Conversioni

$$1slug = \frac{1lbf}{ft/s^2} = \frac{1lbm \cdot g}{ft/s^2} = 32.17lbm = 14.593kg$$

$$g = 9.807\frac{m}{s^2} = 9.807\frac{\frac{1}{0.3048}ft}{s^2} = 32.175\frac{ft}{s^2}$$

$$[\rho g] = \frac{lbf}{ft^3} = \frac{g \cdot 0.45359kg}{(.3048)^3 m^3} = g \cdot 16.02\frac{kg}{m^3}$$

$$1psi = 1\frac{lbf}{in^2} = 1\frac{lbm \cdot g}{ft^2/12^2} = 4632\frac{lbm}{ft \cdot s^2} = 4632\frac{.45359kg}{.3048m \cdot s^2} = 6895 = N$$

$$1BTU = 1Cal\ \frac{lbm \cdot R}{kg \cdot K} = 1kCal\ \frac{.45359}{1.8} = 4186.8 \cdot \frac{.45359}{1.8}J = 1055.1J$$

$$1hp = 550ft \cdot \frac{lbf}{s} = 550 \cdot 0.3048m \cdot 0.45359 \cdot \frac{kg}{s} \cdot g = 745.6W$$

$$xF = (x + 459.67)R = (x + 459.67)/1.8K = (x/1.8 + 255.37)K$$

$$\mathrm{x}F = (x - 32)/1.8C = [(x - 32)/1.8 + 273.15]K$$

Le unità di misura del **consumo specifico** (**TSFC** Thrust Specific Fuel Consumption) sono normalmente:

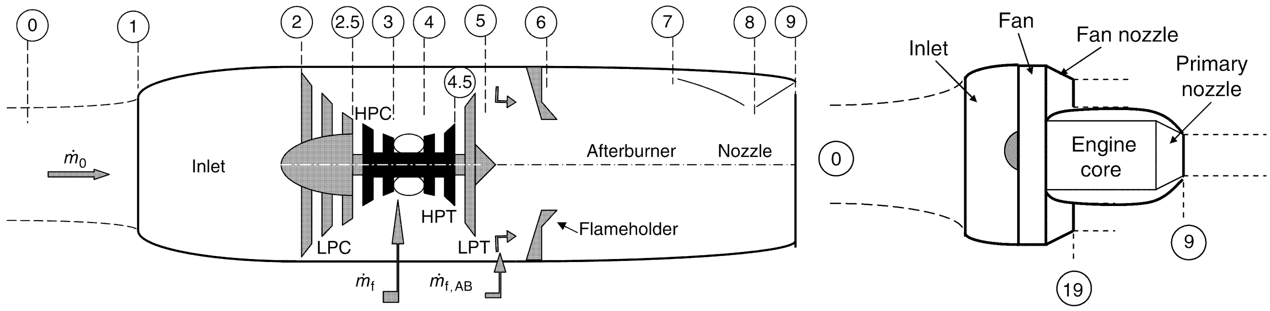
$$\left[TSFC = \frac{\dot{m}_f}{F}\right] = \frac{lbm}{hr \cdot lbf} = \frac{lbm}{3600s \cdot 1lbm \cdot 32.17ft/s^2} = \frac{1}{115830}\frac{s}{ft} = \frac{1}{115830}\frac{s}{0.3048m}$$
$$= \frac{1}{34305}\frac{s}{m} = \frac{1}{34305}\frac{10^6 mg}{s \cdot kg \cdot m/s^2} = 28.325\frac{mg}{s \cdot N}$$

$$\left[TSFC = \frac{\dot{m}_f}{F}\right] = \frac{mg}{s \cdot N} = \frac{g}{s \cdot kN} = \frac{10^3 mg}{s \cdot kN} = \frac{10^{-6}kg}{s \cdot N}$$

Le unità di misura del calorifico del combustibile (fuel heating value) sono:

$$[Q_R] = \frac{BTU}{lbm} = \frac{1055.1J}{lbm} = \frac{1055.1kg \cdot m^2}{lbm \cdot s^2} = \frac{\frac{1055.1}{0.3048^2}ft^2}{.45359 \cdot s^2} = 25038\frac{ft^2}{s^2} = 25038\frac{(0.3048m)^2}{s^2}$$
$$= 2326.1\frac{m^2}{s^2} = 2326.1\frac{J}{kg} = 2.3261\frac{kJ}{kg}$$

Formule PA2



$$f = \frac{\dot{m}_f}{\dot{m}_0}$$

Uninstalled thrust $F_u = \dot{m}_9 V_9 - \dot{m}_0 V_0 + (p_9 - p_0)A_9$

Turbo Fan $F_u = \dot{m}_9 V_9 + \dot{m}_{19} V_{19} - \dot{m}_0 V_0 + (p_9 - p_0)A_9 + (p_{19} - p_0)A_{19}$

Gross thrust: $F_g = \dot{m}_9 V_9 + (p_9 - p_0)A_9$

Internal thrust: $F_e = I_9 - I_1 = \dot{m}_9 V_9 + (p_9 - p_0)A_9 - (\dot{m}_1 V_1 + (p_1 - p_0)A_1)$

Installed thrust: $F_i = \dot{m}_9 V_9 - \dot{m}_0 V_0 + (p_9 - p_0)A_9 - \int_1^9 \tau_w dAx - \int_0^9 (p - p_0) dA_x$

Additive drag $D_{add} = \dot{m}_1 V_1 + (p_1 - p_0)A_1 - \dot{m}_0 V_0 = \int_0^1 (p - p_0) dA_x$

