Phase space analysis of the heat transfer in a shearless particle-laden turbulent flow

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We perform a statistical analysis of single-particle probability density function (pdf) of inertial heavy particles transported by a homogeneous and isotropic, statistically steady turbulent velocity in a thermally inhomogeneous flow which produces a time evolving thermal shearless mixing layer[1]. Numerical results of direct numerical simulations (DNSs) within the Euleria-Lagrangian point particle approach are used to compute the unclosed terms in the pdf transport equation. We observed that particle temperature derivative $\dot{\Theta}_p$ conditional on particle position x, temperature Θ_p and velocity V_p scaled with t^{-1} for any particle Stokes number. This statistical moment is visualized in a reduced order 3-dimensional space, including particle temperature, and its position, and velocity in the direction that temperature field has an inhomogeneity and a thermal mixing layer develops in a self-similar manner. Through the two and three dimensional visual inspection of the pdf evolution in the phase space, a self-similar behavior has been observed independent of particle inertia and thermal inertia. We present the two dimensional map of pdf at the center of thermal mixing at different time and we show how the evolution in phase space develops self-similarly for different particle Stokes numbers. Furthermore, a three dimensional visualization in the whole phase space of the pdf at different time is presented. We also show that the whole dynamics of the flow regime in the physical space can be expresses in a quasi self-similar form and how the delay introduced by the particle thermal inertia allows for self-similarity only in the asymptotic limit of long time.

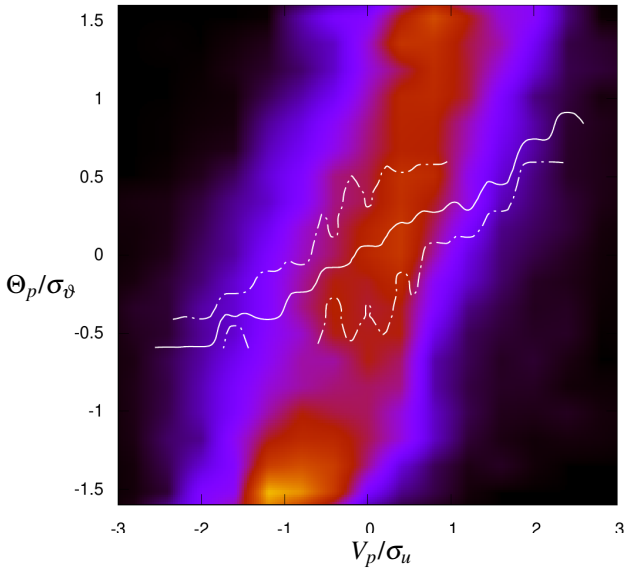

Figure 1: Phase space density f in the central plane $x = 0$. Dark color indicates lower values, brighter colors indicate higher values. Velocity and temperature have been normalized with their standard deviations. The continuous while line indicated the state where the mean temperature derivative is zero, the dashed lines the states where the temperature derivatives is equal to $\pm 0.2\sigma_\vartheta/\tau_\vartheta$. Data is plotted for Stokes number equal to 0.1 and at t/τ=3, where τ is the large eddy turnover time, t denotes the time, and τ_ϑ is the particle thermal response time.

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[1]Zandi Pour and Iovieno, *Fluids*, **7**(11), (2022).