

Fluids – Lecture 1 Notes

1. Introductory Concepts and Definitions
2. Properties of Fluids

Reading: Anderson 1.1 (optional), 1.2, 1.3, 1.4

Introductory Concepts and Definitions

Fluid Mechanics and Fluid Dynamics encompass a huge range of topics which deal with the behavior of gasses and liquids. In UE we will focus mainly on the topic subset called Aerodynamics, with a bit of Aerostatics in the beginning.

Merriam Webster's definitions:

Aerostatics: a branch of statics that deals with the equilibrium of gaseous fluids and of solid bodies immersed in them

Aerodynamics: a branch of dynamics that deals with the motion of air and other gaseous fluids and with the forces acting on bodies in motion relative to such fluids

Related older terms are Hydrostatics and Hydrodynamics, usually used for situations involving liquids. There is surprisingly little fundamental difference between the Aero- and Hydro- disciplines. They differ mainly in the applications (e.g. airplanes vs. ships).

Difference between a Solid and a Fluid (Liquid or Gas):

Solid: Applied tangential force/area (or shear stress) τ produces a proportional deformation angle (or strain) θ .

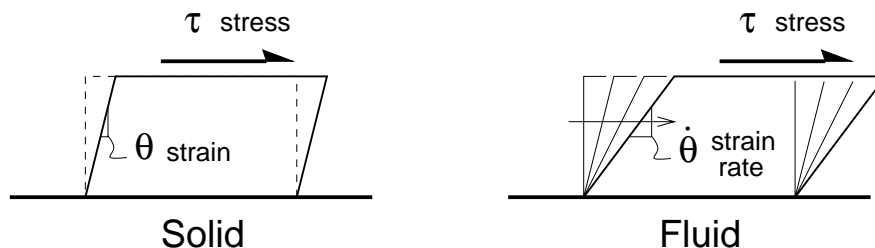
$$\tau = G\theta$$

The constant of proportionality G is called the *elastic modulus* and has the units of force/area.

Fluid: Applied shear stress τ produces a proportional continuously-increasing deformation (or strain rate) $\dot{\theta}$.

$$\tau = \mu\dot{\theta}$$

The constant of proportionality μ is called the *viscosity*, and has the units of force \times time/area.



Properties of Fluids

Continuum vs molecular description of fluid

Liquids and gases are made up of molecules. Is this discrete nature of the fluid important for us? In a liquid, the answer is clearly NO. The molecules are in contact as they slide past each other, and overall act like a uniform fluid material at macroscopic scales.

In a gas, the molecules are not in immediate contact. So we must look at the *mean free path*, which is the distance the average molecule travels before colliding with another. Some known data for air:

- Mean free path at 0 km (sea level) : 0.0001 mm
- Mean free path at 20 km (U2 flight) : 0.001 mm
- Mean free path at 50 km (balloons) : 0.1 mm
- Mean free path at 150 km (low orbit) : 1000 mm = 1m

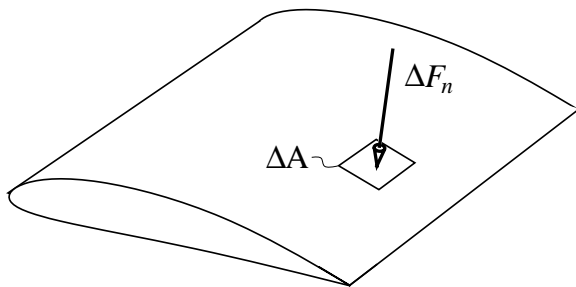
The mean free path is vastly smaller than the typical dimension of any atmospheric vehicle. So even though the lift on a wing is due to the impingement of discrete molecules, we can assume the air is a continuum for the purpose of computing this lift. In contrast, computing the slight air drag on an orbiting satellite requires treating the air as discrete isolated particles.

