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High-Fidelity CFD Analysis of Transitional Flow Dynamics in a Dual-Bell Nozzle

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This study investigates unsteady flow behavior and transition dynamics in a dual-bell nozzle (DBN) at a nozzle pressure ratio (NPR) of 10 using high-fidelity simulations with the k-omega SST Detached Eddy Simulation (DES) model in OpenFOAM. The baseline (no-injection) case is benchmarked against the cold-flow experiments of Léger et al. (2020). The mesh is refined near walls to resolve key boundary and shear layer features. Flow expands cleanly in the base nozzle (TIC) section. Near the inflection point, a separation bubble forms in the constant-pressure extension, consistent with experiments. Vortical structures emerge in the shear layer, showing early signs of Kelvin–Helmholtz instabilities. These interact with the bubble, causing low-frequency axial motion of the separation point and wall pressure fluctuations. The unsteady behavior resembles side-load dynamics reported in tests, likely driven by shear-layer instabilities and acoustic feedback. These preliminary results validate the DES approach and enhance understanding of flow separation and transition in DBNs to support the development of control strategies like radial secondary injection for improved altitude adaptation.

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