

Conversioni

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

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

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

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

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

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

$$x^{\circ}F = (x + 459.67)^{\circ}R = (x + 459.67)/1.8K = (x/1.8 + 255.37)K$$

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

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

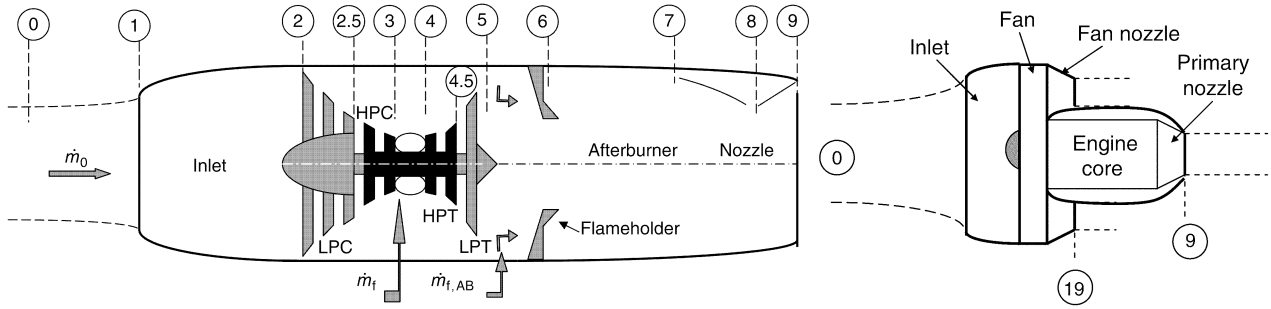
$$\begin{aligned} \left[TSFC = \frac{\dot{m}_f}{F} \right] &= \frac{lbm}{hr \cdot lbf} = \frac{lbm}{3600s \cdot 1lbm \cdot 32.17ft/s^2} = \frac{1}{115830} \frac{s}{ft} = \frac{1}{115830} \frac{s}{0.3048m} \\ &= \frac{1}{34305} \frac{s}{m} = \frac{1}{34305} \frac{10^6 mg}{s \cdot kg \cdot m/s^2} = 28.325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

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

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

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

Formule PA2



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

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

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

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

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

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

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

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

$$\text{Specific thrust: } \frac{F}{\dot{m}_0} \left[\frac{Ns}{kg} \right] \text{ or } \frac{F}{\dot{m}_0 a_0}$$

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

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

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

$$\text{Propulsive efficiency: } \eta_p = \frac{F_i V_0}{\Delta K \dot{E}} \cong \frac{2}{1 + \frac{V_9}{V_0}} \text{ or for turboprop } \eta_p = \frac{F_i V_0}{\Delta K \dot{E} + \dot{P}_s} \cong \frac{F_i V_0}{\dot{P}_s} \text{ or for rockets } \eta_p =$$

$$\frac{FV}{FV + \dot{m}_p (c - V)^2 / 2} = \frac{2 \frac{V}{c}}{1 + \left(\frac{V}{c} \right)^2}$$

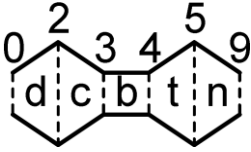
$$\text{Overall efficiency: } \eta_0 = \eta_p \eta_{th} = \frac{F_i V}{\dot{m}_f Q_R} \text{ or for rockets } \eta_0 = \frac{F_i V}{\dot{m}_p Q_R + \dot{m}_p (v_{inj}^2) / 2} \cong \frac{cV}{Q_R}$$

Formule PA3-4

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

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

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



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

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

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

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

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

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

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

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

Ciclo reale turbojet

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

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

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

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

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

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

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

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

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

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

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

Ciclo ideale turbojet

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

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

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

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

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

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

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

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

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

Post bruciatore

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

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

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

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

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

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

Post bruciatore caso ideale

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

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

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

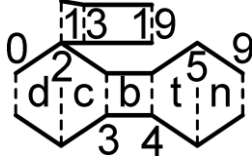
$$\frac{V_9}{a_0} = \frac{M_9 a_9}{a_0} = M_9 \sqrt{\frac{T_9}{T_0}} \quad \frac{p_{t9}}{p_9} = \pi_t \pi_c \pi_r \frac{p_0}{p_9} = \tau_t^{\frac{1}{k}} \tau_c^{\frac{1}{k}} \tau_r^{\frac{1}{k}}$$

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

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

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

Turbofan a flussi separati



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

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

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

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

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

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

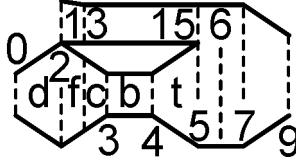
$$TSFC = \frac{f}{F_u/\dot{m}_0} = \frac{f}{(1 + f)V_9 \left(1 + \frac{1 - \frac{p_0}{p_9}}{\gamma M_9^2} \right) + \alpha V_{19} \left(1 + \frac{1 - \frac{p_0}{p_{19}}}{\gamma M_{19}^2} \right) - V_0}$$

