



Coupled zone-adaptive turbulence and combustion modelling of turbulent swirling premixed flames

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The Transported Probability Density Function (TPDF) method is introduced for the first time within the Self-Adaptive Turbulence Eddy Simulation (SATES) framework, and a coupled adaptive turbulence–combustion model is developed based on it. The density function in SATES/TPDF is consistently defined as a spatially filtered quantity determined by the local turbulence integral scale and grid resolution, and the respective scalar-mixing closure strategies for the RANS and LES modes are adopted. The inconsistency in scalar-mixing rate models between these modes is revealed, and a new mixing-frequency model employing a hybrid length scale is proposed to satisfy the derived consistency criteria. This adaptive turbulence model is then coupled with a zone-adaptive combustion model in which either a laminar finite-rate (LFR) model or the TPDF method is dynamically selected based on the local Damköhler number, with a unified hybrid length scale, ensuring a smooth transition between RANS and LES. Through numerical validation on the turbulent premixed swirling burner TECFLAM, the SATES/TPDF approach—with the $k-\omega$ SST model as its baseline—was first demonstrated to reproduce the swirling flow and flame characteristics, and the newly proposed mixing-frequency model was shown to achieve closer agreement with experimental data than classic standalone RANS or LES closures. In the coupled adaptive simulations, the weak “M”-shaped flame and its temperature and equivalence-ratio profiles were reproduced in close agreement with experiment, whereas the standalone LFR model overpredicted reaction rates and flame strength. Only 4.24 % of the particles (0.86 % of the domain) required by full TPDF were needed, yielding a substantial cost reduction. By adjusting the partitioning-criterion parameter, smooth transition between LFR and TPDF limits was also achieved, balancing accuracy and efficiency. The limit for your abstract is one page, including references. Abstracts that do not meet these formatting requirements will be returned.