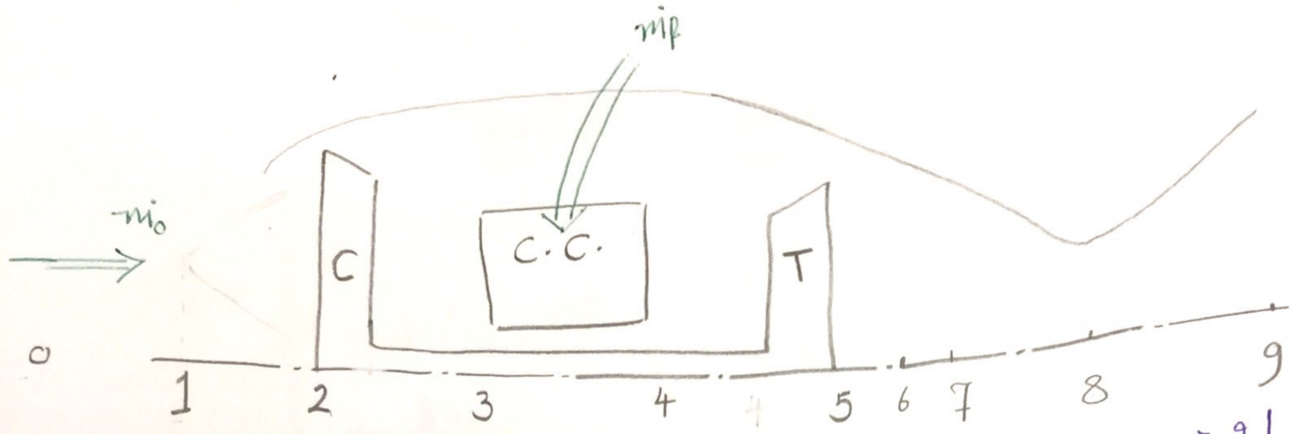
Turbojet Engine Data Sheet

*



Ram air	1 → 2	2 → 3	3 → 4	4 → 5	5 → 6	7 → 8 → 9
0	intake	Compressor	Combustor	Turbine	AB	nozzle

* Flight Conditions

① SLS → Sea level static Conditions:-

$*\ h = 0$, $V_0 = 0$, $T_0 = 288.16\ K$, $P_0 = 101325\ Pa$
$M_0 = 0$

② If h & M_0 are Givens so we can get T_0 & P_0 from tables

* if $h\,(ft) \longrightarrow$ $\boxed{h\,(ft) * 0.3048 = h\,(m)}$ #

* if h from $0 \longrightarrow 11\ km$

$$\left.\begin{aligned} T_0 &= 288 - 6.5 * 10^{-3}\, h \\ P_0 &= 101325\left(1 - 2.257 * 10^{-5}\, h\right)^{5.217} \end{aligned}\right\}\ h \text{ in meters}$$

* $\boxed{V_0 = M_0 \sqrt{\gamma R T_0}}$ Flight speed.

→ Ram effect :-

$$\tau_r = \frac{T_{t0}}{T_0} = 1 + \frac{\gamma_c - 1}{2} M_0^2$$

$$\pi_r = \frac{P_{t0}}{P_0} = \left(1 + \frac{\gamma_c - 1}{2} M_0^2\right)^{\gamma_c/\gamma_c - 1}$$

$0 \longrightarrow 2$ intake:- $\rightarrow * \; T_{t2} = T_{t0} \longrightarrow$ Adiabatic Process $T_{t0} = T_{t1} = T_{t2}$

$$* \; \pi_d = \pi_{d_{max}} \, \eta_r \longrightarrow f(M)$$

$\pi_{d_{max}} \rightarrow$ From table $\rightarrow$ 0.98 $M_0 < 1$; 0.95 $M_0 > 1$ } supersonic losses is more

$$* \; \eta_r = \begin{cases} 1 & M_0 < 1 \\ 1 - 0.075(M_0 - 1)^{1.35} & 1 < M_0 < 5 \\ \dfrac{800}{M_0^4 - 935} & M_0 > 5 \end{cases}$$

