$\dot{m}\vec{v}_1$

$P_{1,g}A_1$

$1\ \text{slug} = 32.2\ \text{lb}_m$

$1\ \text{lb}_f = 32.2\ \frac{\text{lb}_m \cdot \text{ft}}{s^2} \rightarrow 1 = 32.2\ \frac{\text{lb}_m \cdot \text{ft}}{\text{lb}_f \cdot s^2}$

$1\ \text{lb}_f = 1\ \frac{\text{slug}\cdot\text{ft}}{s^2} \rightarrow 1 = 1\ \frac{\text{slug}\cdot\text{ft}}{\text{lb}_f\cdot s^2}$

Universal: $p\forall = n R_u T$ (per moles)

$R_u = 8.314\ \frac{J}{\text{mol}\cdot K}$

$= 1545\ \frac{\text{ft}\cdot\text{lb}_f}{\text{lb}_{mol}\cdot {}^\circ R}$

Specific: $p\forall = m R_{sp} T$

$R_{sp} = \frac{R_u}{M}$

$M = \frac{m}{n}$

${}^\circ R = {}^\circ F + 459.67$

$P_{gauge} = P_{abs} - P_{atm}$

* use P_{gauge}

$\frac{6.022\cdot 10^{23}\ \text{particles}}{\text{gram-mole}} \cdot \frac{1\ \text{gram-mole}}{g} \cdot \frac{\text{lb}_m}{\text{lb}_m\text{-mole}} \cdot \frac{1000g}{kg} \cdot \frac{1kg}{2.2\text{lb}_m} = 2.74\cdot 10^{26}\ \frac{\text{particles}}{\text{lb}_m\text{-mole}}$

$\vec{V}_{fluid/grd} = \vec{V}_{fluid/bdy} + \vec{V}_{bdy/grd}$

$\vec{V}_{abs} = \vec{V}_{rel} + \vec{V}_{boundary}$

$\int d\vec{r} = \int \vec{v}\,dt$

$\int d\vec{v} = \int \vec{a}\,dt$

$\vec{v}(t) - \vec{v}(t_0) = \int \vec{a}(t)\,dt$

sp. vol: $v = \frac{1}{\rho} = \frac{\forall}{m}$ sp. weight: $\gamma = \rho g$ sp. grav: $SG = \frac{\rho}{\rho_{ref,wat}}$

$\dot{m}_{out} = \int_A \rho(\vec{v}_{rel}\cdot\hat{n})\,dA \rightarrow \vec{P}_{transport} = \dot{m}\vec{v}_{abs} = \int_A \rho(\vec{v}_{rel}\cdot\hat{n})\vec{v}_{abs}\,dA = \rho V_{rel} V_{abs} A$

assumptions: (ρ) incomp. fluid, const. ρ | uniform velocity | flow is $\perp$ to boundary | $\vec{V}_{rel} = \vec{V}_{abs}$

$\vec{r}_G = \frac{\sum \vec{r}_i m_i}{\sum m_i} = \frac{\int \rho\vec{r}\,d\forall}{\int \rho\,d\forall}$

colm: $\frac{d}{dt}(\vec{P}_{sys}) = \sum \vec{F}_{ext} + \sum_{in} \dot{m}\vec{v} - \sum_{out} \dot{m}\vec{v}$

$\hookrightarrow$ storage: $m\frac{d\vec{v}}{dt} + \vec{v}\frac{dm}{dt}$

finite $\rightarrow \vec{P}_{sys,final} - \vec{P}_{sys,init} = \int \vec{F}_{ext}\,dt + \ldots$

$\underbrace{\quad}_{F_{av}\Delta t\ =\ \text{impulse}}$

coam: $\frac{d}{dt}(\vec{L}_{sys_o}) = \sum \vec{M}_o + \sum_{in}(\vec{r}\times\dot{m}\vec{v})_o - \sum_{out}(\vec{r}\times\dot{m}\vec{v})_o$

$\hookrightarrow$ storage: $\frac{d}{dt}(\vec{r}\times m\vec{v}) = (\vec{r}\times m\vec{a}) + (\vec{r}\times\vec{v}\frac{dm}{dt})$

$\vec{v} = \vec{r}\times\vec{\omega}$

$\vec{L} = \int_\forall (\vec{r}\times\vec{v})\rho\,d\forall = \omega\underbrace{\int_\forall r^2\rho\,d\forall}_{\text{mass moment of inertia}}$

$I = \int \rho r^2\,d\forall$; $KE_R = \frac{1}{2}I\omega^2$

$E_{sp} = \frac{1}{2}k(x-x_0)^2$

$E_{cap} = \frac{1}{2}CV^2$, $E_{ind} = \frac{1}{2}LI^2$

$\frac{d}{dt}(E_{sys}) = \dot{W}_{in,net} + \dot{Q}_{in,net} + \sum_{net} \dot{m}\left(h + \frac{v^2}{2} + gz\right)$

$x_a\ x_0\ x_b$

	$\int p\,d\forall$	W	who does work?
$\forall\downarrow$	(−)	(+)	surr. on gas
$\forall\uparrow$	(+)	(−)	gas on surrounding