Efective exhaust velocity: $c = \frac{F_r}{\dot{m}_p} = V_9 + \frac{(p_9 - p_0)A_9}{\dot{m}_p}$

Specfic thrust: $\frac{F}{\dot{m}_0}\left[\frac{Ns}{kg}\right]$ o $\frac{F}{\dot{m}_0 a_0}$

TSFC: $\frac{\dot{m}_f}{F}\left[\frac{kg}{kNs}\right] \rightarrow \frac{\dot{m}_f a_0}{F}$ or for rockets $\frac{\dot{m}_p}{F} = \frac{\dot{m}_f + \dot{m}_{ox}}{F} \rightarrow \frac{\dot{m}_p a_0}{F}$

Specific impulse: $I_s = \frac{F}{g_0 \dot{m}_f} = \frac{1}{g_0 TSFC}[s]$ or for rockets $I_s = \frac{F}{g_0 \dot{m}_p} = \frac{1}{g_0 TSFC}[s]$

Thermal efficiency: $\eta_{th} = \frac{\Delta K\dot{E}}{\mathcal{P}_t} = \frac{(1+f)V_9^2 - V_0^2}{2 f Q_R}$ or for turbofan $\eta_{th} = \frac{\frac{\dot{m}_9 V_9^2}{2} + \frac{\dot{m}_{19} V_{19}^2}{2} - \frac{\dot{m}_0 V_0^2}{2}}{\dot{m}_f Q_R}$ or for turboprop $\eta_{th} = \frac{\Delta K\dot{E} + \mathcal{P}_s}{\dot{m}_f Q_R}$

Propulsive efficiency: $\eta_p = \frac{F_i V_0}{\Delta K\dot{E}} \cong \frac{2}{1 + \frac{V_9}{V_0}}$ or for turboprop $\eta_p = \frac{F_i V_0}{\Delta K\dot{E} + \mathcal{P}_s} \cong \frac{F_i V_0}{\mathcal{P}_s}$ or for rockets $\eta_p = \frac{FV}{FV + \dot{m}_p (c - V)^2/2} = \frac{2\frac{V}{c}}{1 + \left(\frac{V}{c}\right)^2}$

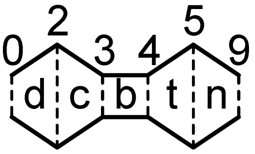
Overall efficiency: $\eta_0 = \eta_p \eta_{th} = \frac{F_i V}{\dot{m}_f Q_R}$ or for rockets $\eta_0 = \frac{F_i V}{\dot{m}_p Q_R + \dot{m}_p \left(v_{inj}^2\right)/2} \cong \frac{cV}{Q_R}$

Formule PA3-4

$k = \frac{\gamma - 1}{\gamma}$ $\psi = 1 + \frac{\gamma - 1}{2} M^2 = \frac{T_t}{T} = \frac{h_t}{h}$ $\theta = \frac{h_t}{h_0}$ $\tau_\lambda = \theta_t = \theta_4 = \frac{h_{t4}}{h_0} = c_{pt} \frac{T_{t4}}{c_p T_0}$

$\tau_r = \frac{h_{t0}}{h_0}$ $\tau_d = \frac{h_{t2}}{h_{t0}}$ $\tau_c = \frac{h_{t3}}{h_{t2}}$ $\tau_b = \frac{h_{t4}}{h_{t3}}$ $\tau_t = \frac{h_{t5}}{h_{t4}}$ $\tau_n = \frac{h_{t9}}{h_{t5}}$

$\pi_r = \frac{p_{t0}}{p_0}$ $\pi_d = \frac{p_{t2}}{p_{t0}}$ $\pi_c = \frac{p_{t3}}{p_{t2}}$ $\pi_b = \frac{p_{t4}}{p_{t3}}$ $\pi_t = \frac{p_{t5}}{p_{t4}}$ $\pi_n = \frac{p_{t9}}{p_{t5}}$



$$\pi_r = \frac{p_{t0}}{p_0} = \left(1 + \frac{\gamma - 1}{2} M_0^2\right)^{1/k} = \psi^k$$

$$\eta_d = \frac{h_{t2s} - h_0}{h_{t2} - h_0} = \frac{\left(\frac{p_{t2s}}{p_0}\right)^k - 1}{\tau_r - 1} = \frac{\left(\frac{p_{t2}}{p_0}\right)^k - 1}{\frac{\gamma - 1}{2} M_o^2} \qquad \frac{p_{t2}}{p_0} = \left(1 + \eta_d \frac{\gamma - 1}{2} M_0^2\right)^{1/k}$$

$$\pi_d = \frac{p_{t2}}{p_0} \frac{p_0}{p_{t0}} = \left(\frac{1 + \eta_d \frac{\gamma - 1}{2} M_0^2}{1 + \frac{\gamma - 1}{2} M_0^2}\right)^{1/k} = \frac{\left(1 + \eta_d \frac{\gamma - 1}{2} M_0^2\right)^{1/k}}{\pi_r}$$

$$\pi_c = \left(\frac{T_{t3}}{t_{t2}}\right)^{\frac{e_c}{k}} = \tau_c^{\frac{e_c}{k}} \qquad \tau_c = \pi_c^{\frac{k}{e_c}} \qquad \eta_c = \frac{h_{t3s} - h_{t2}}{h_{t3} - h_{t2}} = \frac{\pi_c^k - 1}{\tau_c - 1} = \frac{\pi_c^k - 1}{\pi_c^{\frac{k}{e_c}} - 1}$$

