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Evaluating Pilot Modeling Assumptions using Many-Stream Manifold-Based Combustion Models

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Turbulent reacting flow simulation faces dual challenges due to the broad range of scales as well as the high dimensionality of the thermochemical state, which imposes prohibitive computational cost. The computational cost imposed by the high dimensionality of the thermochemical state is alleviated by projecting the thermochemical state space onto a lower-dimensional manifold, reducing the thermochemical state from a function of many state variables (species mass fractions and energy) to a few manifold variables (e.g., mixture fraction) and corresponding parameters (e.g., mixture fraction dissipation rate). However, manifold-based models, albeit computationally efficient, trade-off generality. Manifold-based combustion models are traditionally only applicable to two-stream combustion processes, which are not representative of practical combustion systems. By transporting additional mixture fractions, the mixing between additional inlet streams can be fully characterized, and manifold-based models can be extended beyond two-stream combustion by using the local mixture fractions to derive local effective fuel and oxidizer compositions.

The restriction to two streams is notable when applied to the simulation of even canonical turbulent flames, specifically, piloted jet flames. When restricted to two streams, the pilot must be modeled as a mixture of the oxidizer and the fuel, which often requires compromises on modeling the exact composition of the pilot. Modern many-stream manifold-based models allow for a relaxation of that restriction. However, even when the pilot is considered as a separate stream in a many-stream manifold-based model, constructing a mixture fraction characterizing the mixing of the pilot with fuel and oxidizer streams requires assumptions about which stream boundary conditions are modified by pilot mixing, that is, whether the pilot should be considered as part of the fuel stream, oxidizer stream, or both.

In this work, three possible pilot mixture fraction constructions are demonstrated and tested in Large Eddy Simulation (LES): pilot as part of the effective fuel stream, effective oxidizer stream, or distributed evenly to both. For this high-dimensional model with an additional mixture fraction, In-Situ Adaptive Manifolds (ISAM) [1] is used to avoid expensive pretabulation and precomputation by computing manifold solutions on-the-fly and storing them for efficient reuse. Multiple turbulent piloted jet flames of varying complexity are considered to evaluate the impact of the assumptions about pilot stream mixing. Additionally, computational cost considerations of carrying an additional mixture fraction for the pilot are analyzed in detail.

References

[1] C.E. Lacey, A.G. Novoselov, M.E. Mueller, In-Situ Adaptive Manifolds: Enabling computational efficient simulations of complex turbulent reacting flows, Proc. Combust. Inst. 38 (2021) 2673-2680.