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

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

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

Turbofan a flussi miscelati con post bruciatore



$$\tau_M = \frac{h_{t6}}{h_{t5}} = \frac{\alpha \tau_f \tau_r / \tau_t \tau_\lambda + (1 + f)}{1 + \alpha + f} \quad \pi_t = \frac{\pi_{fd} \pi_f}{\pi_b \pi_c} \quad \alpha = \frac{\eta_m (1 + f) (1 - \tau_t) \tau_\lambda - \tau_r (\tau_c - 1)}{\tau_r (\tau_f - 1)}$$

$$f_{AB} = \frac{\dot{m}_{f,AB}}{\dot{m}_{air}} = \frac{\dot{m}_{f,AB}}{\dot{m}_0 (1 + \alpha)} = \left(1 + \frac{f}{1 + \alpha}\right) \frac{\tau_{\lambda AB} - \tau_M \tau_t \tau_\lambda}{\frac{Q_{R,AB} \eta_{AB}}{c_p T_0} - \tau_{\lambda,AB}} \quad f_{tot} = \frac{\dot{m}_{f,tot}}{\dot{m}_{air}} = \frac{f}{1 + \alpha} + f_{AB}$$

$$\frac{F_u}{\dot{m}_{air} a_0} = (1 + f_{tot}) \frac{V_{9,e}}{a_0} - M_0 \quad \frac{V_{9,e}}{a_0} = \frac{V_9}{a_0} \left(1 + \frac{1 - \frac{p_0}{p_9}}{\gamma_9 M_9^2}\right)$$

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

$$TSFC = \frac{\dot{m}_{f,tot}}{F_u} \frac{f_{tot}}{F_u / \dot{m}_{air}} \quad \eta_{th} = \frac{\Delta K \dot{E}}{\mathcal{P}_t} = \frac{a_0^2 [(1 + f_{tot}) (V_{9,e} / a_0)^2 - M_0^2]}{2 f_{tot} Q_R}$$

$$\eta_p = \frac{F_u V_0}{\Delta K \dot{E}} \approx \frac{2 F_u V_0 / \dot{m}_{air}}{a_0^2 [(1 + f_{tot}) (V_{9,e} / a_0)^2 - M_0^2]}$$

Post-bruciatore Spento

$$f = \frac{\tau_\lambda - \tau_c \tau_r}{\frac{Q_R \eta_b}{c_p T_0} - \tau_\lambda} \quad f_{tot} = \frac{f}{1 + \alpha} \quad \frac{T_9}{T_0} = \frac{T_9}{T_{t9}} \frac{T_{t9}}{T_0} = \frac{\tau_t \tau_\lambda c_p / c_{pt}}{(p_{t9} / p_9)^{k_9}} \quad \frac{p_{t9}}{p_9} = \pi_n \pi_M \pi_t \pi_b \pi_c \pi_d \pi_r \frac{p_0}{p_9}$$

Post-bruciatore acceso

$$f = \frac{\tau_\lambda - \tau_c \tau_r}{\frac{Q_R \eta_b}{c_p T_0} - \tau_\lambda} \quad f_{AB} = \left(1 + \frac{f}{1 + \alpha}\right) \frac{\tau_{\lambda AB} - \tau_M \tau_t \tau_\lambda}{\frac{Q_{R,AB} \eta_{AB}}{c_p T_0} - \tau_{\lambda,AB}} \quad f_{tot} = \frac{f}{(1 + \alpha)} + f_{AB}$$

$$\frac{T_9}{T_0} = \frac{T_9}{T_{t9}} \frac{T_{t9}}{T_0} = \frac{\tau_{\lambda,AB} c_p / c_{pAB}}{(p_{t9} / p_9)^{k_9}} \quad \frac{p_{t9}}{p_9} = \pi_n \pi_{AB} \pi_M \pi_t \pi_b \pi_c \pi_d \pi_r \frac{p_0}{p_9}$$

Turbofan a flussi miscelati con post bruciatore caso ideale

$$\tau_M = \frac{\alpha \tau_c \tau_r / \tau_\lambda + 1}{1 + \alpha} \quad M_{0,lim} = \sqrt{\frac{2}{\gamma - 1} \left(\frac{\tau_c - \tau_f \tau_\lambda}{\tau_c - 1} \frac{\tau_\lambda}{\tau_c} - 1 \right)} \quad \alpha = \frac{(1 - \tau_t) \tau_\lambda - \tau_r (\tau_c - 1)}{\tau_r (\tau_f - 1)}$$

$$f = \frac{\tau_\lambda - \tau_c \tau_r}{Q_R / (c_p T_0)} \quad f_{AB} = \frac{\tau_{\lambda AB}}{Q_R / (c_p T_0)} - \frac{\tau_f \tau_r (\tau_c - 1)}{(\tau_c - \tau_f) Q_R / (c_p T_0)}$$