Comp. $2 \longrightarrow 3$

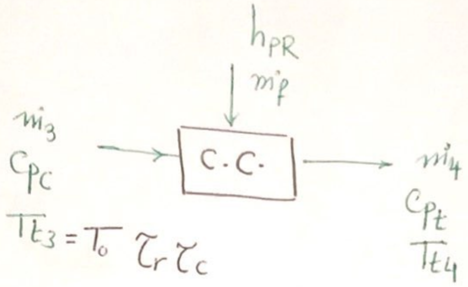
$$\eta_c = \frac{\pi_c^{\frac{\gamma_c - 1}{\gamma_c}} - 1}{\tau_c - 1} \longrightarrow \tau_c = \frac{\pi_c^{\frac{\gamma_c - 1}{\gamma_c}} - 1}{\eta_c} + 1$$

$$\tau_c = \pi_c^{\frac{\gamma_c - 1}{\gamma_c e_c}}$$

For Comp. $\longrightarrow$ $* \; \eta_c = [0.82 \; ; \; 0.88]$, $* \; e_c = [0.85 \; ; \; 0.9]$ } eff. Range

⚠ Fresh Air $\longrightarrow$ 0:3 { $\gamma_c = 1.4$; $R_c = 287$ J/kg.K ; $C_{P_c} = 1004.5$ J/kg.K

3 → 4 Comb. chambers (burner)



⚠ If we have bleed air $\longrightarrow$ $\boxed{\dot{m}_3 = \dot{m}_0 - \dot{m}_b}$

If we don't have bleed air $\longrightarrow$ $\boxed{\dot{m}_3 = \dot{m}_0}$

* $\boxed{\dot{m}_3 + \dot{m}_f = \dot{m}_4}$

* $\left.\text{Energy}\right)_3 + \left.\text{Energy}\right)_f = \left.\text{Energy}\right)_4$

$$\therefore \boxed{h_{t3} + h_{PR}\, f * \eta_b = (1+f)\, h_{t4}}$$

$\boxed{f = \dfrac{\dot{m}_f}{\dot{m}_3}}$ Fuel to air ratio

or

$$\boxed{f = \frac{\tau_\lambda - \tau_r \tau_c}{\dfrac{\eta_b h_{PR}}{C_{pc} T_0} - \tau_\lambda}}$$

$$\boxed{\tau_\lambda = \frac{C_{pt}\, T_{t4}}{C_{pc}\, T_0}}$$

⚠ $\pi_b = \dfrac{P_{t4}}{P_{t3}}$ $\longrightarrow$ if not given we may take it $\boxed{0.96}$

η_b $\longrightarrow$ if not given we may take it $\boxed{0.99}$

h_{PR} $\longrightarrow$ if not given we may take it $\boxed{4.28 * 10^7 \text{ J/Kg}}$

⚠ If we don't have AB the engine γ_t & R_t, C_{pt} from station 4 to station 9 will be the same.

⚠ $4 \longrightarrow 9$ $\begin{cases} \gamma_t = 1.333 \\ C_{pt} = 1148.86 \text{ J/kg·K} \\ C_p = \dfrac{\gamma R}{\gamma - 1} \longrightarrow \text{we can get } R_t \end{cases}$

4 → 5 Turb. :

$$* \ \dot{m}_4 = \dot{m}_5$$

Power : $* \ P)_{Comp} = \eta_m \ P)_{turb.}$

⚠ η_m → if not given, we may assume it $\underbrace{0.99 \text{ or } 0.98}_{\text{From table.}}$

$$\dot{m}_0 \, C_{p_c} \, (T_{t3} - T_{t2}) = \eta_m (1+f) \, \dot{m}_0 \, C_{p_t} \, (T_{t4} - T_{t5}) \qquad \div \ \dot{m}_0 \, C_{p_c} \, T_0$$

$$\frac{T_{t2}}{T_0} \left(\frac{T_{t3}}{T_{t2}} - 1 \right) = \eta_m (1+f) \, \frac{C_{p_t} \, T_{t4}}{C_{p_c} \, T_0} \left(1 - \frac{T_{t5}}{T_{t4}} \right)$$

$$\tau_r (\tau_c - 1) = \eta_m (1+f) \, \tau_\lambda (1 - \tau_t)$$

$$\boxed{\tau_t = 1 - \frac{\tau_r (\tau_c - 1)}{\eta_m (1+f) \, \tau_\lambda}}$$

$$\eta_t = \frac{1 - \tau_t}{1 - \pi_t^{\frac{\gamma_t - 1}{\gamma_t}}} \quad , \quad \pi_t = \left[1 - \frac{1 - \tau_t}{\eta_t} \right]^{\frac{\gamma_t}{\gamma_t - 1}}$$