$\pi_b \approx 1 - \epsilon \frac{\gamma}{2} M_b^2$ $\epsilon \sim 2$ $\dot{m}_4 = (1 + f)\dot{m}_0$

$h_{t3} + f Q_R \eta_b = (1 + f) h_{t4} \rightarrow f = \frac{h_{t4} - h_{t3}}{Q_R \eta_b - h_{t4}}$ $f = \frac{\tau_\lambda - \tau_c \tau_r}{Q_R \eta_b / h_0 - \tau_\lambda}$ $\tau_b = \frac{h_{t4}}{h_{t3}} = \frac{\tau_\lambda}{\tau_r \tau_c}$

$\pi_t = \tau_t^{\frac{1}{k_t e_t}}$ $\tau_t = \pi_t^{k_t e_t}$ $\eta_t = \frac{h_{t4} - h_{t5}}{h_{t4} - h_{t5s}} = \frac{1 - \tau_t}{1 - \pi_t^{k_t}}$ $\tau_t = 1 - \frac{(\tau_c - 1)\tau_r}{\eta_m (1 + f) \tau_\lambda}$

$$\eta_n = \frac{\left(\frac{p_{t7}}{p_9}\right)^{k_9} - \pi_n^{-k_9}}{\left(\frac{p_{t7}}{p_9}\right)^{k_9} - 1} = \frac{\left(NPR \frac{p_0}{p_9}\right)^{k_9} - \pi_n^{-k_9}}{\left(NPR \frac{p_0}{p_9}\right)^{k_9} - 1}$$

Ciclo reale turbojet

$$\frac{F_u}{\dot{m}_0} = (1+f)V_9 - V_0 + \frac{(p_9 - p_0)A_9}{\dot{m}_0} = (1+f)V_9\left[1 + \frac{1}{\gamma_9 M_9^2}\left(1 - \frac{p_0}{p_9}\right)\right] - V_0$$

$$\frac{F_u}{\dot{m}_0 a_0} = (1+f)\frac{V_9}{a_0}\left(1 + \frac{1 - \frac{p_0}{p_9}}{\gamma_9 M_9^2}\right) - M_0$$

$$\frac{V_9}{a_0} = \frac{M_9 a_9}{a_0} = M_9\sqrt{\frac{\gamma_9 R_9 T_9}{\gamma R T_0}} \qquad M_9^2 = \frac{2}{\gamma_9 - 1}\left[\left(\frac{p_{t9}}{p_9}\right)^{k_9} - 1\right] \qquad \frac{p_{t9}}{p_9} = \pi_n \pi_t \pi_b \pi_c \pi_d \pi_r \frac{p_0}{p_9}$$

$$\frac{T_9}{T_0} = \frac{T_9}{T_{t9}}\frac{T_{t9}}{T_0} = \frac{\theta_9}{\left(\frac{p_{t9}}{p_9}\right)^{k_t}} \qquad \theta_9 = \frac{T_{t9}}{T_{t5}}\tau_t \frac{T_{t4}}{T_{t0}} = \tau_t \tau_\lambda \frac{c_p}{c_{pt}}$$

$$f = \frac{\tau_\lambda - \tau_c \tau_r}{Q_R \eta_b/(c_p T_0) - \tau_\lambda} \qquad \tau_b = \frac{\tau_\lambda}{\tau_c \tau_r}$$

$$\tau_t = 1 - \frac{(\tau_c - 1)\tau_r}{\eta_m (1+f)\tau_\lambda} \qquad \pi_t = \tau_t^{\frac{1}{k_t e_t}} \qquad \tau_c = \pi_c^{\frac{k}{e_c}}$$

$$\tau_r = \theta_0 = \frac{T_{t0}}{T_0} = \psi_0 \qquad \pi_d = \left(\frac{1 + \eta_d \frac{\gamma - 1}{2} M_0^2}{1 + \frac{\gamma - 1}{2} M_0^2}\right)^{1/k}$$

$$\eta_t = \frac{1 - \tau_t}{1 - \tau_\tau^{\frac{1}{e_t}}} \qquad \eta_c = \frac{\pi_c^k - 1}{\tau_c - 1} \qquad TSFC = \frac{f}{F_u/\dot{m}_0}$$

$$\eta_{th} = \frac{\Delta K\dot{E}}{\mathcal{P}_t} = \frac{(1+f)V_9^2 - V_0^2}{2 f Q_R} = \frac{a_0^2[(1+f)(V_9/a_0)^2 - M_0^2]}{2 f Q_R}$$

$$\eta_p = \frac{F_i V_0}{\Delta K\dot{E}} \approx \frac{2 F_u V_0/\dot{m}_0}{a_0^2[(1+f)(V_9/a_0)^2 - M_0^2]}$$

$$V_{9.e} = V_9\left[1 + \frac{1 - \frac{p_0}{p_9}}{\gamma_9 M_9^2}\right]$$

Ciclo ideale turbojet

$\gamma_9 = \gamma \quad \tau_t = \pi_t^{k_t} \quad \tau_c = \pi_c^k \quad \pi_d = \pi_n = \pi_b = 1$

