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Data-driven methods for classification and prediction of flame shape transitions via latent-space representations

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We investigate data-driven strategies for monitoring and predicting combustion instabilities in a lean premixed prevaporized (LPP) combustor, with the goal of identifying reduced-order representations suitable for digital twinning. The study centers on the BIMER combustor, a two-stage swirl-stabilized system that exhibits distinct flame shape transitions as the staging factor varies. Instantaneous flame states are labeled using microphone signals and compared with labels obtained through unsupervised clustering of low-dimensional manifolds extracted from chemiluminescence images. While latent-space clustering accurately identifies the staging factor at which transitions occur, it remains limited in predicting transition duration, which can vary drastically in the experiments.

Prior work by Renaud *et al.* [1] identified two distinct transition types, and simulations by Mesquita *et al.* [2] suggested that these are driven by interactions between hydrodynamic structures and thermoacoustic instabilities. To address these issues, we introduce a preliminary step: clustering the types of transitions in the frequency domain and correlating them with influential physical parameters. Our results support the hypothesis that the rate of change of the staging factor is a key parameter governing the timing and nature of transitions, while clustering in the frequency domain is shown to enhance the separability of transition types.

Furthermore, we benchmark unsupervised and supervised methods for the detection and classification of flame shape transitions. These findings contribute to defining an optimal reduced-order model of the BIMER combustor and lay the groundwork for robust digital twins of renewable synthetic fuel combustion systems.

References

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