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Large Eddy Simulations of Turbulent Combustion Basing on the Eulerian Stochastic Field Method Coupled to Flamelet Progress Variable Approach Using OpenFOAM Code

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Introduction

The present trend in energy consumption shows ever increasing energy demand to servemultitude of reasons such as: transportation, electricity, manufacturing, and heating. Eventhough there is a strong development towards the usage of renewable energy to phase outtraditional energy, most of the energy production will still be continued by fuel scombustion. The turbulent combustion process presents a challenging area for research andinvestigation, since the interaction between the turbulence and flame occurs in broad rangesof time and length scales that need to be considered while carrying out numerical modelingand simulation [1].

Methods

In this perspective, a novel, well-designed numerical combustion model is investigated andcompared in the current project to usual existing technique (β-PDF) in order to assess thegeneral prediction capability in reproducing main turbulent characteristics. This methodcombines a transported joint scalar probability density function (T-PDF) following theEulerian Stochastic Field methodology (ESF) on the one hand, and a flamelet progressvariable (FPV) turbulent combustion model under consideration of detailed chemicalreaction mechanism on the other hand [2,3,4,5]. It was implemented and tested inboth; Reynolds averaging-based numerical simulation (RANS) and large eddy simulation(LES) frameworks. The validation used case for this technique was the well-known air-piloted methane jet flame (Sandia Flame-D) in [6]. Additionally, applying the same novelapproach, an investigation on the predictions of combustion characteristics of a turbulentOxy-methane non-premixed flame operating under highly diluted conditions of CO_2 and H_2 in oxidizer and fuel streams respectively [7], is reported in the project. All numericalsimulations have been performed on the Lichtenberg cluster and high performancecomputing systems are needed as the detailed resolution of the Flame-D and the Oxy-fueldomains still require immense computational resources.

Results

By applying both, the novel combustion method based on the transported probabilitydensity function and the FPV chemical technique (ESF/FPV) and the presumed-probabilitydensity function (β-PDF)-based FPV, on different Sandia Flame-D grids in RANS and LES frameworks, obtained results show a reliable agreement between simulated data and experimental ones. However, the novel hybrid approach removes the weaknesses of the P-PDF modeling where an over-estimation was noticed for some major species like the COand H_2O and under-estimation of Temperature profile once turbulent Oxy-fuel non-premixed flames were investigated as application cases.

Discussion

In this project, it was demonstrated so far that the combustion characteristics of a turbulentair-piloted jet flame (Sandia flame-D) in both RANS and LES frameworks can be predictedand analyzed using both, the novel hybrid ESF/FPV model and the presumed β-PDF. However, for more complex reacting turbulent cases presented in the oxy-methane non-premixed flame series operating under highly diluted conditions of CO_2 and H_2 ,employing the hybrid ESF/FPV model removed the weaknesses of the β-PDF anddemonstrated its high capability in capturing the main flame properties and flow fieldvariables applying RANS and LES turbulent models.

Outlook

Nonetheless, the novel model needs to be further evaluated by using premixed and partiallypremixed FPV tables. Also chemical tables with a non-unity Lewis number and byconsidering advanced micro-mixing models can be further studied. These tasks are left forfuture work.

Reference

[1] Janicka J.; Sadiki A.: Large eddy simulation of turbulent combustion systems, Proceedings of the Combustion Institute, Volume 30, 2005. https://doi.org/10.1016/j.proci.2004.08.279

[2] Avdic A.; Kuenne G.; Ketelheun A.; Sadiki A.; Jakirlic S.; Janicka J.: High performance computing of the Darmstadt stratified burner by means of large eddy simulation and a joint ATF-FGM approach, Computing and Visualization in Science, Volume 16, 2013. https://doi.org/10.1007/s00791-014-0225-8

[3] Jones W.P.; Marquis A.; Prasad V.: LES of a turbulent premixed swirl burner using the Eulerian stochastic field method, Combustion and Flame, Volume 159, 2012. https://doi.org/10.1016/j.combustflame.2012.04.008

[4] Mahmoud R.; Jangi M.; Fiorina B.; Pfitzner M.; Sadiki A.: Numerical Investigation of an Oxyfuel non-premixed combustion using a Hybrid Eulerian Stochastic Field/Flamelet Progress Variable approach:Effects of H2/CO2 enrichment and Reynolds number, Institute of Energy and Power Plant Technology, Technical University of Darmstadt, 2018. https://doi.org/10.3390/en11113158

[5] Mahmoud R.; Jangi M.; Ries F.; Fiorina B.; Janicka B.; Sadiki A.: Combustion Characteristics of a Non-Premixed Oxy-Flame Applying a Hybrid Filtered Eulerian Stochastic Field/Flamelet Progress VariableApproach, Institute of Energy and Power Plant Technology, Technical University of Darmstadt, 2019. https://doi.org/10.3390/app9071320

[6] Schneider C.; Dreizler A.; Janicka J.; Hassel E.: Flow field measurements of stable and locallyextinguishing hydrocarbon-fuelled jet flames, Combustion and Flame, Volume 135, 2003. https://doi.org/10.1016/S0010-2180(03)00150-0

[7] Sevault A.; Dunn M.; Barlow S.; Ditaranto M.: On the Structure of the Near Field of Oxy-Fuel JetFlames Using Raman/Rayleigh Laser Diagnostics, Conbustion and Flame, Volume 159, 2012. https://doi.org/10.1016/j.combustflame.2012.06.017

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