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From Direct Numerical Simulation to Macroscopic Modeling: Heat Flux Analysis in Fluid-Particle Media

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Fluid-particle flows, ubiquitous in industrial applications and natural phenomena, involve com- plex hydrodynamic interactions coupled with heat and mass transfers. The modeling of these flows fundamentally relies on Partial Differential Equation (PDE) systems, traditionally ana- lyzed through continuous (multi-fluid) or discrete (Euler-Lagrange) approaches. Direct Numeri- cal Simulation (DNS) provides a high-resolution solution of these PDEs at the microscopic scale, enabling a deep understanding of interfacial interactions, particularly for heat transfer governed by conduction, convection, and radiation. This study aims to improve the macroscopic modeling of heat fluxes. By leveraging global balances and multi-realization statistics, we derive closed and consistent models. These models highlight the respective contributions of convection and conduction to the total heat flux exchanged between constant-temperature solid particles and the surrounding fluid, thereby establishing a rigorous bridge between particle-scale PDE resolution and macroscopic continuum models.