Pressure

Pressure p is defined as the force/area acting normal to a surface. A solid surface doesn't actually have to be present. The pressure can be defined at any point x, y, z in the fluid, if we assume that a infinitesimally small surface ΔA could be placed there at whim, giving a resulting normal force ΔF_n .

$$p = \lim_{\Delta A \rightarrow 0} \frac{\Delta F_n}{\Delta A}$$

The pressure can vary in space and possibly also time, so the pressure $p(x, y, z, t)$ in general is a time-varying scalar field.



Normal force on area element due to pressure

Density

Density ρ is defined as the mass/volume, for an infinitesimally small volume.

$$\rho = \lim_{\Delta \mathcal{V} \rightarrow 0} \frac{\Delta m}{\Delta \mathcal{V}}$$

Like the pressure, this is a point quantity, and can also change in time. So $\rho(x, y, z, t)$ is also a scalar field.

Velocity

We are interested in motion of fluids, so velocity is obviously important. Two ways to look at this:

- Body is moving in stationary fluid – e.g. airplane in flight
- Fluid is moving past a stationary body – e.g. airplane in wind tunnel

The pressure fields and aerodynamics forces in these two cases will be the same if all else is equal. The governing equations we will develop are unchanged by a *Galilean Transformation*, such as the switch from a fixed to a moving frame of reference.

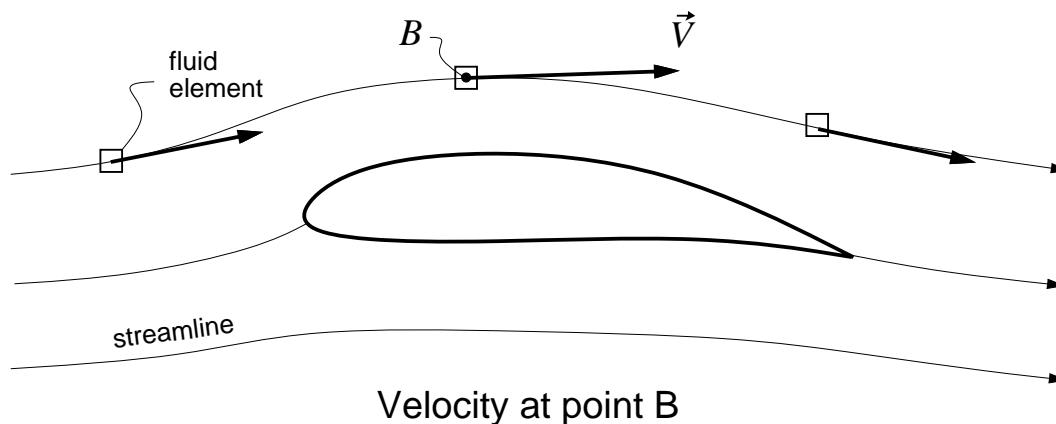
Consider a fluid element (or tiny “blob” of fluid) as it moves along. As it passes some point B, its instantaneous velocity is defined as the *velocity at point B*

\vec{V} at a point = velocity of fluid element as it passes that point

This velocity is a vector, with three separate components, and will in general vary between different points and different times.

$$\vec{V}(x, y, z, t) = u(x, y, z, t)\hat{i} + v(x, y, z, t)\hat{j} + w(x, y, z, t)\hat{k}$$

So \vec{V} is a time-varying vector field, whose components are three separate time-varying scalar fields u, v, w .



A useful quantity to define is the *speed*, which is the magnitude of the velocity vector.

$$V(x, y, z, t) = |\vec{V}| = \sqrt{u^2 + v^2 + w^2}$$

In general this is a time-varying scalar field.

Steady and Unsteady Flows

If the flow is *steady*, then p, ρ, \vec{V} don't change in time for any point, and hence can be given as $p(x, y, z), \rho(x, y, z), \vec{V}(x, y, z)$. If the flow is *unsteady*, then these quantities do change in time at some or all points.

For a steady flow, we can define a *streamline*, which is the path followed by some chosen fluid element. The figure above shows three particular streamlines.