ME407 THERMODYNAMICS II

FORMULA SHEET

Entropy

$\Delta S = S_2 - S_1 = \oint \frac{\delta Q}{T} \le 0$ $\Delta S = \frac{Q}{T_0}$ $\Delta S_{System} = S_2 - S_1 = m(s_2 - s_1)$ $\Delta S_{environment} = \sum \frac{Q}{T_R}$

$\dot{S}_{Generated=\dot{m}}(s_2 - s_1) + \frac{\dot{Q}_{environment}}{T_{environment}} \ge 0$ $S_{gen} = \sum \dot{m} s_{exit} - \sum \dot{m} s_{inlet} + \frac{Q_{env}}{T_0}$ $S_{gen} = (s_2 - s_1)_{CV} + \sum \dot{m} s_{exit} - \sum \dot{m} s_{inlet} + \frac{Q_{env}}{T_0}$

Phase change of incompressible substances: $s_2 - s_1 = C_{avg} \ln \frac{T_2}{T_1}$

Phase change of Ideal Gases (*constant* specific heats)

$$s_2 - s_1 = C_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1} \qquad s_2 - s_1 = C_P \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}$$

Isentropic Phase Change:

$$\left(\frac{T_2}{T_1}\right)_{s=const} = \left(\frac{v_1}{v_2}\right)^{k-1} \qquad \left(\frac{T_2}{T_1}\right)_{s=const} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} \qquad \left(\frac{p_2}{p_1}\right)_{s=const} = \left(\frac{v_1}{v_2}\right)^{k}$$

Phase change of Ideal Gases (*variable* specific heats)

Any Phase Change: $s_2 - s_1 = \dot{s}_2 - \dot{s}_1 - R \ln \frac{p_2}{p_1}$

Isentropic Phase Change: $\dot{s}_2 = \dot{s}_1 + R \ln \frac{P_2}{P_1}$ $\left(\frac{P_2}{P_1}\right)_{s=const} = \frac{P_{r2}}{p_{r1}}$ $\left(\frac{v_2}{v_1}\right)_{s=const} = \frac{v_{r2}}{v_{r1}}$

Isentropic Flow Work (v=const.) $W = v(P_1 - P_2) - \Delta ke - \Delta pe$

Isentropic Work: $w = \frac{kR(T_1 - T_2)}{k-1} = \frac{kRT_1}{k-1}\left[1 - \left(\frac{p_2}{p_1}\right)^{(k-1)/k}\right]$

Polytropic Work: $w = \frac{nR(T_1 - T_2)}{n-1} = \frac{nRT_1}{n-1}\left[1 - \left(\frac{p_2}{p_1}\right)^{(n-1)/n}\right]$

Isothermal Work: $w = RT \ln \frac{p_1}{p_2}$

Turbine Isentropic (Adiabatic) Efficiency:

$\eta_T = \frac{w}{w_s}$ $\eta_{T\cong} \frac{h_1 - h_2}{h_1 - h_{2s}}$

Turbine Isentropic (Adiabatic) Efficiency:

$\eta_K = \frac{w_s}{w}$ $\eta_{K\cong} \frac{h_{2S} - h_1}{h_2 - h_1}$

Nozzle Isentropic (Adiabatic) Efficiency: $\eta_N = \frac{h_1 - h_2}{h_1 - h_{2s}}$ Useful Work: $w_y = w - w_{env} = w - P_0(v_2 - v_1)$

Irreversibility: $I = W_{tr} - W_y = T_0 S_{gen}$ $i = w_{tr} - w_y = T_0 s_{gen}$ $\dot{I} = T_0 \dot{S} = T_0\left(\sum \dot{m}_ç s_ç - \sum \dot{m}_g s_g + \frac{\dot{Q}_R}{T_R}\right)$ $i = T_0\left(\frac{q_ç}{T_l} - \frac{q_q}{T_H}\right)$

Second-law Efficiency: $\eta_{II} = \frac{\eta_{th}}{\eta_{th,tr}} = \frac{W_Y}{W_{tr}}$ $\eta_{II} = \frac{COP}{COP_{tr}} = \frac{W_{tr}}{W_y}$

Nonflow Exergy of a System: $\phi = (u - u_0) - T_0(s - s_0) + P_0(v - v_0)$

Flow Exergy of a System: $\psi = (h - h_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$

Reversible Work: $W_{rev} = \eta_{th,rev} Q_H$ $-W_{rev} = \frac{O_L}{COP_{R,rev}}$ $-W_{rev} = \frac{Q_H}{COP_{HP,rev}}$

Reversible Work in Closed Systems: $W_s = (U_1 - U_2) - T_0(S_1 - S_2) + P_0(V_1 - V_2) = m(\phi_1 - \phi_2)$

Reversible Work in Single-input Single-output (SISO)

$$\dot{W}_{th} = \dot{m}\left[(h_i - h_e) - T_0(s_i - s_e) + \frac{V_i^2 - V_e^2}{2} + g(z_i - z_e)\right] = \dot{m}(\psi_i - \psi_e)$$

Carnot Efficiency: $\eta_{th,Carnot} = 1 - \frac{T_l}{T_H}$ Compression Ratio: $r = \frac{V_{BDC}}{V_{TDC}}$

Mean Effective Pressure: $MEP = \frac{w_{net,out}}{v_{\max} - v_{\min}}$

$\eta_{th,otto} = 1 - \frac{1}{r^{k-1}}$ $\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$ $r_c = \frac{v_3}{v_2}$ $\eta_{th,Brayton} = 1 - \frac{1}{r_p^{(k-1)/k}}$

Regenerator Efficiency: $\varepsilon = \frac{q_{regen,actual}}{q_{regen,\max}}$ $r_p = \frac{P_2}{P_1}$ $\eta_{th,regen} = 1 - \left(\frac{T_1}{T}\right)(r_p)^{(k-1)/k}$

Net Thrust: $F = \dot{m}(V_e - V_i)$ Propulsive Power: $\dot{W}_P = \dot{m}(V_e - V_i)V_{aircraft}$ Propulsive Efficiency: $\eta_P = \frac{\dot{W}_P}{\dot{Q}_{in}}$

Coefficient of Performance of a Gas Refrigeration System: $COP_R = \frac{q_L}{w_{net,g}} = \frac{q_L}{w_{k,g} - w_t}$

Coefficient of Performance of an Absorption Refrigeration System: $COP_{R,rev} = \frac{Q_L}{Q_{gen} + W_{pump}}$

Enthalpy Change of Air: $\Delta h_{dryair} = C_p \Delta T = [1{,}005 kJ/(kg.^0C)]\Delta T$

Specific Humidity: $w = \frac{m_v}{m_a} = \frac{0{,}622 P_v}{P - P_v}$ (kg water vapor/kg air) $\phi = \frac{wP}{(0{,}622 + w)P_g}$

Relative Humidity: $\phi = \frac{m_v}{m_g} = \frac{P_v V/(R_v T)}{P_g V/(R_v T)} = \frac{P_v}{P_g}$ $P_g = P_{sat,T}$ $h = C_p T + w h_g$

Mass of Dry Air: $\sum \dot{m}_{a,input} = \sum \dot{m}_{a,exit}$ Water Mass: $\sum \dot{m}_{a,g} w_g + \dot{m}_{su,g} = \sum \dot{m}_{a,ç} w_ç + \dot{m}_{su,ç}$

Energy: $\dot{\theta} - W = \sum \dot{m}_{exit} h_{exit} - \sum \dot{m}_{input} h_{input}$