$\dot{m}_0 \approx \dot{m}_9 \quad \rightarrow \quad 1 + f \rightarrow 1 \quad p_9 = p_0$

$$\eta_{th} = 1 - \frac{1}{\tau_c \tau_r} = 1 - \frac{1}{\pi_c^k \left(1 + \frac{\gamma - 1}{2} M_0^2\right)} \quad \pi_{c.max.F} = \left(\frac{\sqrt{\tau_\lambda}}{1 + \frac{\gamma - 1}{2} M_0^2}\right)^k$$

$$\tau_r = \psi_0 = 1 + \frac{\gamma - 1}{2} M_0^2 \quad \tau_t = 1 - \frac{(\tau_c - 1)\tau_r}{\tau_\lambda}$$

$$M_9^2 = \frac{2}{\gamma - 1}\left[(\pi_t \pi_c \pi_r)^k - 1\right] = \frac{2}{\gamma - 1}(\tau_t \tau_c \tau_r - 1)$$

$$\frac{T_9}{T_0} = \frac{\tau_\lambda}{\tau_c \tau_r} = \tau_b$$

$$\frac{F_u}{\dot{m}_0 a_0} = \frac{V_9}{a_0} - M_0 = \sqrt{\frac{2}{\gamma - 1}\frac{\tau_\lambda}{\tau_c \tau_r}(\tau_t \tau_c \tau_r - 1)} - M_0 = \sqrt{\frac{2}{\gamma - 1}\tau_r(\tau_b - 1)(\tau_c - 1) + \tau_b M_0^2} - M_0$$

$$f = \frac{c_p T_0}{Q_R}(\tau_\lambda - \tau_c \tau_r) \quad \tau_b = \frac{\tau_\lambda}{\tau_c \tau_r}$$

$$TSFC = \frac{f}{F_u / \dot{m}_0} = \frac{\frac{c_p T_0}{a_0 Q_R}(\tau_\lambda - \tau_c \tau_r)}{\sqrt{\frac{2}{\gamma - 1}\tau_r(\tau_b - 1)(\tau_c - 1) + \tau_b M_0^2} - M_0}$$

Post bruciatore

$$\frac{F_u}{\dot{m}_0 a_0} = (1+f+f_{AB})\frac{V_9}{a_0}\left(1+\frac{1-\frac{p_0}{p_9}}{\gamma_9 M_9^2}\right) - M_0 \qquad f_{AB} = \frac{(1+f)(\tau_{\lambda.AB} - \tau_\lambda \tau_t)}{\frac{Q_{R.AB}\eta_{AB}}{c_p T_0} - \tau_{\lambda.AB}}$$

$$\frac{V_9}{a_0} = \frac{M_9 a_9}{a_0} = M_9\sqrt{\frac{\gamma_9 R_9 T_9}{\gamma R T_0}} \qquad M_9^2 = \frac{2}{\gamma_9 - 1}\left[\left(\frac{p_{t9}}{p_9}\right)^{k_9} - 1\right] \qquad \frac{T_9}{T_0} = \frac{T_9}{T_{t9}}\frac{T_{t9}}{T_0} = \frac{\tau_{\lambda.AB}}{\left(\frac{p_{t9}}{p_9}\right)^{k_9}}$$

$$\frac{p_{t9}}{p_9} = \pi_n \pi_{AB} \pi_t \pi_b \pi_c \pi_d \pi_r \frac{p_0}{p_9}$$

$$TSFC = \frac{f+f_{AB}}{F_u/\dot{m}_0}$$

$$\eta_{th} = \frac{\Delta K\dot{E}}{\mathcal{P}_t} = \frac{(1+f+f_{AB})V_9^2 - V_0^2}{2(f+f_{AB})Q_R} = \frac{a_0^2[(1+f+f_{AB})(V_9/a_0)^2 - M_0^2]}{2(f+f_{AB})Q_R}$$

$$\eta_p = \frac{F_i V_0}{\Delta K\dot{E}} \approx \frac{2F_u V_0/\dot{m}_0}{a_0^2[(1+f+f_{AB})(V_9/a_0)^2 - M_0^2]}$$

Post bruciatore caso ideale

$$\eta_{AB} = \qquad \tau_t = \pi_t^{k_t} \qquad \tau_c = \pi_c^k \qquad \pi_{AB} = 1 \quad \dot{m}_0 \approx \dot{m}_9 \ \to 1+f+f_{AB} \to 1 \qquad p_9 = p_0$$

$$f = \frac{\tau_\lambda - \tau_c\tau_r}{\frac{Q_R}{c_p T_0}} \qquad f_{AB} = \frac{\tau_{\lambda AB} - \tau_\lambda\tau_t}{\frac{Q_R}{c_p T_0}} \qquad f+f_{AB} = \frac{\tau_{\lambda.AB} + \tau_r}{Q_R/c_p T_0}$$

$$\frac{F_u}{\dot{m}_0 a_0} = (1+f+f_{AB})\frac{V_9}{a_0}\left(1+\frac{1-\frac{p_0}{p_9}}{\gamma_9 M_9^2}\right) - M_0 = \frac{V_9}{a_0} - M_0$$

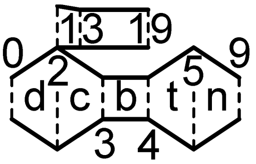
$$\frac{V_9}{a_0} = \frac{M_9 a_9}{a_0} = M_9\sqrt{\frac{T_9}{T_0}} \qquad \frac{p_{t9}}{p_9} = \pi_t \pi_c \pi_r \frac{p_0}{p_9} = \tau_t^{\frac{1}{k}}\tau_c^{\frac{1}{k}}\tau_r^{\frac{1}{k}}$$

$$M_9^2 = \frac{2}{\gamma-1}\left[\left(\frac{p_{t9}}{p_9}\right)^k - 1\right] = \frac{2}{\gamma-1}(\tau_t\tau_c\tau_r - 1)$$

