Development of a Digital Twin for Combustion Systems Using Automated Data Generation and Machine Learning

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Abstract: The optimization of combustion systems is essential for achieving decarbonization targets within the transportation sector and addressing the critical challenges posed by climate change. Combustion systems are pivotal in determining engine performance and emissions, and their efficient design can substantially mitigate greenhouse gas production [1]. In the development of propulsion systems, digital twins facilitate enhanced designs with a reduced time-to-market, yielding significant benefits for both business performance and result quality. However, the intricate nature of combustion processes introduces substantial challenges, particularly in balancing model accuracy with cost-effective data generation. This study presents the development of a Digital Twin for combustion systems, incorporating automated data generation and machine learning to optimize engine design. Model training data are generated through automated 3D CFD combustion simulations using an open-source tool, thereby reducing reliance on expensive physical testing. The simulations were conducted on a diesel engine to capture the relevant combustion dynamics. The generated data are utilized to train machine learning models [2], focusing on optimizing the trade-off between model accuracy and minimizing computational costs. A comprehensive range of input parameters was varied in this study, and CFD simulation cases were generated through sampling from the input space. These input parameters included injector design, bowl design, and various in-cylinder flow and thermodynamic conditions at intake valve closure (IVC). The outputs of interest, which are related to engine performance and emissions, served as targets for the simulations. Compared to previous work [3], this study employs open-source CFD tools [4] and investigates advanced machine learning algorithms to enhance data efficiency in the combustion system design process. The proposed approach aims to improve predictive accuracy while significantly reducing the number of required simulations, thereby minimizing computational costs. These advancements position the digital twin as an effective tool for optimizing combustion system design while ensuring high predictive reliability.

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