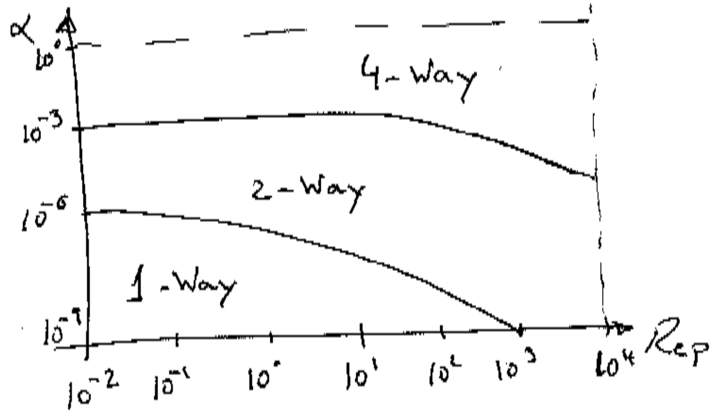
PARTICLE - FLUID INTERACTION.

The level of interaction between a fluid and particles immersed in it can be characterized as 1-way coupling, 2-way coupling and 4-way coupling, depending on the number of particles in the flow (void fraction α) and their size (Re_p). The following is a map that tries to **delineate** the border between the 3 different behaviours.



- 1-way coupling is the simplest interaction where the flow drives the particle behaviour but the presence of particle does not influence the flow. This is characteristic of very dilute multiphase flows and small particles that have small "footprint" on the flow in the form of wake or flow disturbance (St or Oseen streamlines).

- 2-way coupling is an interaction mode where the flow drives the behaviour of the particles as isolated bodies, independently of the presence of other particles, and the particles feedback into the **flow**, disturbing **it**.

2-way coupling is typically implemented in DNS simulatio of particle laden flows in conjuction with the point force assumption (although they are independent hypothesis). Thi calculates the force that the fluid exerts on the particle through the particle equation of motion (Maxey & Riley, Pof 198 and

(28)

PARTICLE DISPERSION BY TURBULENCE

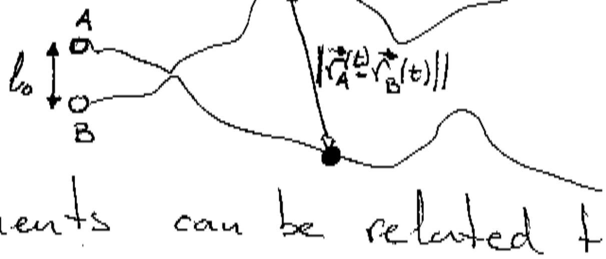
The effect of turbulence on the dispersion of particles in the flow is a topic of great importance for both environmental and industrial engineering applicatio

The evaporation of liquid fuels from the injected droplet and its subsequent mixing, depends very strongly on the dynamics of the droplets in a very energetic turbulent flow

The fate of pollutants in the atmosphere is determined by the dynamics of pollutant particles or inoguous aerosols where polluting vapours are adsorbed and convected with them.

Dispersion **is** defined as the standard deviation of the distribution of particle pair distances; that is take a large number of particle pairs that start moving in a non-unif flow from a **constant** distance, measure their distance at a certain later time and take the root mean square

$$D_{disp.\,coeff}(t) = \frac{1}{N} \sum_{\substack{\text{each}\\ \text{pair } A,B}} \|\vec{r}_A - \vec{r}_B\|^2$$



The dispersion of fluid elements can be related t turbulence statistics by $D_{f ij}(t) = \frac{1}{2} \frac{d}{dt} \overline{X_i(t)\, X_j(t)}$

$$= v'^2 \int_0^t R_{L ij}(s)\, ds$$

Where X_i is the position of the fluid particle (x, y or z
v'^2 is the rms of the turbulent velocity and $R_{L_{ij}}(s)$ is the turbulent velocity correlation for a spacing s:

$$R_{L_{ij}}(s) = \frac{\overline{v_i(t)\, v_j(t+s)}}{v'^2}$$

The autodispersion function can be defined as the evolution of the rms of the distance to the origin

$$\sum_{i=1}^{3}(X_i - 0)^2 = \overline{X^2}(T) = 2v'^2 \int_0^T \left[\int_0^t R_{L_{ii}}(t')\,dt'\right] dt$$

The problem of the effect of inertia and gravitational velocity of the particles on their dispersion characteristics has been studied thoroughly in the last 20 yea
Several reviews (Crowe 1993, 95) and (Eaton & Fessler 199
have summarized the findings:

1. Large scale structures (vortices) are important for dispersion processes. AND SO ARE SMALL SCAL STRUCTURES.
2. Particle dispersion is maximum for Stokes ≈ 1
3. Intermediate Stokes numbers (St ~1) tend to concentrate preferentially near the outer boundaries of vortices. THIS CONTRADICTS 2.