Post bruciatore spento

Post bruciatore acceso

$$\frac{F_u}{\dot{m}_{air}a_0} = \sqrt{2 \frac{\tau_\lambda}{\tau_c \tau_r} \frac{\tau_f \tau_r - 1}{\gamma - 1}} - M_0$$

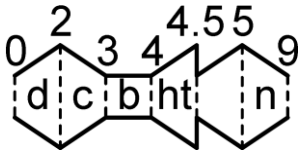
$$\frac{F_u}{\dot{m}_{air}a_0} = \sqrt{2 \frac{\tau_{\lambda AB}}{\tau_f \tau_r} \frac{\tau_f \tau_r - 1}{\gamma - 1}} - M_0$$

$$f_{tot} = \frac{\tau_\lambda - \tau_c \tau_r}{Q_R / (c_p T_0)}$$

$$f_{tot} = \frac{\tau_{\lambda AB} + \tau_r}{Q_R / (c_p T_0)}$$

$$TSFC = \frac{f_{tot}}{F_u / \dot{m}_{air}} \quad \eta_{th} = \frac{a_0^2 [(V_9/a_0)^2 - M_0^2]}{2 f_{tot} Q_R} \quad \eta_p = \frac{2 F_u V_0 / \dot{m}_{air}}{a_0^2 [(V_9/a_0)^2 - M_0^2]}$$

TurboProp



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

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

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

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

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

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

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

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

Formule PA5

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

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

diffusori

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

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

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

$$\pi_d = 1 - 0.1(M_0 - 1)^{1.5} \quad 1 < M_0 \quad \text{AIA-Standard} \quad (6.34)$$

$$\pi_d = 1 - 0.075(M_0 - 1)^{1.35} \quad 1 < M_0 < 5 \quad \text{MIL-E-5008B} \quad (6.35)$$

$$\pi_d = 800/(M_0^4 + 935) \quad 5 < M_0 \quad \text{MIL-E-5008B} \quad (6.36)$$

Ugelli

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

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

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

$$\frac{A_{8PB}}{A_8} = \frac{1 + f + f_{AB}}{1 + f} \sqrt{\frac{\gamma_9}{\gamma_5}} \frac{p_{t8}}{p_{t8AB}} \left[\frac{\left(\frac{\gamma_9 + 1}{2} \right)^{\frac{\gamma_9 + 1}{2(\gamma_9 - 1)}}}{\left(\frac{\gamma_5 + 1}{2} \right)^{\frac{\gamma_5 + 1}{2(\gamma_5 - 1)}}} \right]$$

Formule PA6

Miscela

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

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

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

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

$$h_i = c_{p_i} T_m \quad h_m = c_{p_m} T_m$$

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

Reazioni chimiche

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

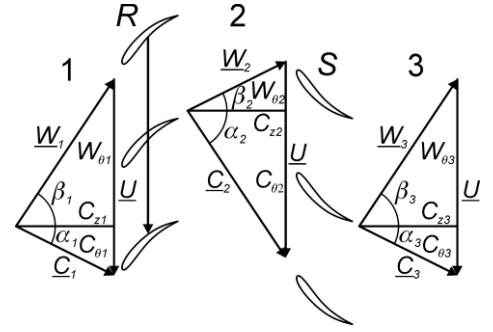
$$\bar{c}_p = MW c_p \quad [\bar{c}_p] = \frac{kJ}{kmol \cdot K} \quad \Delta \bar{h}_f^0 = MW \Delta h_f^0 \quad [\Delta \bar{h}_f^0] = \frac{kJ}{kmol}$$

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

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

$$K_p = \frac{k_f}{k_r} = \frac{p_C^{n_C} p_D^{n_D}}{p_A^{n_A} p_B^{n_B}} = K_n (p_m)^{n_C + n_D - n_A - n_B} \quad K_n = \frac{\chi_C^{n_C} \chi_D^{n_D}}{\chi_A^{n_A} \chi_B^{n_B}}$$

Formule PA7



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

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

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

$$\text{Eulero } w = \frac{\mathcal{P}}{\dot{m}} = \omega \Delta(r C_\theta) = \Delta(U C_\theta) \quad \frac{h_{t2}}{h_{t1}} = 1 + \frac{\omega \Delta(r C_\theta)}{h_{t1}}$$

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

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

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

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

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

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

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

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

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

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

$$\text{Per } (C_{z2} = C_{z1}): {}^\circ R = 1 - \frac{C_{\theta 2} + C_{\theta 1}}{2U} = 1 - \frac{C_{\theta, \text{mean}}}{U} = \frac{1}{2} - \phi \frac{\tan \beta_2 + \tan \alpha_1}{2}$$