$$\frac{T_9}{T_0} = \frac{\tau_{\lambda.AB}}{\tau_t\tau_c\tau_r} = \tau_{AB}\tau_b \qquad \frac{F_u}{\dot{m}_0 a_0} = \sqrt{\frac{2}{\gamma-1}\tau_{AB}\tau_b(\tau_t\tau_c\tau_r - 1)} - M_0 = \sqrt{\frac{2}{\gamma-1}\left(1-\frac{\tau_{\lambda.AB}}{\tau_t\tau_c\tau_r}\right)} - M_0$$

$$\tau_{c_{max}} = \frac{\tau_\lambda + \tau_r}{2\tau_r} \to \pi_{c_{max}} = \left(\frac{\tau_\lambda + \tau_r}{2\tau_r}\right)^{\frac{1}{k}}$$

turbofan



$$\eta_f = \frac{\pi_f^k - 1}{\tau_f - 1} = \frac{\pi_f^k - 1}{\pi_f^{\frac{k}{e_f}} - 1} \qquad \tau_f = \pi_f^{\frac{\gamma-1}{\gamma e_f}}$$

$$\tau_t = 1 - \frac{\tau_r\left[(\tau_c - 1) + \alpha\left(\tau_f - 1\right)\right]}{\eta_m(1+f)\tau_\lambda}$$

$$\frac{F_u}{\dot{m}_{air}a_0} = \frac{(1+f)}{1+\alpha}\frac{V_9}{a_0}\left(1 + \frac{1 - \frac{p_0}{p_9}}{\gamma_9 M_9^2}\right) + \frac{\alpha}{1+\alpha}\frac{V_{19}}{a_0}\left(1 + \frac{1 - \frac{p_0}{p_{19}}}{\gamma M_{19}^2}\right) - M_0$$

$$\dot{m}_{air} = (1+\alpha)\dot{m}_0$$

$$\frac{V_{19}}{a_0} = \frac{M_{19}a_{19}}{a_0} = M_{19}\sqrt{\frac{T_{19}}{T_0}} \qquad M_{19}^2 = \frac{2}{\gamma - 1}\left[\left(\frac{p_{t19}}{p_{19}}\right)^k - 1\right]$$

$$\frac{p_{t19}}{p_9} = \pi_{fn}\pi_f\pi_d\pi_r\frac{p_0}{p_9} \qquad \frac{T_{19}}{T_0} = \frac{T_{19}}{T_{t19}}\frac{T_{t19}}{T_0} = \frac{\tau_f\tau_r}{\left(\frac{p_{t19}}{p_{19}}\right)^k} \qquad \tau_f = \pi_f^{\frac{\gamma-1}{\gamma e_f}}$$

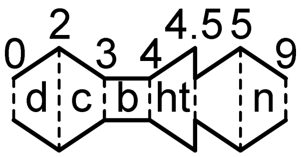
$$TSFC = \frac{f}{F_u/\dot{m}_0} = \frac{f}{(1+f)V_9\left(1 + \frac{1 - \frac{p_0}{p_9}}{\gamma_9 M_9^2}\right) + \alpha V_{19}\left(1 + \frac{1 - \frac{p_0}{p_{19}}}{\gamma M_{19}^2}\right) - V_0}$$

$$\eta_{th} = \frac{\Delta K\dot{E}}{\mathcal{P}_t} = \frac{(1+f)V_{9.e}^2 + \alpha V_{19.e}^2 - (1+\alpha)V_0^2}{2fQ_R} = \frac{(1+f)V_{9.e}^2 - V_0^2}{2fQ_R} + \alpha\frac{V_{9.e}^2 - V_0^2}{2fQ_R}$$

$$V_{9.e} = V_9\left[1 + \frac{1 - \frac{p_0}{p_9}}{\gamma_9 M_9^2}\right] \qquad V_{19.e} = V_{19}\left[1 + \frac{1 - \frac{p_0}{p_{19}}}{\gamma M_{19}^2}\right]$$

$$\eta_p = \frac{2V_0\{[(1+f)V_{9.e}] + \alpha V_{19.e} - (1+\alpha)V_0\}}{(1+f)V_{9.e}^2 + \alpha V_{19.e}^2 - (1+\alpha)V_0^2} \approx \frac{2V_0[V_9 + \alpha V_{19} - (1+\alpha)V_0]}{V_9^2 + \alpha V_{19}^2 - (1+\alpha)V_0^2}$$

TurboProp



$$\alpha_p = \frac{\mathcal{P}_{i.LPT}}{\mathcal{P}_{i.tot}} = \frac{\frac{\mathcal{P}_{LPT}}{\eta_{tL}}}{\mathcal{P}_{i.tot}} = \frac{h_{t45} - h_{t5s}}{h_{t45} - h_{9s}} \qquad \tau_{tL} = \frac{h_{t5}}{h_{t45}} \qquad \eta_{tL} = \frac{h_{t45} - h_{t5}}{h_{t45} - h_{t5s}} \qquad \eta_{tL}\alpha_p = \frac{h_{t45} - h_{t5}}{h_{t45} - h_{9s}}$$

$$\tau_{tL} = 1 - \eta_{tL}\alpha_p \left[1 - \left(\frac{p_{9s}}{p_{t45}}\right)^{k_9}\right] \qquad \eta_{tL} = \frac{1 - \tau_{tL}}{1 - \pi_{\tau L}^{k_9}} = \frac{1 - \tau_{tL}}{1 - \tau_{\tau L}^{\frac{1}{e_{tL}}}}$$

$$F = F_p + F_{core} \qquad \frac{F_{core}}{\dot{m}_0 a_0} = (1 + f)\frac{V_9}{a_0}\left(1 + \frac{1 - \frac{p_0}{p_9}}{\gamma_9 M_9^2}\right) - M_0 \qquad \frac{F_p}{\dot{m}_0 a_0} = \frac{\eta_{prop}\mathcal{P}_s}{\dot{m}_0 V_0 a_0}$$

