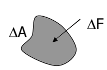
Properties

- Density, ρ
  - The measure of the mass per unit volume
  - Mathematically: $\rho = Lim_{\Delta V \to 0}\left(\frac{\Delta M}{\Delta V}\right)$
  - Units: kg/m^3 (SI)
- Specific volume, υ
  - The term "specific" implies "per unit mass".
  - Thus, "specific volume" = "volume per unit mass"
  - $\upsilon = 1/\rho$
  - Specific volume is primarily used when dealing with thermodynamics - density is preferred in most heat transfer!

Properties (continued)

- Pressure, p
  - The measure of the average momentum exchanged per unit area between a gas and a solid surface.
  - Closely related to the average momentum due to the random motion in a gas or liquid.
  - The force due to pressure always acts **normal** to the surface.



  - Mathematically: $p = Lim_{\Delta A \to 0}\left(\frac{\Delta F}{\Delta A}\right)$
  - Units: N/m^2=Pascal (SI)
  - Alternate units: lb_f/in^2, atm, bar, mm_{hg}, mm_{H20}, in_{H20}, ...

Properties (continued)

- Temperature, T
  - A tough cookie to define! Usually described in terms of energy content:
    - The measure of the average random kinetic energy per unit mass in a gas or liquid
    - A measure of the vibrational/electron energy in solids.
    - The distribution of particles within quantum energy states.
  - Best known, however, by its capacity to lead to heat transfer!
  - Units: ^oK (SI)
  - Alternate units: ^oC
    - Learn the conversion! $0^oC=273^oK$

Properties (continued)

- Equation of State/Perfect Gas Law
  - Equation expressing the relationship between ρ, p, and T
  - For a perfect gas: $p\forall = mRT$ (Perfect Gas Law)
    - Where R is the specific gas constant (specific meaning for a certain gas!).
    - But, what is a perfect gas?
  - Can also be written as $p\forall = N\mathcal{R}T$
    - Where $\mathcal{R}$ (8.314 kJ/kg-mole/°K) is the universal gas contant and N is the number of moles of a the gas.
  - Since $R = \mathcal{R} / \mathcal{M}$ ($\mathcal{M}$ = molecular weight)
    - For Oxygen, M = 32.00 kg/kg-mole => R = .2598 kJ/kg/°K
    - For Hydrogen, M = 2.016 kg/kg-mole => R = 4.124 kJ/kg/°K
    - For Air, M = 28.97 kg/kg-mole => R = .2870 kJ/kg/°K

Properties (continued)

- Velocity, V
  - A **vector** describing the direction and magnitude (speed) of motion
  - In Cartesean coordinates: $\overline{V} = u\overline{i} + v\overline{j} + w\overline{k}$
- Viscosity, μ
  - A measure of the resistance a fluid offers to a shearing velocity gradient.
  - On surfaces, a shearing gradient is created by the **no slip condition.** The resulting shearing stress, τ, due to viscosity always acts **tangent** to the surface
  - Units: kg/m/sec (SI)

Properties (continued)

- Internal energy, U
  - The energy stored in the particles themselves, I.e. random KE, rotation, vibration, chemical bonding, etc.
  - specific internal energy, u = U/m.
  - Units: U Joules u J/kg=m²/sec²
- Enthalpy, H
  - Mathematically, $H = U + P\forall$
  - Enthalpy is the sum of the internal energy and the energy associated with having brought all the particles together into a given volume of space.
  - Same units at U!
- Other properties (like entropy) to be discussed later!

Fluid Mechanics

- In order to use fluids as a working fluid, we need (as a minimum) an expression to provide for mass conservation.
- Ideally, we would also need to provide for momentum and energy conservation, but for many cases of practical interest, mass conservation suffices.
- To simplify the math, we will restrict ourselves to case of **steady flow** - thus the total mass, momentum and energy do not change at any point over time!!

