FORMULAE SHEET

<u>Fundamentals of Engine Design and Operating Parameters</u>

Displacement/Swept volume, V_s

$$V_s = \frac{\pi B^2}{4} L$$

Compression ratio, Cr

$$Cr = \frac{V_s + V_c}{V_c}$$

Average/mean piston speed, S_p

$$S_p = 2LN$$

Torque, T

$$T = \frac{W_b}{2\pi\, n_R}$$

Brake power, $\dot{W}_b$

$$\dot{W}_b = 2\pi NT \qquad \dot{W}_b = \frac{W_b N}{n_R}$$

Mean effective pressure (mep) measures

$$imep_{\text{gross}} = \frac{W_{c,ig}}{(nV_s)} \qquad bmep = \frac{W_b}{(nV_s)} \qquad imep_{\text{net}} = \frac{W_{c,in}}{(nV_s)} \qquad pmep = \frac{W_p}{(nV_s)}$$

Gross indicated Specific fuel consumption

$$\text{gross isfc} = \frac{\dot{m}_f}{\dot{W}_{i,g}} \qquad \text{gross isfc} = \frac{1}{\eta_f Q_{LHV}}$$

Mechanical efficiency

$$\eta_m = \frac{\dot{W}_b}{\dot{W}_{i,g}} = \frac{isfc}{bsfc}$$

Combustion efficiency

$$\eta_c = \frac{Q_{in}}{m_f Q_{LHV}}$$

Thermal efficiency

$$\eta_{i,g} = \frac{W_{c,ig}}{Q_{in}} \qquad \eta_{i,g} = \frac{W_{c,ig}}{\eta_c m_f Q_{LHV}}$$

Fuel conversion efficiency

$$\eta_f = \frac{W_{c,ig}}{m_f Q_{LHV}} \qquad \eta_{i,g}\eta_c = \frac{W_{c,ig}}{m_f Q_{LHV}} = \eta_f \qquad \eta_f = \frac{\dot{W}_{c,ig}}{\dot{m}_f Q_{LHV}}$$

Air fuel ratio (AFR) and fuel air ratio (FAR)

Air/fuel ratio (AFR) = $\frac{m_a}{m_f} = \frac{\dot{m}_a}{\dot{m}_f}$ Fuel/air ratio (FAR) = $\frac{m_f}{m_a} = \frac{\dot{m}_f}{\dot{m}_a} = \frac{1}{\text{AFR}}$

Equivalence ratio, ϕ and lambda, λ

$$\phi = \frac{(\text{AFR})_{\text{stoich}}}{(\text{AFR})_{\text{actual}}} = \frac{(\text{FAR})_{\text{actual}}}{(\text{FAR})_{\text{stoich}}} \qquad \lambda = \frac{1}{\phi} = \frac{(\text{AFR})_{\text{actual}}}{(\text{AFR})_{\text{stoich}}} = \frac{(\text{FAR})_{\text{stoich}}}{(\text{FAR})_{\text{actual}}}$$

Volumetric efficiency for a four stroke

$$\eta_v = \frac{\dot{m}_a}{\rho_a (nV_s) N/2}$$

Engine Cyclic Analysis

Ideal gas for air-standard engine cycles

$PV = mRT$ or $Pv = RT \ (v = V/m)$ or $P = \rho RT \ (v = 1/\rho)$

$dh = c_p \, dT$ $\quad du = c_v \, dT$ $\quad c_v = \dfrac{R}{(\gamma - 1)}$ $\quad c_p = \dfrac{\gamma R}{(\gamma - 1)}$

For perfect gas undergoing isentropic processes

$$P_1 v_1^{\gamma} = P_2 v_2^{\gamma} \qquad \left(\frac{v_2}{v_1}\right) = \left(\frac{T_2}{T_1}\right)^{\frac{1}{1-\gamma}} = \left(\frac{T_2}{T_1}\right)^{-\frac{1}{\gamma-1}} \qquad \frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

where γ is the ratio of specific heats.

Gas Exchange Processes

For the analysis of a supercharger and the compressor of a turbocharger

$$(\eta_m) = \frac{P_{actual}}{P_{engine\ to\ compressor}} \qquad (\eta_{overall}) = (\eta_m)(\eta_{isen})$$

$$(\eta_{isen}) = \left(\frac{P_{isen}}{P_{actual}}\right) = \frac{\dot{m}_a (h_{2s} - h_1)}{\dot{m}_a (h_{2A} - h_1)} = \frac{\dot{m}_a c_p (T_{2s} - T_1)}{\dot{m}_a c_p (T_{2A} - T_1)} \quad \text{where } T_{2s} = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{(\gamma-1)}{\gamma}}$$

For the analysis of the turbine of a turbocharger

$$(\eta_{isen}) = \left(\frac{P_{actual}}{P_{isen}}\right) = \frac{\dot{m}_{ex} c_p (T_1 - T_{2A})}{\dot{m}_{ex} c_p (T_1 - T_{2S})} = \frac{(T_1 - T_{2A})}{(T_1 - T_{2S})}$$

For the analysis of the entire turbocharger configuration

$$(\eta_m) = \left(\frac{P_{compressor}}{P_{turbine}}\right)_{actual} \qquad (\eta_{overall})_{tc} = (\eta_m)(\eta_{isen})_{compressor} (\eta_{isen})_{turbine}$$

Combustion

Net rate of heat release per crank angle degree for diesel engine

$$\frac{dQ_n}{d\theta} = \frac{\gamma}{\gamma - 1} p \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dp}{d\theta}$$

Wiebe function

$$x_b = 1 - \exp\left[-a \left(\frac{\theta - \theta_s}{\theta_o} \right)^n \right]$$