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Comparison of Reacting DDES and LES CFD Simulation Methodologies for a Dual Inlet Ramjet Engine Combustor

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Extended Abstract

The concept of an integrated rocket ramjet was initially introduced in the 1960s, leading to decades of research into dump combustor design [1]–[3]. The incoming air jets generate four corner vortices, while the dump section creates suction, collectively shaping the reactors. Therefore, the design of dump section is critical for a successful propulsion systems development. Parameters such as pressure drop, pressure fluctuations, and combustion efficiency must be evaluated across various flight regimes. Some of the known factors that affect overall ramjet engine performance include the size and efficiency of the reactors, dump effects, the dimensions of air intakes, angle, intake curvature, the flow separators in the intake flow stream, Reynolds number, and combustor dimensions [4]–[7]. The inherent inability to scale ramjet engine combustion chambers [8] poses a challenge when evaluating various geometrical configurations and operating points through experimentation. As a result, Computational Fluid Dynamics (CFD) becomes a crucial tool for advancing the development of ramjet propulsion engines.

In this study, Large Eddy Simulation (LES) and Delayed Detached Eddy Simulation (DDES) techniques, coupled with the Steady Laminar Flamelet combustion model, are used to model a generic ramjet combustor which is introduced by Ristori et al. [9]. The experimental data used in context of the work is studied by many researchers to have more insight of combustion phenomenon in ramjet engine combustor [10], [11]. Grid convergence was ensured through the application of the Richardson extrapolation method [12], and the grid quality was evaluated using the M-index defined by Pope [13]. A close agreement between both LES and DDES approaches, and experimental data was observed, confirming their accuracy in simulating the complex flow behaviour of the combustor. The findings reveal that both approaches provide good agreement with the experimental data regarding velocity profiles with only some minor discrepancies. However, a noteworthy distinction between DDES and LES is the behaviour of Turbulent Kinetic Energy and its distribution. The LES with WALE subgrid scale model tends to predict higher levels of Turbulent Kinetic Energy in the near-wall region compared to DDES, resulting in improved mixing and the formation of an early heated zone. This early combustion phase leads to a higher flow expansion and hence an increase in axial velocity, causing LES WALE to overestimate axial velocity at x=270 mm, whereas DDES predictions align slightly better with the experimental data.

Both DDES and LES WALE simulations tend to overestimate combustion efficiency compared with measurements. However, the total pressure loss is well predicted by both approaches with only a discrepancy of lower than 0.3% compared to measured data that is well within the measurement error range. It's important to note that the overprediction of combustion efficiency remains an open issue, as discussed by other researchers also [11]. Future simulations could be extended to calculate heat loss to the walls what could be an explanation for the overprediction of combustion efficiency.

The present research demonstrates that the Steady Laminar Flamelet model is capable of predicting flow structures in a ramjet combustor under reacting conditions. Within LES simulations, the prediction of turbulent kinetic energy within the near-wall region was enhanced, resulting in faster mixing and an overestimation of combustion efficiency. Even closer agreement with experimental data was achieved in DDES predictions, highlighting the effectiveness of employing eddy simulation with near-wall modeling when wall resolution is unfeasible. This approach not only demonstrates better

agreement between DDES predictions and experimental data but also showcases its efficiency in reducing the need for excessively refined meshes in the study of dump-type low subsonic combustors.

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