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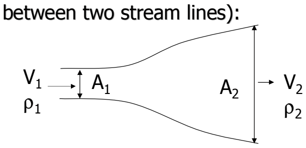
Mass Conservation

- To conserve mass, **what flows in must equal what flows out**.
- So, consider the flow through a stream tube (the region between two stream lines):



mass flow in = mass flow out

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Mass Conservation (continued)

- The mass flow rate in is: $\dot{m}_1 = \rho_1 V_1 A_1$
- The mass flow rate out is: $\dot{m}_2 = \rho_2 V_2 A_2$
- For mass conservation: $\dot{m}_1 = \dot{m}_2$ or

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2 \qquad \text{Continuity}$$

- Why call it "continuity"?
  - Well, if you didn't conserve mass, you would end up with voids in the flow. Thus, to have a continuous flow you must have mass conservation.

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Incompressible Flow

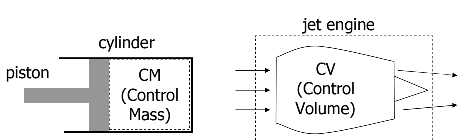
- Liquids are incompressible fluids. But **gasses are compressible fluids**, I.e. density changes under the influence of pressure.
- However, in many fluid flow situations, the changes in density are so small, accurate results can be obtained assuming ρ = constant.
- These situations are called **incompressible flow** and are typical of low speed flight (V < 100 m/sec) and no heat addition.
- For incompressible flow, the continuity equation is even simpler: $V_1A_1 = V_2A_2$

Systems and Processes

- System: a collection of things of interest to the observer.
  - Can be an entire assembly, or just a part of one.
  - Can be isolated from the surroundings but usually interacts with them.
- Closed System [Control Mass]: A collection of matter of fixed identity of interest.
  - This system can change shape or volume, but always includes the same particles.
  - Interactions with surroundings can occur via surface forces on boundaries or by body forces like gravity.

Systems and Processes

- Open System [Control Volume]: A region in space of fixed size of interest.
  - This system has a fixed volume and fixed shape.
  - Interactions with surroundings can occur via surface forces or by body forces as before, but also by matter exchange through the boundaries.



Systems and Processes (continued)

- Property: a characteristic of a system which can be measured.
  - Pressure, temperature, density are easy examples.
  - Most properties are not directly measured, but deduced from other measurements.
- State: the condition of a system as determined by the properties.
  - Or, tying these two together….
  - A property is a characteristic of a system which helps define its state.
  - Often, only a few properties are needed, like in the equation of state for gasses.

Systems and Processes (continued)

- Process: a mechanism by which the state (properties) of a system are changed.
  - Heat addition is a good example. Work, such as in compressing a gas, is another.
  - Can you think of others?
- Equilibrium: a state in which the properties do not change with time.
  - Static equilibrium: there are no processes in action.
  - Dynamic equilibrium: forward and reverse processes are equal but opposite.
  - Quasi-static equilibrium: processes occur very slowly over time such that at an one time, the system can be effectively defined as in static equilibrium.

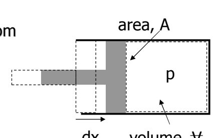
Processes - Work

- One work process is of particular importance: the work done by squeezing a fluid element against the resistance of pressure.
- Consider doing work by compressing a piston:

$$\delta W = Fdx = pAdx = -pd\forall$$

  - Thus, the total work done going from initial to final volume is:

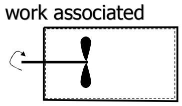
$$\int_i^f \delta W = -\int_{\forall_i}^{\forall_f} pd\forall$$



  - To compute, you would need a relation between p and ∀

Processes - Work (cont)

- The form of work expressed by $\delta W = -p\,dV$ is often called **reversible work** since the work required to compress the gas can be recovered by expanding it again.
- The term **reversible** means that the exact opposite process returns the system the original state.
- Contrast this type of work with the work associated with stirring as illustrated.
  - In this case, the motion induced by the propeller is dissipated by friction and cannot be recovered as work.
  - It requires work to turn the shaft one direction AND the other way!



propeller driven by shaft work