$W_{sp} = \frac{1}{2}k\left[(x_b - x_0)^2 - (x_a - x_0)^2\right]$

$\dot{W}_{shaft} = \omega T$

h = sp. enthalpy $\frac{v^2}{2}$ = ke gz = pe

$W = -\int p\,d\forall$

$W = \int \vec{F}\cdot d\vec{s}$; $\dot{W} = \vec{F}\cdot\vec{v}$

$\dot{W}_{elec} = IV$

$h = u + pv \rightarrow u$ = sp int. energy

$\rightarrow pv$ = sp. flow energy $= p\left(\frac{1}{\rho}\right)$

$\dot{W}_{flow} = \dot{m}(pv) \rightarrow$ transport term

heat transfer

n	type	work
0	isobaric	$W_{in} = -p(\forall_2 - \forall_1)$
1	$p\forall$ = const.	$W_{in} = p_1\forall_1 \cdot \ln\left(\frac{\forall_1}{\forall_2}\right)$
n	Polytrophic $p\forall^n$ = const.	$W_{in} = \frac{p_2\forall_2 - p_1\forall_1}{n-1}$

Fourier's Law Conduction: $\dot{Q} = -kA\frac{dT}{dx}$ | $k = \frac{W}{m\cdot K}$ thermal conductivity

$C_v = \frac{\partial u}{\partial T}\Big|_{v=const.}$ $C_p = \frac{\partial h}{\partial T}\Big|_{P=const.}$

Newton's Cooling (convect): $\dot{Q} = hA(T_{surf} - T_\infty)$ | $h = \frac{W}{m^2 K}$ heat transfer coeff.

Stefon Boltzmann (radiat.): $\dot{Q} = \varepsilon\sigma A_s(T_{surf}^4 - T_{surr}^4)$ | $0 \le \varepsilon \le 1 \rightarrow$ emissivity

$\sigma = 5.67\cdot 10^{-8}\ \frac{W}{m^2 K^4}$

incompressible: $u_2 - u_1 = C_v(T_2 - T_1)$; $h_2 - h_1 = u_2 - u_1 + v(P_2 - P_1)$; $C_p = C_v$

ideal gases: $u_2 - u_1 = C_v(T_2 - T_1)$; $h_2 - h_1 = C_p(T_2 - T_1)$; $C_p = C_v + R_{sp}$

power cycle thermal efficiency: $\eta = \frac{\text{want}}{\text{provide}} = \frac{W_{out} - W_{in}}{Q_{in}}$ $0 \le \eta \le 1$

Kelvin plank: Q_{in}, $W_{out,net}$, Q_{out} $\rightarrow$ have to have Q_{out}

refridgeration: cop $= \frac{Q_{in}}{W_{in} - W_{out}} \ge 1$

Clausius: $T_C \rightarrow T_H \rightarrow$ impossible w/o W_{in}

heat pump: cop $= \frac{Q_{out}}{W_{in} - W_{out}}$

$S_{sys} = \sum_i m_i s_i = \int \rho s\,d\forall$

$\dot{S}_{gen} \rightarrow < 0$ = impossible

$= 0 \rightarrow$ ideal

$> 0 \rightarrow$ possible

Power Cycle: $\eta = 1 - \frac{Q_{out}}{Q_{in}} = 1 - \left(\frac{T_c}{T_H} + \frac{T_c S_{gen}}{Q_{in}}\right) = 1 - \frac{T_c}{T_H}$ if $\dot{S}_{gen} = 0$ best case

$\frac{d}{dt}(S_{sys}) = \sum_{in,net} \frac{\dot{Q}}{T_b} + \sum_{net} \dot{m}s + \dot{S}_{gen}$

(closed, SS)

$\dot{S}_{gen} = \dot{Q}\left(\frac{1}{T_c} - \frac{1}{T_h}\right)$

Refridgeration: cop $= \frac{1}{\frac{Q_{out}}{Q_{in}} - 1} = \frac{T_c}{T_H - T_c + \frac{T_H T_c S_{gen}}{Q_{in}}} = \frac{T_c}{T_H - T_c}$ if $\dot{S}_{gen} = 0$

Heat Pump: $= \frac{T_H}{T_H - T_c}$ for heat pump

$Tds = du + pdv$

$Tds = dh - vdp$

ideal gas: $s_2 - s_1 = C_v\ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{v_2}{v_1}\right)$ $\xrightarrow{\text{isentropic}}$ $\frac{T_2}{T_1} = \left(\frac{v_2}{v_1}\right)^{1-k}$ or $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$

$s_2 - s_1 = C_p\ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)$ $(s_2 - s_1 = 0)$ or $p_1 v_1^k = p_2 v_2^k$, where $k = \frac{C_p}{C_v}$ $k_{air} \approx 1.4$

incompressible: $s_2 - s_1 = C_v\ln\left(\frac{T_2}{T_1}\right)$ $T_2 = T_1$ (incompressible)

isentropic: adiabatic/reversible: $0 = \dot{m}(s_{in} - s_{out})$