LETTERS TO THE EDITOR

To the Editor:

Yuu *et al* (1978) have presented a computational algorithm for the prediction of the turbulent diffusion of particles in a round air jet. In the process, they dismiss an existing analytical theory (Davidson and McComb 1975: DMcC for brevity) as 'using Hinze's relation' and as 'not adequate'. We take this to refer to our putting the particle diffusivity D_p equal to the fluid-point value D_f, at long diffusion times (Tchen 1947: see Hinze 1975). Yuu *et al* have criticised this conclusion from Tchen's analysis at an earlier point in their paper, on the grounds that a particle may escape from the fluid which originally surrounded it. This criticism is, of course, well known (Hinze 1975) but, as applied by Yuu *et al* to DMcC it is misleading in two ways.

First, it is out of context. DMcC is based on the theory of the random walk for fluid-point diffusion (McComb 1974). Added particles were treated by perturbation methods and the approximation $D_p = D_f$ was made as part of a general first-order approximation scheme. Concentration profiles and particle mean velocities were predicted and have now been confirmed by measurements using laser-Doppler anemometry (McComb and Salih 1978).

Second, it is imponderable. Yuu *et al* themselves assume:

a) continuous diffusion may be replaced by a primitive model, in which Lagrangian equations of motion are integrated over an uncorrelated sequence of eddies;
b) the spectrum of eddies is represented by a single eddy;
c) the eddy viscosity is assumed independent of radius; and
d) the Lagrangian and Eulerian turbulent intensities are assumed to be equal.

All of these are imponderable. Consequently Yuu *et al* have no grounds for a general *a priori* assertion that their simulation is more accurate than DMcC.

Finally, two aspects of the work by Yuu *et al* seem open to serious adverse criticism. The first of these is their averaging of the simulated Lagrangian trajectories of particles which start from the same point at different times. They justify this by stating that the turbulent flow field is homogeneous in time (ie stationary). But this is only true of the Eulerian field. The Lagrangian field in a jet is non-stationary and so their averaging procedure seems to be invalid.

Also their measurement of particle diffusivity is ambiguous, as concentration curves depend on mean-motion effects, as well as diffusion. Yuu *et al* assume that particle and fluid velocities are equal but they also have to make the hidden assumption that the divergence of the particle velocity vanishes. As Hinze (1972) has pointed out, this is particularly incompatible with the presence of "overshooting" and as a result the calculated eddy diffusivity must contain mean motion effects. It should be noted that only optical measurements can distinguish between mean-motion and eddy effects. LDA measurements (McComb and Salih 1978) indicate that particle velocities are generally less than fluid velocities and that DMcC can entirely account for the reduced spread of particles by mean motion effects opposing the action of the fluid eddy diffusion.

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LITERATURE CITED

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Reply:

In an aerosol jet, Davidson and McComb (1975) evaluated the region where $D_p = D_f$ by using their Eq. (1,12) and in this region ($\epsilon \leqq 0.2$) they calculated the particle mean velocity and the number density distributions by perturbation method, where D_p, D_f and ϵ are particle and fluid turbulent diffusivities, and perturbation parameter, respectively. In the letter to the editor, McComb and Davidson have mentioned that the approximation $D_p = D_f$ was made as part of a general first-order approximation scheme. As their Eq. (4, 35) indicates, the terms in which $m \geqq 2$ have very small contributions to D_p, when $\epsilon \leqq 0.2$. Hence, on the calculation, they substantially used the relation that $D_p = D_f$. As Hinze (1st. Ed. 1959, 2nd. Ed. 1975) describes in detail in his textbook, Eq. (1,12) was derived under the assumption that the same fluid surrounds the particle as it moves (no overshooting). The eddies in real turbulence are distorted, stretched into long thin ribbons, and finally disappeared. Hence no overshooting assumption is unreasonable for a real turbulence field like an aerosol jet and especially for a long time diffusion. Since particles do not follow the fluid motion thoroughly owing to their inertia in an aerosol jet which has fluid property distributions and overshooting effect, it seems that D_p is not equal to D_f even if $\epsilon \leqq 0.2$. The calculation of Davidson and McComb showed that the particle mean velocity was not equal to fluid mean velocity even if $D_p \fallingdotseq D_f$ in the region $\epsilon \leqq 0.2$. Turbulent diffusion is dominated by higher frequency components of fluid motion than particle mean velocity is. We know that the higher the frequency of fluid motion, the larger the lag between particle and fluid due to particle inertia. Hence their result seems to be invalid. In their letter they have asserted that their theoretical concentration and particle mean velocity profiles were confirmed by measurements using laser-Doppler anemometry (McComb and Salih 1978). However, we doubt it by considering their experimental errors and the way of normalization. They have only compared the similarity forms with those obtained experiments.

We have not asserted that our study (1978) is better than that of Davidson and McComb (1975). Their study has interesting and useful points. For example, their calculation method has made it possible to predict the Eulerian particle mean velocity and concentration distributions in an aerosol jet, only if D_p is known. We think that it is interesting and useful for researchers and engineers.

As McComb and Davidson have mentioned in their letter, our model (1978) have some imponderable assumptions (a), b), c), d), and averaging procedure). The objective of our study is also to explain approximately these imponderable subjects by examining the agreement between the particle turbulent diffusivities calculated based on our simple ideas and the measured ones.

We (1978) have obtained the experimental particle turbulent diffusivities in the region far from the nozzle exit ($x/d \geqq 30$ for $\psi = \frac{\epsilon}{0.72}\left(\frac{x}{d}\right)^2 = 3.4$ ($\epsilon \leqq 0.026$), $\frac{x}{d} \geqq 46$ for $\psi = 15$($\epsilon \leqq 0.050$), and $\frac{x}{d} \geqq 65$ for $\psi = 30$ ($\epsilon \leqq 0.050$)), where d, x and ψ are nozzle diameter, distance from jet exit, and Stokes number, respectively. We have compared the calculated diffusivities with the experimental ones in these regions. As shown in Fig. 8 of our paper, the calculated particle mean velocities based on our model are equal to the fluid ones. As mentioned above, the perturbation parameter ϵ of Davidson the McComb is smaller than 0.05 in these regions. Hence the result that particle mean velocity U_p and fluid mean velocity U_f are nearly equal in these regions is also obtained by using the theory of Davidson and McComb. As already mentioned, the lag between particle and fluid increase with the increasing frequency of fluid motion due to particle inertia. Hence the result that $U_p = U_f$ and $D_p < D_f$ is reasonable. We have already pointed out in our paper (around Eq. (22)) that the experimental particle diffusivity in the region $U_p \neq U_f$ cannot be obtained by using the Eulerian method based on experimental results of particle concentrations if we do not get particle mean velocity.

Literature cited is the same as the McComb and Davidson letter.

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