Comments on "Studies of the Behavior of Heavy Particles in a Turbulent Fluid Flow"

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Meek and Jones (1973) consider the important problem of the motion of a heavy particle in a turbulent fluid flow, their main contribution being the inclusion of a (uniform) free-fall velocity due to gravitational field. While the inclusion of the effect of gravity is important, Meek and Jones have, as have others in the past, failed to account for the most important effect of the turbulent field on the particle motion, namely, the effect of the space-time correlation of the turbulent flow. A heavy particle initially coincident with the fluid point naturally lags behind that fluid point as a result of inertia. As a result of this lag, the particle encounters different fluid particles. If each fluid particle encountered by the heavy particle was statistically equivalent, the diffusivity (mean-square displacement) of the heavy particle would be identical to that of the mean-square displacement of the fluid points. This is what is implied by Meek and Jones' Eq. (23) in the absence of gravitational field. (Of course, gravity can be expected to reduce the heavy particle diffusivity.) In fact, however, the fluid points encountered by the heavy particle are not statistically equivalent and would only be so in a turbulent field with infinitely large space and time Eulerian correlation scales. Finite correlation scales imply that the fluid points encountered by the heavy particle as it lags behind the original coincident point are not statistically identical. This, of course, is the crux of the Eulerian-Lagrangian problem. For example, if the spatial correlation scale was very large, the fluid points encountered would all be equivalent in a statistical sense, and the heavy particle diffusivity would be the same as the fluid diffusivity. If the spatial correlation scale is very small the heavy particle effectively encounters nearly random forcing and this would result in a very small mean-square displacement. It is the Eulerian space-time correlation which controls particle diffusivity.

In Meek and Jones' Eq. (13), where the particle energy spectrum is linearly related to the fluid Lagrangian spectrum through a response function, this effect of space-time correlation is being neglected. It has been shown (Peskin, 1971) that this correlation effect is extremely important in determining the heavy particle diffusivity even in the absence of gravity, and in ignoring this, Meek and Jones ignore a problem of primary importance in heavy particle dynamics.

Eq. (18) in the Meek and Jones paper has been obtained before (Peskin, 1960) and can be shown to be the long-time limit for the particle autocorrelation in the case where the fluid particle Lagrangian correlation is assumed to have a simple exponential functional form. This particular heavy particle correlation implies a ratio of heavy particle diffusivity to fluid particle diffusivity of 1 in the absence of gravity. More important, however, is the fact that the full equation (Peskin, 1960) clearly indicates that the heavy particle autocorrelation is not stationary except in the long-time limit, long-time implying long-time from release. This situation persists even though the supporting turbulence field is stationary. Thus, when Meek and Jones make assumptions about stationarity of the heavy particle velocity fluctuations, such assumptions must be viewed in the context of very long-time release, and this must be considered when comparing the results to data. Furthermore, the comments made in the paper concerning isotropy of the particle motion are not clear in view of the fact that a gravitational field is considered. Isotropy in this situation would persist only if the heavy particles instantaneously attained their vertical fall velocity so that fall velocity could be considered as a uniform drift. Otherwise the forcing function acting on the particles is not isotropic and therefore it is difficult to see how the velocity statistics can be isotropic.

This important problem needs as much additional research, both theoretical and experimental, and at the crux of this issue lies the relation between Eulerian and Lagrangian statistics of turbulent flow.

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