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

$$\text{Solidità: } \sigma_r = \frac{c_r}{s_r} \quad \bar{\omega} = \frac{p_{tr1} - \bar{p}_{tr2}}{\rho_1 W_1^2 / 2}$$

Formule PA8

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

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

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

$$\text{Stadio ripetuto } (C_1 = C_3) \text{ e } (C_{z2} = C_{z1}): {}^\circ R = 1 - \frac{C_{\theta 2} + C_{\theta 3}}{2U} = 1 - \frac{C_{\theta, \text{mean}}}{U}$$

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

Cooling

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

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

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

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

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

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

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

Formule PA9 Off Design

$$\dot{m}_0 = \frac{p_{t0} A_0 \Psi_0}{a_{t0}} \quad \Psi(M, \gamma) = \gamma M \psi^{-K} \quad \delta_i = \frac{p_{ti}}{p_{ref}} \quad \theta_i = \frac{T_{ti}}{T_{ref}}$$

$$\dot{m}_{ci} = \frac{\dot{m}_i \sqrt{\theta_i}}{\delta_i} = \sqrt{\frac{\gamma_i}{R_i} \frac{p_{ref}}{\sqrt{T_{ref}}}} A_i M_i \psi_i^{-K_i} \quad \frac{p_{t2}}{p_{t0}} \frac{A_2}{A_0} M_{z2} \psi_{z2}^{-K_2} = \psi_0^{-K_0}$$

$$\dot{m}_4 = (1 + f) \dot{m}_2 \rightarrow \sqrt{\frac{\gamma_4}{R_4} \frac{\pi_b \pi_c A_4}{\sqrt{T_{t4}/T_{t2}}}} \left(\frac{\gamma_4 + 1}{2} \right)^{-K_4} = (1 + f) \sqrt{\frac{\gamma_2}{R_2}} A_2 M_{z2} \psi_{z2}^{-K_2}$$

$$f = \frac{h_{t4} - h_{t3}}{Q_R \eta_b - h_{t4}} = \frac{(c_{p4}/c_{p2}) T_{t4}/T_{t2} - \tau_c}{Q_R \eta_b / (c_{p2} T_{t2}) - (c_{p4}/c_{p2}) T_{t4}/T_{t2}}$$

$$\dot{m}_{c2} = \frac{\dot{m}_{c4}}{1 + f} \frac{p_{t4}}{p_{t2}} \frac{1}{\sqrt{T_{t4}/T_{t2}}} = \frac{\dot{m}_{c4}}{1 + f} \frac{\pi_b \pi_c}{\sqrt{T_{t4}/T_{t2}}} \quad \frac{\dot{m}_{c4}}{\dot{m}_{c5}} = \frac{\pi_t}{\sqrt{\tau_t}} \left(1 - \frac{\epsilon_1 + \epsilon_2}{1 + f} \right)$$

$$\tau_{t,OD} = \tau_{t,D}$$

$$\tau_c - 1 = \eta_m (1 + f) \frac{c_{p4}}{c_{p2}} \frac{T_{t4}}{T_{t2}} (1 - \tau_t) \quad \frac{N_{c2}}{N_{c4}} = \sqrt{\frac{T_{t4}}{T_{t2}}}$$

$$\tau_{c,OD} = 1 + (\tau_{c,D} - 1) \frac{(T_{t4}/T_{t2})_{OD}}{(T_{t4}/T_{t2})_D}$$

$$\pi_{c,OD} = \left[1 + \eta_c (\tau_{c,D} - 1) \frac{(T_{t4}/T_{t2})_{OD}}{(T_{t4}/T_{t2})_D} \right]^{\frac{1}{k}}$$

$$N_{c4,OD} \approx N_{c4,D} \approx cost \quad \frac{N_{c2,OD}}{N_{c2,D}} \approx \sqrt{\frac{(T_{t4}/T_{t2})_{OD}}{(T_{t4}/T_{t2})_D}} = \sqrt{\frac{\tau_{c,OD} - 1}{\tau_{c,D} - 1}}$$

$$\frac{\dot{m}_{c2,OD}}{\dot{m}_{c2,D}} \approx \frac{\pi_{c,OD}}{\pi_{c,D}} \sqrt{\frac{(T_{t4}/T_{t2})_D}{(T_{t4}/T_{t2})_{OD}}} = \frac{\pi_{c,OD}}{\pi_{c,D}} \sqrt{\frac{\tau_{c,D} - 1}{\tau_{c,OD} - 1}}$$

$$\frac{\dot{m}_{c2,OD}}{\dot{m}_{c2,D}} = \frac{M_{z2,OD} \psi_{z2,OD}^{-K_2}}{M_{z2,D} \psi_{z2,D}^{-K_2}}$$