$$\frac{F_p}{\dot{m}_0 a_0} = \frac{\eta_{prop}(1 + f)\eta_{gb}\eta_{m_{tL}}\eta_{tL}(1 - \tau_{tL})\tau_{tH}\tau_\lambda c_p T_0}{V_0 a_0}$$

$$\eta_{th} = \frac{\Delta K\dot{E}}{\mathcal{P}_t} = \frac{(1 + f)V_{9.e}^2 - V_0^2 + 2\mathcal{P}_S/\dot{m}_0}{2fQ_R} = \frac{a_0^2[(1 + f)(V_{9.e}/a_0)^2 - M_0^2] + 2\mathcal{P}_S/\dot{m}_0}{2fQ_R}$$

$$\eta_p = \frac{F_i V_0}{\Delta K\dot{E}} \approx \frac{2(F_p + F_{core})V_0/\dot{m}_0}{a_0^2[(1 + f)(V_{9.e}/a_0)^2 - M_0^2] + 2\mathcal{P}_S/\dot{m}_0}$$

$$TSFC = \frac{f}{(F_p + F_{core})/\dot{m}_0}$$

$$\tau_{tL}^* = \frac{\tau_b}{\tau_{tH}\tau_\lambda} + \frac{\frac{\gamma - 1}{2}M_0^2}{\tau_{tH}\tau_\lambda\eta_{prop}^2} \qquad \alpha_p^* = 1 - \frac{(\tau_r - 1)/\eta_{prop}^2}{\tau_{tH}\tau_\lambda - \tau_b}$$

Formule PA5

$$\dot{m} = \frac{p_t A\Psi}{a_0} \qquad \Psi(\gamma, M) = \frac{A^*}{A}\Psi^* = \gamma M\left(1 + \frac{\gamma - 1}{2}M^2\right)^{-\frac{(\gamma+1)}{2(\gamma-1)}} = \gamma M\psi^{-K}$$

$$\frac{A_0}{A_1} = \frac{M_1}{M_0}\left(\frac{\psi_0}{\psi_1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \qquad \psi(\gamma, M) = 1 + \frac{\gamma - 1}{2}M^2 \qquad K(\gamma) = \frac{(\gamma + 1)}{2(\gamma - 1)}$$

diffusori

$$C_{PR} = \frac{p_2 - p_1}{\bar{q}_1} = \frac{\Delta p}{\frac{1}{2}\rho_1\bar{V}_1^2} \qquad C_{PR_{ideal}} = 1 - \left(\frac{A_1}{A_2}\right)^2 = 1 - \frac{1}{AR^2}$$

$$D_{add} = \int_{A_0}^{A_1} (p - p_0)dA = \dot{m}_0(V_1 - V_0) + (p_1 - p_o)A_1$$

$$\frac{D_{add}}{p_0 A_1} = \gamma M_0 \frac{A_0}{A_1}\left(\frac{a_1}{a_0}M_1 - M_0\right) + \frac{p_1}{p_o} - 1 == \gamma M_1 \left(\frac{\psi_0}{\psi_1}\right)^K \left(M_1\sqrt{\frac{\psi_0}{\psi_1}} - M_0\right) + \left(\frac{\psi_0}{\psi_1}\right)^{\frac{\gamma}{\gamma-1}} - 1$$

$\pi_{\mathrm{d}} = 1 - 0.1(M_0 - 1)^{1.5}$	$1 < M_0$	AIA-Standard	**(6.34)**
$\pi_{\mathrm{d}} = 1 - 0.075(M_0 - 1)^{1.35}$	$1 < M_0 < 5$	MIL-E-5008B	**(6.35)**
$\pi_{\mathrm{d}} = 800/(M_0^4 + 935)$	$5 < M_0$	MIL-E-5008B	**(6.36)**

Ugelli

$$NPR = \frac{p_{t7}}{p_0} \qquad \eta_n = \frac{h_{t7} - h_9}{h_{t7} - h_{9s}} = \frac{V_9^2/2}{V_{9s}/2} = \frac{1 - \left(\frac{p_9}{p_{t9}}\right)^{k_9}}{1 - \left(\frac{p_9}{p_{t7}}\right)^{k_9}} = \frac{\left(\frac{p_{t7}}{p_9}\right)^{k_9} - \pi_n^{-k_9}}{\left(\frac{p_{t7}}{p_9}\right)^{k_9} - 1} = \frac{\left(NPR\frac{p_0}{p_9}\right)^{k_9} - \pi_n^{-k_9}}{\left(NPR\frac{p_0}{p_9}\right)^{k_9} - 1}$$

$$\frac{p_{t9}}{p_9} = \left(1 + \frac{\gamma - 1}{2}M_9^2\right)^{k_9} = \psi_9^{k_9}$$

$$F = C_A \dot{m}_9 V_9 + (p_9 - p_0)A_9 \qquad \begin{cases} 3D \quad C_A = \dfrac{1 + \cos\alpha}{2} \\ 2D \quad C_A = \dfrac{\sin\alpha}{\alpha} \end{cases}$$

$$\frac{A_{8_{PB}}}{A_8} = \frac{1 + f + f_{AB}}{1 + f}\sqrt{\frac{\gamma_9}{\gamma_5}}\frac{p_{t8}}{p_{t8_{AB}}}\left[\frac{\left(\frac{\gamma_9 + 1}{2}\right)^{\frac{\gamma_9+1}{2(\gamma_9-1)}}}{\left(\frac{\gamma_5 + 1}{2}\right)^{\frac{\gamma_5+1}{2(\gamma_5-1)}}}\right]$$

