15.Particles

Thursday, March 03, 2011

Today: Particle generation and injection techniques in air and water
Next: Refractive techniques
Final Final due date for reports, edited images etc: Wednesday May 8

II Particles

Heavy seeding

Number density high enough to look like a dye

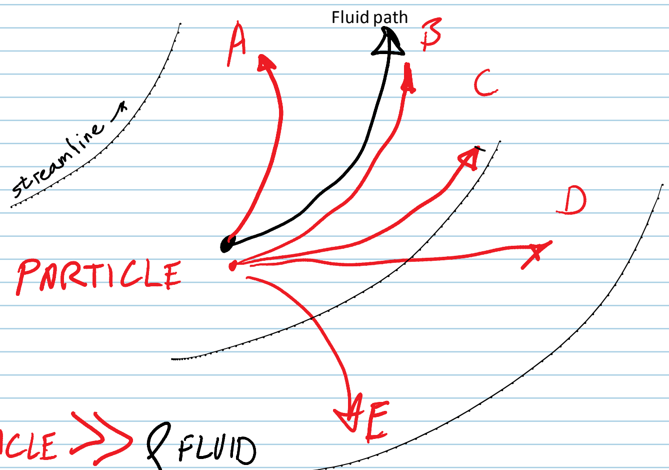
Similar considerations to dyes:
1)Particles must track with the flow ← Big difference from dyes
Dyes are molecules, track with the flow just fine.

2)Want particles to NOT disturb flow
3)Want particles to show up - HIGH VISIBILITY

1) When will particles track well, be good tracers?

Minute paper: Consider a curved streamline. Consider a small particle, much denser than the fluid, BUT small enough that gravity is negligible compared to forces of the fluid on the particle. (diameter ~ 100μm in water) ← human hair diameter

What will the particle path look like compared to the fluid path?



$\rho_{PARTICLE} \gg \rho_{FLUID}$

Next, consider same scenario, but a bubble instead of a particle.

$\rho_{BUBBLE} \ll \rho_{FLUID}$

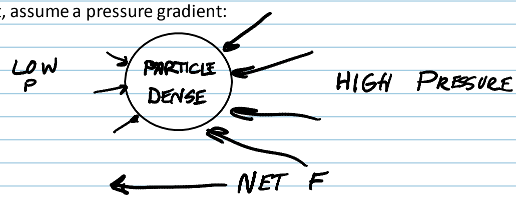
Ever been hit in the back of the head by a balloon when you are accelerating in a car?
http://www.youtube.com/watch?v=XXpURFYgR2E

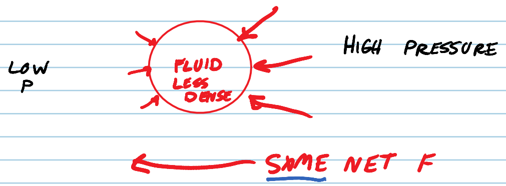
For particles (or bubbles) to track with the surrounding fluid, they must accelerate the same as the neighboring fluid

Forces **on particle**:
Body: gravity, neglect.

Surface:	normal = pressure parallel = shear	} from fluid

First, assume a pressure gradient:

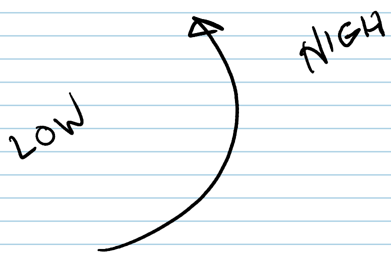




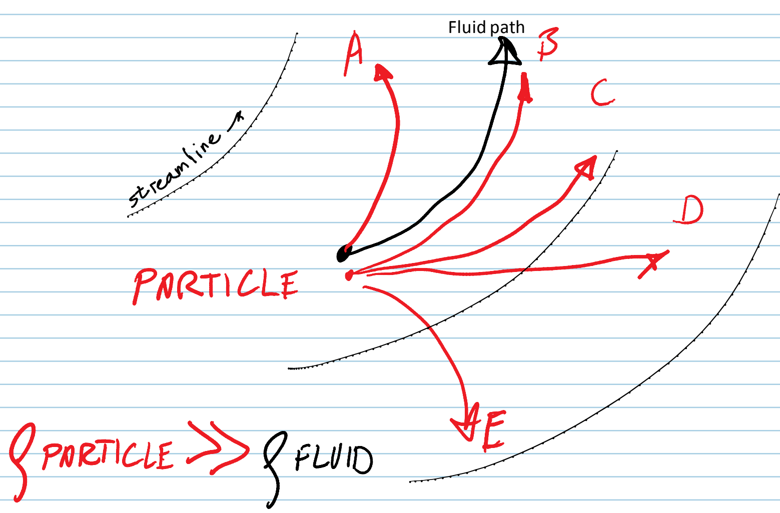
Which particle will accelerate more?
Newton's Second Law: $\sum F = ma$

What makes streamlines curve?

(what is a streamline?)



Streamlines curve because of pressure gradient. Low P is inside curve



Rules of thumb:

- In water, particles of 100 µm diameter or less, any density, will track most flows.
- In air, particles of 1 µm diameter or less, any density, will track most flows.

Similar considerations to dyes:
1) Particles must track with the flow
2) Want particles to NOT disturb flow
3)Want particles to show up - HIGH VISIBILITY

2)Want particles to NOT disturb flow

- As with dyes, minimize injection differential velocity; inject at local flow speed.
- Want particles to not introduce new forces. Avoid:
  - soluble particles
  - surface tension
  - chemical reactions
  - significant change of density
  - particle-particle interaction
    - Number density of particles = # of particles / unit volume. (Contrast to mass/volume of solid alone). Keep low enough to avoid interactions.
    - Particle-particle interaction (collisions, drag) lead to non-Newtonian effects. Slurries, oobleck, blood, shampoo, silly putty, other polymers. Gets into 'complex fluid' categories. Interesting field.

3) High visibility

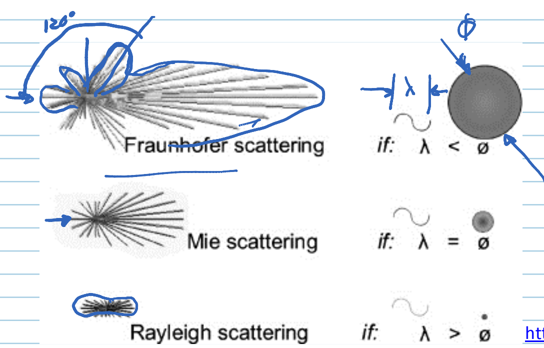
Particles only scatter light. Interaction depends on size (d) compared to λ.
Scattering = ∑ of reflection, refraction, diffraction & absorption

d ~O(λ) : Mie scattering regime.
e.g. visible light =0.7 - 0.4µm, so diameters of 1 µm to 0.1µm (100 nm, 1000 A).

- Scattering efficiency drops as particles get smaller. Better tracking, but less light.
- Independent of wavelength; no colors from particles this small. Makes clouds white.
- Particles large enough to have color are too big to track well.

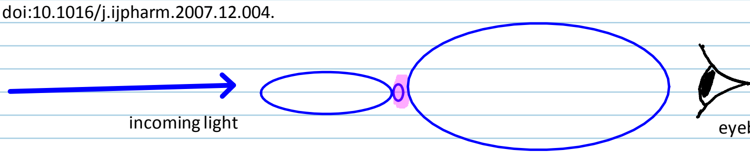
"NASA wing tip vortex. Information for ID # EL-1996-00130," n.d., http://lisar.larc.nasa.gov/UTILS/info.cgi?id=EL-1996-00130.

