

Properties

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

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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: $p = \lim_{\Delta A \rightarrow 0} \left(\frac{\Delta F}{\Delta A} \right)$
- Units: $\text{N/m}^2 = \text{Pascal}$ (SI)
- Alternate units: lb_f/in^2 , atm, bar, mmHg , mmH_2O , inH_2O , ...

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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: $^{\circ}\text{K}$ (SI)
- Alternate units: $^{\circ}\text{C}$
 - Learn the conversion! $0^{\circ}\text{C} = 273^{\circ}\text{K}$

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Properties (continued)

- Equation of State/Perfect Gas Law
 - Equation expressing the relationship between p , v , and T
 - For a perfect gas: $pV = mRT$ (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 $pV = N\mathcal{R}T$
 - Where \mathcal{R} (8.314 kJ/kg-mole/°K) is the universal gas constant 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 $\Rightarrow R = .2598$ kJ/kg/°K
 - For Hydrogen, $M = 2.016$ kg/kg-mole $\Rightarrow R = 4.124$ kJ/kg/°K
 - For Air, $M = 28.97$ kg/kg-mole $\Rightarrow R = .2870$ kJ/kg/°K

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Properties (continued)

- Velocity, V
 - A **vector** describing the direction and magnitude (speed) of motion
 - In Cartesian coordinates: $\vec{V} = u\vec{i} + v\vec{j} + w\vec{k}$
- 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)

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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, $H = U + PV$
 - 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 as U !
- Other properties (like entropy) to be discussed later!

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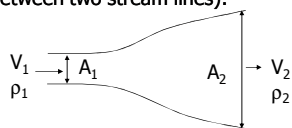
Fluid Mechanics

- 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

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

- 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 $\rho = \text{constant}$.
- These situations are called **incompressible flow** and are typical of low speed flight ($V < 100 \text{ m/sec}$) and no heat addition.
- For incompressible flow, the continuity equation is even simpler: $V_1 A_1 = V_2 A_2$

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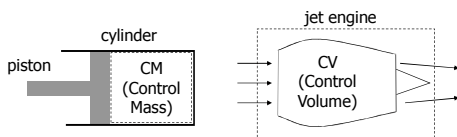
Systems and Processes

- **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.

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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.



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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.

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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.

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Processes - Work

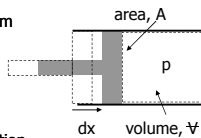
- One work process is of particular importance: the work done by squeezing a fluid element against the resistance of pressure.
- Consider doing work by compressing a piston:

$$\delta W = Fdx = pAdx = -pdV$$

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

$$\int_i^f \delta W = - \int_{V_i}^{V_f} p dV$$

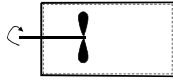
- To compute, you would need a relation between p and V



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Processes - Work (cont)

- The form of work expressed by $\delta W = -pdV$ 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

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