Formule PA6

Miscele

$$n_A = \frac{m_A}{MW_A} \qquad p_m = p_1 + p_2 + \cdots + p_n = \sum_{i=1}^{n} p_i \qquad H_m = H_1 + H_2 + \cdots + H_n = \sum_{i=1}^{n} H_i$$

$$h_m = \frac{m_1 h_1 + m_2 h_2 + \cdots + m_n h_n}{m_m} = \sum_{i=1}^{n} m_i\, h_i \Big/ \sum_{i=1}^{n} m_i \qquad m_m = n_m MW_m = \sum_{i=1}^{n} m_i = \sum_{i=1}^{n} n_i MW_i$$

$$MW_m = \frac{\sum_{i=1}^{n} n_i MW_i}{n_m} \sum_{i=1}^{n} \chi_i MW_i \qquad \chi_i = \frac{n_i}{n_m} = \frac{p_i}{p_m} = \frac{V_i}{V_m}$$

$$p_i V_m = n_i \bar{R} T_m \qquad p_m V_i = n_i \bar{R} T_m \qquad V_m \sum_{i=1}^{n} p_i = V_m p_m = n_m \bar{R} T_m = \bar{R} T_m \sum_{i=1}^{n} n_i$$

$$h_i = c_{p_i} T_m 123456 h_m = c_{p_m} T_m$$

$$c_{p_m} = \frac{\sum m_i\, c_{p_i}}{m_m} = \frac{\sum n_i MW_i\, c_{p_i}}{n_m MW_m} = \frac{\sum \chi_i MW_i\, c_{p_i}}{MW_m} \qquad \gamma_m = \frac{c_{p_m}}{c_{v_m}} = \frac{\sum m_i\, c_{p_i}}{\sum m_i\, c_{v_i}}$$

Reazioni chimiche

$$H = mh = m\left(\int_{T_f}^{T} c_p dT + \Delta h_f^0\right)$$

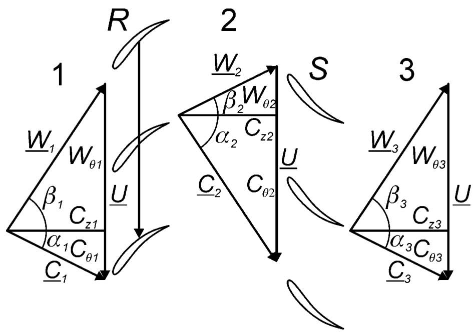
$$\bar{c}_p = MW c_p \qquad [\bar{c}_p] = \frac{kJ}{kmol \cdot K} \qquad \Delta\bar{h}_f^0 = MW \Delta h_f^0 \qquad [\Delta\bar{h}_f^0] = \frac{kJ}{kmol}$$

$$Q_{ext} = \sum_j \left[n_j \bar{c}_{pj} (T_2 - T_f)\right]_{prod} - \sum_i \left[n_i \bar{c}_{pi} (T_1 - T_f)\right]_{rea} + \Delta H_{RPf}$$

$$\Delta H_{RPf} = \sum_j \left[n_j \Delta\bar{h}_{fj}^0\right]_{prod} - \sum_i \left[n_i \Delta\bar{h}_{fi}^0\right]_{rea}$$

$$K_p = \frac{k_f}{k_r} = \frac{p_C^{nC} p_D^{nD}}{p_A^{nA} p_B^{nB}} = K_n (p_m)^{nC+nD-nA-nB} \qquad K_n = \frac{\chi_C^{nC} \chi_D^{nD}}{\chi_A^{nA} \chi_B^{nB}}$$

Formule PA7



$\underline{U} = \omega r \hat{e}_\theta \qquad \underline{W} = \underline{C} - \underline{U} \qquad \underline{C} = \underline{W} + \underline{U}$

$\tau_{fluid} = \dot{m}(r_2 C_{\theta 2} - r_1 C_{\theta 1})$

$\mathcal{P} = \tau_{fluid}\omega = \dot{m}\omega(r_2 C_{\theta 2} - r_1 C_{\theta 1}) = \dot{m}\omega\Delta(rC_\theta)$

Eulero $w = \dfrac{\mathcal{P}}{\dot{m}} = \omega\Delta(rC_\theta) = \Delta(UC_\theta) \qquad \dfrac{h_{t2}}{h_{t1}} = 1 + \dfrac{\omega\Delta(rC_\theta)}{h_{t1}}$

$r_m = \dfrac{r_h + r_t}{2} \qquad w = \omega\Delta(rC_\theta) \cong \omega r\Delta C_\theta = U\Delta C_\theta \qquad C_{\theta 1} = C_{z1}\tan(\alpha_1) \qquad W_{\theta 1} = C_{z1}\tan(\beta_1)$

$\tau_r = -\tau_{fluid} = -\dot{m}r(C_{\theta 2} - C_{\theta 1}) \qquad \tau_s = -\tau_{fluid} = -\dot{m}r(C_{\theta 3} - C_{\theta 2})$

$\dfrac{T_{t2}}{T_{t1}} = 1 + \dfrac{U^2}{c_p T_{t1}}\dfrac{C_{z1}}{U}\left(\dfrac{C_{z2}}{C_{z1}}\tan\alpha_2 - \tan\alpha_1\right) \qquad \dfrac{C_{z2}\,tan\,\alpha_2}{U} = \dfrac{C_{\theta 2}}{U} = \dfrac{U + W_{\theta 2}}{U} = 1 + \dfrac{C_{z2}}{U}tan\,\beta_2$