Light is not scattered uniformly:

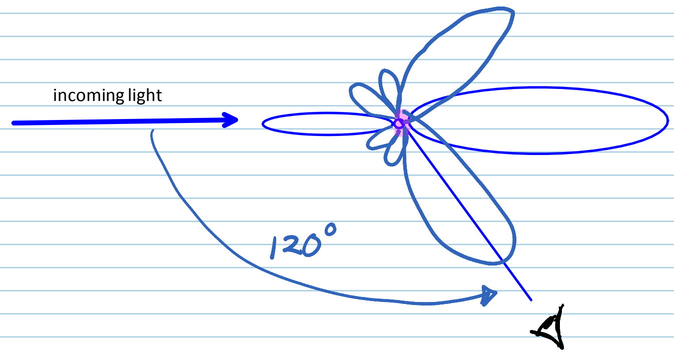


http://www.sciencedirect.com/science/article/pii/S0378517307010113

Keck, Cornelia M., and Rainer H. Müller. "Size Analysis of Submicron Particles by Laser Diffractometry—90% of the Published Measurements Are False." International Journal of Pharmaceutics 355, no. 1–2 (May 1, 2008): 150–163. doi:10.1016/j.ijpharm.2007.12.004.



Mie regime, small particles:
Back scatter < Forward scatter



Mie regime, larger particles: Back scatter < Forward scatter
+
Often a strong lobe at 120 degrees to incoming light. *SWEET SPOT*
Best to play with camera-light angles.

Smaller particles, d << λ,
Rayleigh scattering regime. Elastic collision of photons with particles. No energy exchange.
Blue sky is Rayleigh scattering; sunlight scattered by molecules of air, preferentially blue. Longer wavelengths are too long to interact much; are only seen at sunset due to long passage through atmosphere, and when scattered by larger molecules of pollutants or dust.

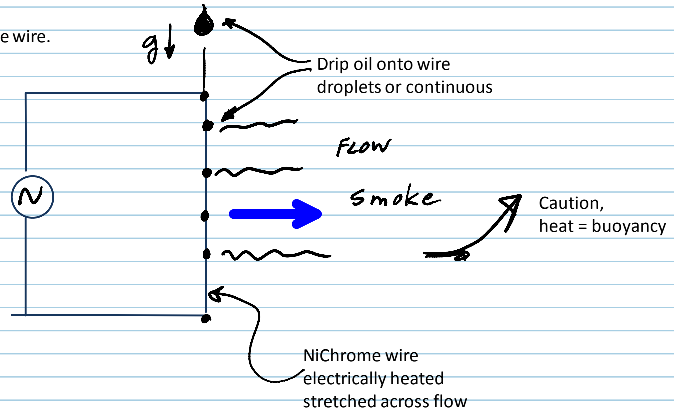
Next: How to make or get particles

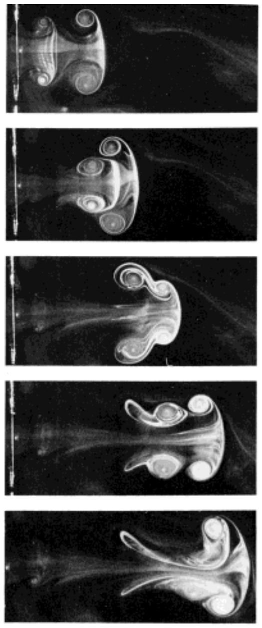
http://www.youtube.com/watch?v=DOUfyDHxkYQ&feature=related
NCFMF film 'Flow Visualization'
Hydrogen bubble technique

In air: smoke and fog
solids liquids

A) Smoke = soot usually, carbon particles

Smoke wire.



