Fluids

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1. Introduction

- What is a fluid?
- Something that flows!
  - Liquid

29. A Round Jet in Cross-Flow

  - gas - either neutral or ionised (plasma)
    - (c.f. solid where atoms held quasi-rigidly together)

http://www.eng.vt.edu/fluids/msc/gallery/gall.htm

1.1 Topics covered

- What is the essential physics of fluids?
- What is vorticity?
- Why do boundary layers form?
- How do sound waves travel?
- ….and what happens when they form a shock?
- What happens when fluids are unstable?

1.2 Fluid equations

- Based on concept of a "fluid element" - a patch over which we define local variables (e.g. ρ,T etc)
- Size of patch L_{el} is such that:

1. Small enough that we can ignore systematic variations across it, i.e.

$$L_{el} << L_{scale} \approx \frac{q}{|\nabla q|}$$

Any quantity

Length scale over which q varies by order unity

2. Large enough that it contains enough particles that you can ignore fluctuations due to a finite number of particles

$$nL_{el}^3 >> 1$$

Number density (units m^{-3})

3. Large enough that constituent particles "know" about local conditions through colliding with each other, i.e.

$$L_{el} >> \lambda$$

Mean free path

N.B.

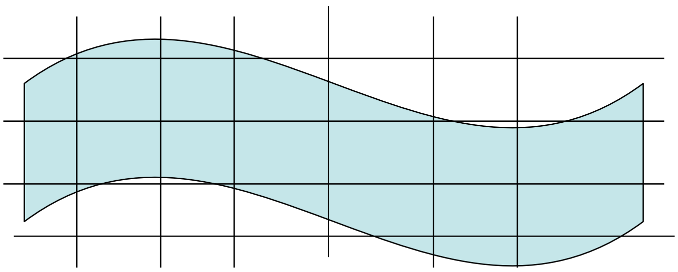
- Fluid elements are just conceptual quantities!
- L_{el} doesn't enter the fluid equations… BUT…conditions (1)-(3) limit the applicability of the fluid equations.

2. Choosing the best description

- You want to go swimming in the river Etive … but you hate cold water
- At what time and place is the water hottest?
- Water flows into river over sun-warmed stones
  - Early or upstream -> cold
  - Later or downstream -> warmer
- How do you measure the temperature as a function of position and time?

2.1 Method 1:Grid

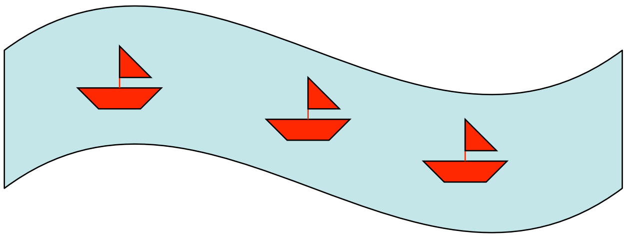
- Set up a grid $\underline{r} = (x,y)$
- Place a thermometer at each grid point -> T(x,y)
- Read the temperature throughout the day -> $T(\underline{r},t)$



- Independent variables $(\underline{r},t)$. Variation with time is partial $\partial T/\partial t$ evaluated at a fixed position.

2.2 Method 2: Boats

- Make many boats (labelled “a”)...each with a thermometer that can record temperature -> T(a,t)
- Release them at the head of the river…recover them later and read the temperature record.



- Independent variables (a,t). Time derivative (dT/dt) is at fixed a (i.e. for a given boat).

- In this case, position is not an independent variable, but instead $\underline{r} = r(a,t)$.
- This description (Lagrangian) refers to the world as seen by an observer riding on a fluid element; the grid description (Eulerian) refers to the world as seen at a fixed spatial location.

2.3 Advantages and disadvantages

- Boats/Lagrangian: useful if the behaviour of an individual element is important (usually it isn't) - e.g. if a fluid element carries with it some property that distinguishes it from its neighbours.
  - E.g put different thicknesses of wetsuit on 10 thermometers and compare their temperature records!

- Grid/Eulerian: usually more useful if motion of individual element is not of interest. Particularly good for steady flows i.e. $\partial/\partial t = 0$ everywhere (which has no special properties in Lagrangian descriptions as in a steady flow an element still changes its properties as it goes from place to place)