water vapor (H_2O) generated in the pre-chamber, which potentially reduced NOx emissions due to the high local heat capacity. The underlying NOx formation mechanisms were further analyzed, providing insights into the emission characteristics of the combustion strategy.

References

[1] Weller, H. G., Tabor, G., Jasak, H., & Fureby, C. (1998). A tensorial approach to computational continuum mechanics using object-oriented techniques. Computers in physics, 12(6), 620-631.