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Reduced-order Modeling of Combined Cycle Rotating Detonation Rocket-Dual Cycle Scramjet Engine

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Dual cycle scramjet engines have been of interest for hypersonic flight vehicles due to their ability to operate over a wide range of Mach number [1]. Combining such a system with rotating detonation rocket cycle (RDRC) is considered for high thermodynamic efficiency of detonations but also zero-speed startup capability [2]. Since high-fidelity simulations and experiments are too expensive to perform over a wide range of operating conditions, the present work develops a reduced-order quasi-one-dimensional reactive solver to explore the design space of such a system. The complex interaction of reactions, wall friction, mixing, and area change effects is solved through the flow path comprised of the diffuser, isolator, combustor, mixing chamber and nozzle flow. The study considers the use of hydrogen as fuel, with simulations conducted for a Mach 8 combined cycle engine is designed for flight conditions at 30 km altitude. The dual-cycle scramjet is integrated with the rocket RDE, with inflow conditions specified by a total pressure $P_{t,\text{RDE}} = 10$ atm and a total temperature $T_{t,\text{RDE}} = 300$ K. This configuration enhances the thermodynamic efficiency of the combustion process compared to direct fuel injection in a basic scramjet engine configuration. The simulation results are compared with a basic scramjet operating at the same lean fuel-air equivalence ratio, $\phi = 0.1$, in terms of flow variables and thrust. In the combustor section, the flow process is limited by mixing rather than detailed chemical kinetics [3]. Therefore, a mixing model is developed following fuel injection for the combustor section calculations. For validation of the reduced-order model, scramjet calulations are compared to HyShot-II experiments [4]. Further analysis will be done by comparing the results to high-fidelity DNS simulation of the designed combined cycle engine with the finest grid size $\Delta x_{min} = 9.76\ \mu m$, which corresponds to 27 cells across the induction length.

References

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