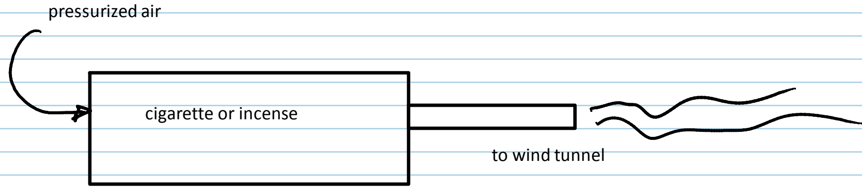


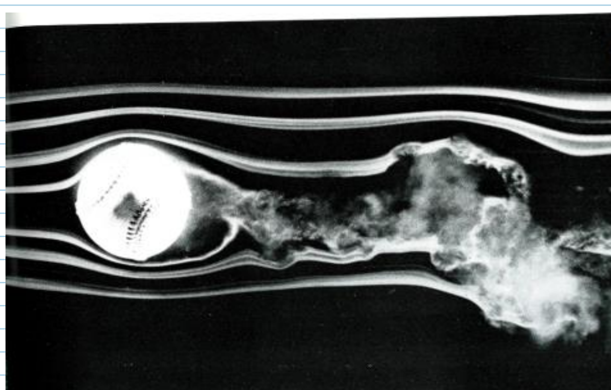
79. Leapfrogging of two vortex rings. Two successive puffs of air are ejected from an orifice of 8-cm diameter by a piston that is driven by the impacts of two pendulums. The flow is made visible by a smoke wire stretched across the orifice, at the left of the photographs. At this Reynolds number of about 1600 based on orifice diameter, the second ring travels faster in the induced field of the first, and has slipped through it in the third photograph. Then the process is repeated, the first ring slipping through the second in the last photograph. *Yamada & Matsui 1978*

Van Dyke, Milton. *Albumof Fluid Motion*. 10th ed. Parabolic Press, Inc., 1982.

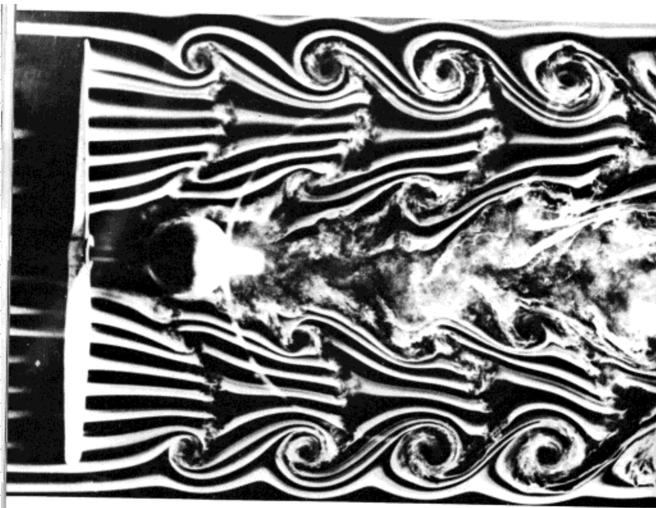
Most oils work. Veg is less toxic.
Generates 1µm particles. Penetrates into lungs, causes cancer, regardless of composition.

Alt technique:
pressurized air



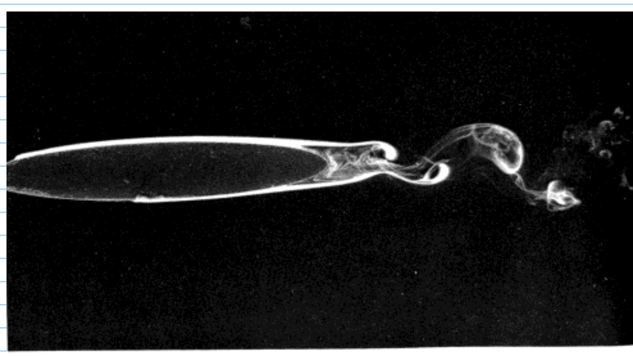


66. Spinning baseball. The late F. N. M. Brown devoted many years to developing and using smoke visualization in wind tunnels at the University of Notre Dame. Here the flow speed is about 77 ft/sec and the ball is rotated at 630 rpm. This unpublished photograph is similar to several in Brown 1971. *Photograph courtesy of T. J. Mueller*



75. Vortices behind a rotating propeller. A striking pattern of helical tip and root vortices is revealed by smoke in the Notre Dame wind tunnel. The stream flows at 48 ft/s while the propeller rotates at 4080 rpm. *Brown 1971, courtesy of T. J. Mueller*

Chemically generated particles:
TiO_2 Titanium dioxide particles from
titanium tetrachloride + water vapor = dense TiO2 smoke + HCl
HCl + water vapor = hydrochloric acid vapor
Spectacular smoke, but toxic, and hard on equipment, corrosive



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32. Laminar separation on a thin ellipse. A 6:1 elliptic cylinder is held at zero angle of attack in a wind tunnel. The Reynolds number is 4000 based on chord. Drops of titanium tetrachloride on the surface form white smoke, which shows the laminar boundary layer separating at the rear. *Bradshaw 1970*