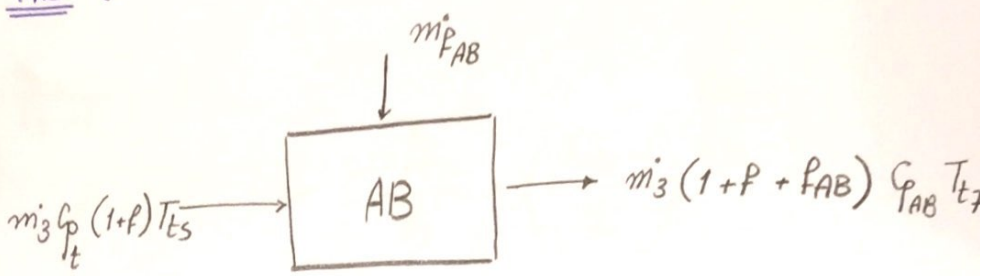
$$\pi_t = \tau_t^{\frac{\gamma_t}{(\gamma_t - 1) e_t}}$$

5 → 6 Duct (If we don't have AB)

$$\boxed{T_{t6} = T_{t5}}$$

$$\boxed{P_{t6} = P_{t5}}$$

$5 \longrightarrow \begin{matrix}6\\7\end{matrix}$ If we have $\underline{\underline{AB}}$:



$$\dot{m}_5 + \dot{m}_{AB} = \dot{m}_6 = \dot{m}_7$$

$$\dot{m}_3 (1+f) + \eta_{AB} \dot{m}_3 f_{AB} = \dot{m}_3 (1+f+f_{AB})$$

$$\therefore \dot{m}_3 (1+f) C_{p_t} T_{t5} + \eta_{AB} h_{PR} f_{AB} = (1+f+f_{AB}) C_{p_{AB}} T_{t7}$$

$$\therefore \boxed{f_{AB} = (1+f) * \left[\frac{\tau_{\lambda AB} - \tau_\lambda \tau_t}{\frac{h_{PR} \eta_{AB}}{C_{p_c} T_0} - \tau_{\lambda AB}} \right]} \qquad \tau_{\lambda_{AB}} = \frac{C_{p_{AB}} T_{t7}}{C_{p_c} T_0}$$

⚠ if not given (η_{AB}) we may take it $\eta_{AB} = 0.99$

⚠ with increasing T_t across the engine $\gamma \downarrow$ & $C_p \uparrow$

we may assume $\left.\begin{matrix}\gamma_{AB} = 1.3 \\ C_{p_{AB}} = 1243.67 \text{ J/kg.K}\end{matrix}\right\}$ if not given

⚠ $\left.\pi_{AB}\right)_{off} = \sqrt{\left.\pi_{AB}\right)_{on}}$

$7 \longrightarrow 8 \longrightarrow 9$ nozzle :

$7 \longrightarrow \begin{matrix}8\\9\end{matrix}$ C.N

$7-8-9$ C.D.N

Convergent Nozzle :

* $$\left.\frac{P_{t9}}{P_9}\right|_{critical} = \left(\frac{\gamma_t + 1}{2}\right)^{\frac{\gamma_t}{\gamma_t - 1}}$$ or $$\frac{P_{t9}}{P_9} = \left(\frac{\gamma_{AB} + 1}{2}\right)^{\frac{\gamma_{AB}}{\gamma_{AB} - 1}}$$

Without AB: $\gamma_n = \gamma_t$ — With AB: $\gamma_n = \gamma_{AB}$

* $$\frac{P_{t9}}{P_0} = \pi_r \, \pi_d \, \pi_c \, \pi_b \, \pi_t \, \pi_{AB} \, \pi_N$$

$\frac{P_{t9}}{P_0} < \left.\frac{P_{t9}}{P_9}\right)_{critical}$	$\frac{P_{t9}}{P_0} \geq \left.\frac{P_{t9}}{P_9}\right)_{critical}$
* Unchoked nozzle	* Choked nozzle
* $P_9 = P_0$	* $P_9 = P_0 * \frac{P_{t9}}{P_0} * \frac{1}{\left.\frac{P_{t9}}{P_9}\right)_{critical}}$
* $M_9 < 1$	* $M_9 = 1$
* $\frac{P_{t9}}{P_0} = \left(1 + \frac{\gamma_n - 1}{2} M_9^2\right)^{\frac{\gamma}{\gamma_n - 1}}$ $\longrightarrow$ get M_9	
* $T_9 = T_{t9} - \frac{V_9^2}{2 C_{p_n}}$	* $T_9 = \frac{T_{t7}}{1 + \frac{\gamma_n - 1}{2}}$
$V_9 = \sqrt{2 C_{p_n} T_{t7} \left(1 - \left(\frac{P_0}{P_{t9}}\right)^{\frac{\gamma_n - 1}{\gamma_n}}\right)}$	* $V_9 = \sqrt{\gamma_n R_n T_9}$

