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Low-order stochastic modelling of global blow-off in an RQL swirl combustor

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Predicting the blow-off (BO) curve is critical for characterising the operability limits of gas turbine engines. Current approaches often rely on Large eddy simulation (LES) with detailed chemistry, which remain impractical from an engineering perspective due to its high computational resources [1,2]. To address this, low-order modelling tools capable of predicting flame extinction efficiently at a reasonably low computational cost remain important. The stochastic Imperfectly Stirred Reactor (sISR), which is based on a stochastic variant of the Imperfectly Stirred Reactor (ISR) approach [3], is a low-order modelling framework for the prediction of flame global extinction using a limited set of Computational Fluid Dynamics (CFD) simulations as reference conditions [4]. The model provides a map that shows the extinction probability (i.e., the proportion of a flame's stoichiometric iso-surface undergoing local extinctions) at different values of scalar dissipation rates (SDR). It relies on a key assumption, supported by experimental and numerical studies [2,5], which suggests that global flame blow-off occurs when 30% of the stochiometric iso-surface experiences local extinction. Thus, from the extinction threshold, the model predicts the blow-off SDR, which is then extrapolated using reference CFD data and simple scaling laws, to determine critical blow-off conditions such as velocity or dilution ratio. The model has been validated against atmospheric Cambridge swirl spray flames (ethanol/kerosene fuels), demonstrating its capability to predict blow-off velocities within 13% of experimental values [5]. This study extends the sISR validation by investigating its applicability in predicting the BO curve as a function of dilution ratio in a Rich-Quench-Lean (RQL)-like combustor. In the present study, sISR utilises a set of Reynolds-Averaged Navier-Stokes (RANS) cold-flow simulations at different global equivalence ratios as reference conditions. It has been found that the sISR modelling framework can predict the BO dilution ratio at different global equivalence ratios, showing reasonable agreement with the experimental data. This further validates sISR as an efficient low-order modelling flame extinction tool, which can significantly contribute to the development of robust RQL combustors by enabling rapid exploration of combustor operability during preliminary design phases.

References

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