Coef. di Flusso: $\phi = \dfrac{C_z}{U} = \dfrac{C_z/a_1}{U/a_1} = \dfrac{M_z}{M_T} \qquad \dfrac{T_{t2}}{T_{t1}} = 1 + \dfrac{U^2}{c_p T_{t1}}[1 + \phi(tan\,\beta_2 - tan\,\alpha_1)]$

$$\frac{T_{t2}}{T_{t1}} = 1 + \frac{(\gamma - 1)}{\dfrac{1}{M_T^2} + \dfrac{\gamma - 1}{2\cos^2\alpha_1}\phi^2}\left[1 + \frac{M_z}{M_T}(\tan\beta_2 - \tan\alpha_1)\right]$$

rotalpia: $h_t - C_\theta U \qquad h_{tr} = h_1 + \dfrac{W_1^2}{2} = h_2 + \dfrac{W_2^2}{2}$

$h_{t2} - h_{t1} = \dfrac{\mathcal{P}}{\dot{m}} = w_c = C_{\theta 2}U - C_{\theta 1}U$

Coefficiente di carico: $\Psi_c = \dfrac{\Delta h_t}{U^2} = \dfrac{C_{\theta 2}}{U} - \dfrac{C_{\theta 1}}{U} = 1 + \phi(tan\beta_2 - tan\,\alpha_1)$

Grado di reazione: $°R = \dfrac{h_2 - h_1}{h_3 - h_1} = \dfrac{h_{t2} - h_{t1} - (C_2^2 - C_1^2)/2}{h_{t2} - h_{t1} - (C_3^2 - C_1^2)/2}$

Stadio ripetuto($C_1 = C_3$): $°R = \dfrac{h_{t2} - h_{t1} - (C_2^2 - C_1^2)/2}{h_{t2} - h_{t1} - (C_3^2 - C_1^2)/2} = 1 - \dfrac{(C_2^2 - C_1^2)/2}{h_{t2} - h_{t1}}$

Per ($C_{z2} = C_{z1}$): $°R = 1 - \dfrac{C_{\theta 2} + C_{\theta 1}}{2U} = 1 - \dfrac{C_{\theta.mean}}{U} = \dfrac{1}{2} - \phi\dfrac{tan\,\beta_2 + tan\,\alpha_1}{2}$

Fattore di diffusione: $D_r = 1 - \dfrac{W_2}{W_1} + \dfrac{|W_{\theta 2} - W_{\theta 1}|}{2\sigma_r W_1} \qquad D_s = 1 - \dfrac{C_3}{C_2} + \dfrac{|C_{\theta 3} - C_{\theta 2}|}{2\sigma_s W_2}$

Solidità: $\sigma_r = \dfrac{c_r}{s_r} \qquad \overline{\omega} = \dfrac{p_{tr1} - \bar{p}_{tr2}}{\rho_1 W_1^2/\,2}$

Formule PA8

$$\tau_f = \dot{m}(r_2 C_{\theta 2} - r_1 C_{\theta 1})$$

$\mathcal{P}_r = -\mathcal{P}_f = \dot{m}(h_{t2} - h_{t3}) = \tau_f \omega = \dot{m}\omega(r_2 C_{\theta 2} - r_3 C_{\theta 3}) = \dot{m}\omega\Delta(rC_\theta)$

Grado di reazione: $°R = \dfrac{h_2 - h_3}{h_1 - h_3} = \dfrac{h_{t2} - h_{t3} - (C_2^2 - C_3^2)/2}{h_{t2} - h_{t3} - (C_1^2 - C_3^2)/2}$

Stadio ripetuto$(C_1 = C_3)$ e $(C_{z2} = C_{z1})$: $°R = 1 - \dfrac{C_{\theta 2} + C_{\theta 3}}{2U} = 1 - \dfrac{C_{\theta.mean}}{U}$

$w_t \cong U\Delta C_\theta = UC_{\theta 2} = UC_{z2} \tan \alpha_2$

Cooling

$T_{aw} = T_g + r\dfrac{C^2}{2c_p}$ $\quad T_{aw,r} = T_g + r\dfrac{W^2}{2c_p}$ $\quad r = \sqrt{Pr}$ lam $\quad r = \sqrt[3]{Pr}$ turb

$Pr = \dfrac{c_p \mu}{k} = \dfrac{\nu}{\alpha}$ $\quad \eta = \dfrac{T_t - T_{wg}}{T_t - T_c}$

legge di Newton; $q = h_g(T_{aw} - T_{wg})$

$Nu = \dfrac{hL}{k}$ $\quad St = \dfrac{h}{\rho u\, c_p}$ $\quad Nu = Nu(Re, Pr)$ $\quad St = St(Re, Pr)$

analogia di Reynolds: $St = \dfrac{c_f}{2}$ $\quad \sigma_c = A_c / A_w$

$\dot{Q} \cong 2\sigma \dot{m}_g c_{pg} St_g (T_{aw} - T_{wg}) \cong \sigma_c \dot{m}_c c_{pc} St_c (T_{wc} - T_c)$ $\quad \epsilon \cong \dfrac{\dot{m}_c}{\dot{m}_g} = \dfrac{2\sigma}{\sigma_c}\dfrac{c_{pg}}{c_{pc}}\dfrac{St_g}{St_c}\dfrac{T_{aw} - T_{wg}}{T_{wc} - T_c}$

$$T_{wc} = T_{wg} - \frac{t_w}{k_w}\frac{\dot{m}_g}{A_g} c_{pg} St_g (T_{aw} - T_{wg})$$