C.D. Nozzle :-

* If we assume full expansion ($P_0 = P_9$)

$$V_9 = \sqrt{2 C_{p_n} T_{t7} \left(1 - \left(\frac{P_0}{P_{t9}}\right)^{\frac{\gamma_n - 1}{\gamma_n}}\right)}$$

$$T_9 = T_{t9} - \frac{V_9^2}{2 C_{p_n}}$$

* If $\frac{P_9}{P_0}$ given $\longrightarrow$ get P_9

- $\frac{P_{t9}}{P_9} = \left(1 + \frac{\gamma_n - 1}{2} M_9^2\right)^{\frac{\gamma_n}{\gamma_n - 1}} \longrightarrow$ get M_9

- $\frac{T_{t9}}{T_9} = 1 + \frac{\gamma_n - 1}{2} M_9^2 \longrightarrow$ get T_9

- $V_9 = M_9 \sqrt{\gamma_n R_n T_9} \longrightarrow$ get V_9

Thrust

* $F = \overbrace{\dot{m}_e V_e + A_e (P_9 - P_0)}^{\text{Gross thrust}} - \overbrace{\dot{m}_0 V_0}^{\text{ram drag}}$

$F \rightarrow$ uninstalled thrust

$$\dot{m}_0 = \frac{\rho_9 A_9 V_9}{(1+f)}$$

$$\rho_9 = \frac{P_9}{R T_9}$$

$$M_9^2 = \frac{V_9^2}{\gamma_n R_n T_9}$$

* if we have AB

$$\dot{m}_0 = \frac{\rho_9 A_9 V_9}{(1 + f + f_{AB})}$$

* $\frac{F}{\dot{m}_0} = (1+f) V_9 - V_0 + \frac{A_9}{\dot{m}_0} (P_9 - P_0)$

$$= (1+f) V_9 - V_0 + \frac{A_9 (1+f)}{\rho_9 A_9 V_9} (P_9 - P_0)$$

$$= (1+f) V_9 - V_0 + \frac{R T_9 (1+f)}{V_9} \left(1 - \frac{P_0}{P_9}\right)$$

$$= \boxed{(1+f) V_9 - V_0 + \frac{V_9}{\gamma_n M_9^2} \left(1 - \frac{P_0}{P_9}\right)(1+f)}$$ specific thrust

* $T = F - D_{en}$ installed thrust

$D_{en} \rightarrow$ engine drag

Scanned with CamScanner

$$V_{g_e} = V_g + \frac{V_g}{\gamma_n M_g^2}\left(1 - \frac{P_0}{P_g}\right)$$

$$\therefore \frac{F}{\dot{m}_0} = (1+f)\,V_{g_e} - V_0$$

V_{g_e} * Effective jet velocity at station 9 due to Pressure difference

⚠ In Case of optimum expansion $P_0 = P_g \longrightarrow \boxed{V_{g_e} = V_g}$ #

Thermal efficiency: η_{th}

$$\eta_{th} = \frac{(1+f)\,V_{g_e}^2 - V_0^2}{2f\,h_{PR}}$$

Propulsive efficiency: η_p

$$\eta_p = \frac{2\frac{F}{\dot{m}_0}\cdot V_0}{(1+f)\,V_{g_e}^2 - V_0^2} = \frac{2}{NDST + 2}, \quad NDST = \frac{F}{\dot{m}_0 V_0}$$

NDST → non-dim. specific thrust.

overall efficiency: η_0

$$\eta_0 = \eta_p * \eta_{th} = \frac{F\cdot V_0}{\dot{m}_f\,h_{PR}} = \frac{\frac{F}{\dot{m}_0}\,V_0}{f\,h_{PR}}$$

⚠ η_0 Not indicative at static Conditions $(V_0 = 0)$

Specific Fuel Consumption $S.F.C. \equiv S$

$$S.F.C. = \frac{\dot{m}_f}{F} = \frac{f}{\frac{F}{\dot{m}_o}}$$

Mil & Max. Conditions:

$$S_{Mil.} = \frac{f}{\left.\frac{F}{\dot{m}_o}\right)_{Mil}} \quad , \quad S_{Max.} = \frac{f + f_{AB}}{\left.\frac{F}{\dot{m}_o}\right)_{Max}}$$

$$\left.\pi_{AB}\right)_{Mil} \longrightarrow \text{off} \quad , \quad \left.\pi_{AB}\right)_{Max.} \longrightarrow \text{on}$$

Range Factors RF

$$\boxed{RF = \frac{W_f + W_{eng.}}{F - D_{eng.}}}$$

*

0