Mechanical Engineering Dissertation Defense

Understanding the Mechanism of Vortex Flow Modulation by Inertial Particles

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Abstract

This dissertation investigates the complex dynamics of semi-dilute inertial particles suspended in vortices using the Eulerian-Lagrangian method. The study explores the modulation of flow induced by inertial particles, focusing on the characteristics of a single vortex, instability analysis within particle-laden flows, and the merging process of corotating vortices.

Simulations reveal a preferential concentration mechanism, where inertial particles cluster around a void fraction bubble, accelerating the decay of the vortex tube. Small- scale clusters, arising from particle-trajectory crossings, induce significant gradients in the fluid vorticity field, contributing to rapid vortex breakdown. Within a specific Stokes number range, increased particle inertia results in faster vortex decay and stronger inhomogeneity in the particle phase.

The instability mechanism in particle-laden flows is explored using a Rankine vortex model. Two-way coupling triggers azimuthal perturbations, leading to the breakdown of the vortex structure. Linear Stability Analysis and Two-Fluid modeling demonstrate that the dusty vortex flow exhibits unstable modes, with growth rates increasing with wavenumber. Eulerian-Lagrangian simulations validate these results, showing excellent agreement between computed and predicted growth rates.

The dissertation also delves into the co-rotating vortex merger in a semi-dilute dusty flow. For weak inertial effects, merger experiences a delay compared to particle- free vortices. Under moderate inertial conditions, the merger process exhibits repulsion, increased separation, and eventual convective merger stages. Highly inertial particles stretch the vortex core, initiating a merger with an outcome of a particle-free vortex core surrounded by a halo of concentrated particles.

In conclusion, the feedback force from the dispersed phase induces instability and significantly influences the dynamics of vortices in particle-laden flows. The findings contribute to a deeper understanding of the intricate interactions between inertial particles and vortical structures.

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