There is the common misconception that increased dispersion is equivalent to increased mixing.

STIRRING ↔ MIXING

Turbulence at the large scales produces stirring, stretching interfaces and generating surface area and increa the steepness of gradients. All of this promotes mixing.

Mixing occurs at the molecular scale and is typicall modeled as proportional to the amount of surface area and the strength of the gradient at the interface. Although turbulence at the small scales contains very little energy (as a fraction of the total under the spectrum) it is the key to the enhancement of mixing due to turbulence. By creating stirring at the smallest scales, it generates a concentration microstructure at length scales where diffusi is most effective.

The effect of gravitational velocity on particle dispersion has been difficult to understand due to the coupling of gravity and inertia in experiments on Ear
The crossing trajectories effect (the interactions of partic with turbulence under the influence of a drift velocity induced by gravity) makes the particle velocity correlation smaller and therefore decreases dispersion (WELLS & STOCK, JFM 1983).

TURBULENCE MODULATION BY PARTICLES

1-way coupling: carrier fluid turbulence is unaffected by the disperse phase (particles). This happens for very dilute flows $\phi = \frac{V_p}{V_p + V_f} \ll 1$ or very small density difference between particles and fluid. $\rho_p/\rho_f \simeq 1$ $\left(\frac{\rho_p}{\rho_f} - 1 \ll 1\right)$

There are 2 main ways to look at this: volume fraction or mass loading. For particles that are heavier than the carrier fluid mass loading is useful since it encompasses the 2 different variables of influence $\frac{M_p}{M_p + M_f} \simeq \frac{m_p}{m_f} = \frac{\rho_p \cdot V_p}{\rho_f \cdot V_f} \simeq \frac{\rho_p}{\rho_f} \cdot \phi$

- Mass loading can be significant because particles are very heavy although there are (relatively) few of them $\frac{\rho_p}{\rho_f} \gg 1$, $\phi \ll 1$ $\frac{\rho_p}{\rho_f} \cdot \phi \overset{\ll}{\gg} 1$ or because there are a lot of particles despite their small density difference $\frac{\rho_p}{\rho_f} \simeq 1$ $\phi \simeq 1$ (ϕ always$<$
- Volume fraction represents the geometric effect of partic moving (as blunt objects) in the flow. As long as they have a relative velocity to the fluid, they will perturb the flow (as a wake or Stokeslet, depending on the Re_p).

Particle relative velocity is associated to gravity or inertia in both cases these effects are related to density ratio. The exception is bubbles. Bubbles have a rise velocity relative to the fluid despite the fact that their density ratio is essentially zero. This is because of their buoyancy exerting a force on them.

In 2-way coupling:

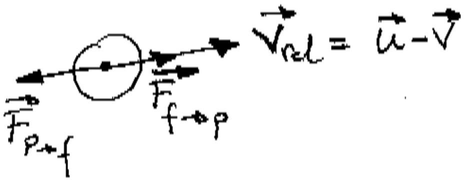
Particles may enhanced the turbulent intensity due to the energy deposited at small scales through work done by the particles as they move relative to the fluid (typically due to gravitational forces) or they may reduce the intensity of turbulence due to the additiona dissipation occurring at the particle/fluid interface due to the no-slip condition. (Under which conditions bubbles and droplets are subject to the no-slip condition is a subject of study. A review can be found in "Bubbles, drops & particles" Dover Book Clift, Grace & Weber)

Quantifying turbulence modulation is tricky as the effect of particles can be distributed non-unifor ly across the scales of the turbulence.

The turbulence kinetic energy is an integral of the kinetic energy present in the fluctuating velocity field across all length (or time) scales. The impact of particles may show up in this quantity or the different effects at different scales may conteract each other and obscure the net effect on T.K.E.

Different mechanisms of turbulence modification

- Effect on mean shear → turbulence production
- Unsteady particle wakes → high Re_p (Vortex shedding)
- Superposition of random laminar wakes ⇒ increased energy at small scales.
- Dissipation due to force on the particles:



$$\vec{F}_{p\to f} \cdot \vec{u} = \dot{W}_{particles} < 0$$

dissipation

Some of this energy is transferred to the fluctuating kinetic energy of the particles but most goes into small scale perturbation of the flow that dissipates quickly through viscosity.