ESERCIZI

PROPULSIONE

AEROSPAZIALE

A.A. 2022/23

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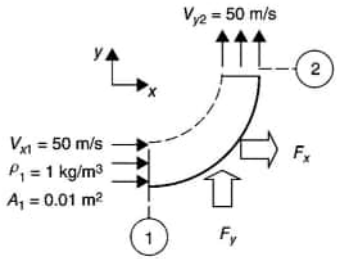
Esercizi, vedi ESPA per conversioni

2.32 Consider the flow of perfect gas (air) on a vane, as shown. Apply momentum principles to the fluid to calculate the components of force F_x and F_y that act on the vane.

Assume the flow is uniform, and due to low speeds, $p_1 = p_2 = p_0$, where p_0 is the ambient pressure.



hp: ρ cost $\quad p_1 = p_2 = p_0$

$F_x = I_{1x} - I_{2x}$

$= \rho_1 V_{1x} A_1 \cdot (V_{1x} - V_{2x}) + [p_1 - p_0] A_1 - [p_2 - p_0] A_2$

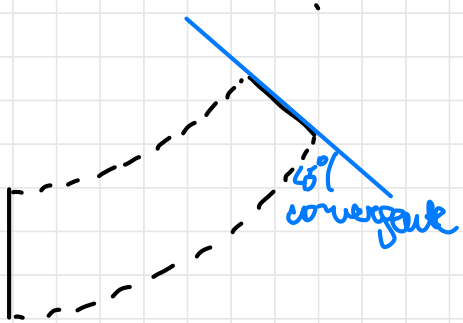
$= 1 \cdot 50 \cdot 0{,}01 \cdot 50 = \frac{50^2}{100} = 25\ N$

forza che fluido esercita su palette

$F_y = I_{1y} - I_{2y} = \rho_1 V_{1x} A_{1x} (V_{1y} - V_{2y})$

è portata quindi conservo x

$= 1 \cdot 50 \cdot 0{,}01\ (0 - 50) = -\frac{50^2}{100} = -25\ N$, spinta diretta da alto verso basso



ρ cost ma non p cost

$V_1 A_1 = V_2 A_2$

$V_2 = \frac{V_1 A_1}{A_2} = 50\ \frac{0{,}01}{0{,}005} = 100\ m/s$

per p_2: $p_2 = p_1 + \frac{1}{2}\rho_1 (V_1^2 - V_2^2) = 10^5 + \frac{1}{2} \cdot 1\ (50^2 - 100^2)$

$p_1 = 1\ bar = 10^5\ Pa$

$= 10^5 + \frac{2500 - 10^4}{2} = 96{,}25\ kPa$

$P_2 - P_1 = P_2 = 86.25 - 100 = -3,75\ KPa$

$I_1 = \rho_1 A_1 V_1 V_1 + (P_1 - P_0) A_1 = 25N$ (0)

per : KPa

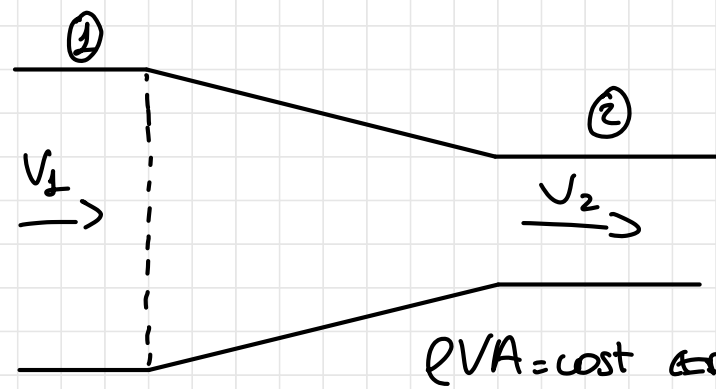
$I_2 = \rho_1 A_2 V_2 \cdot V_2 + (P_2 - P_0) A_2 = \frac{1 \cdot 50}{100} \cdot 100 + (-3,75) \cdot 0,005 \cdot 1000$

$= 31,25\ KPa$

$F_x = I_{1x} - I_{2x} = I_1 - I_2 \cos\alpha = 25 - 31,25 \cdot \frac{\sqrt{2}}{2} = 2,89\ N$

$F_y = I_{1y} - I_{2y} = 0 - I_{2y} \sin\alpha = -31,25 \cdot \frac{\sqrt{2}}{2} = -22,10N$ ↓ F_y

Alveo es



$TIC = 20$

$\gamma = 1,4$

$V_1 = V_2$

$\rho VA = cost \Leftrightarrow \rho A = cost$

$\frac{A_2}{A_1} = \frac{\rho_1}{\rho_2} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}}$

$\frac{A_2}{A_1} = (TIC)^{-\frac{1}{\gamma}} = (20)^{-\frac{1}{\gamma}} = 0,118$

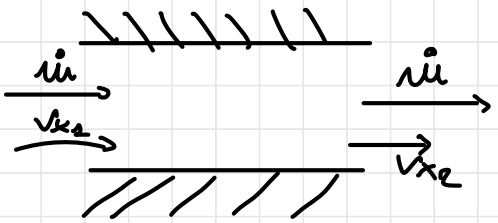
$\frac{F_x}{\rho_1 A_2} = \rho_1 V_1^2 A_1 - \rho_2 V_2^2 A_1 + (P_1 - P_3) A_2 + (P_2 - P_3) A_2 =$

$$= \dot{m}(V_1 - V_2) + \underbrace{(P_1 - P_0)A_1}_{A_2 P_2} - \underbrace{(P_2 - P_3)A_2}_{A_2 P_3} = 1 - \frac{P_2}{P_1}\frac{A_2}{A_1} =$$

$$= 1 - 20 \cdot 0,11$$

$$= -1,36$$

←



$\tau_b = 1,8$ $\quad \frac{F_x}{\dot{m} V_1} = ?$

$\gamma = 1.4$ $\quad P_2 = P_2$

$$\frac{F_x}{\dot{m} V_1} = \frac{I_{x_2} - I_{x_2}}{\dot{m} V_1}$$

non avendo i termini di pressione avendo $p = cost$

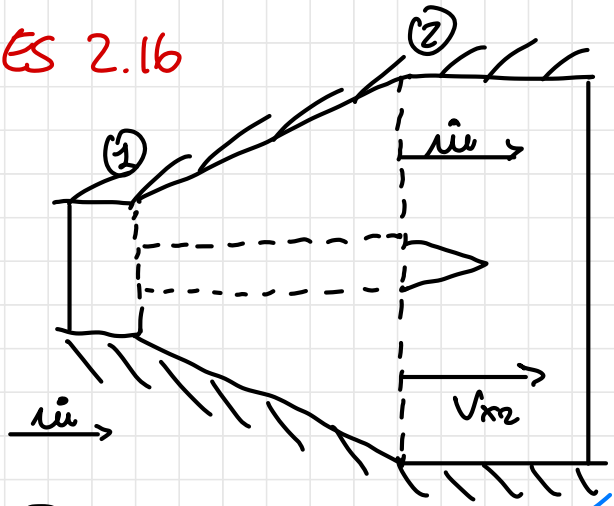
$$\frac{F_x}{\dot{m} V_1} = \frac{\dot{m} V_2 - \dot{m} V_2}{\dot{m} V_1} = 1 - \frac{V_2}{V_1} = 1 - 1,8 = -0,8$$

←
F_x

$\dot{m} = cost$ $\quad \rho_2 V_1 A_1 = \rho_2 V_2 A_2 \Rightarrow \frac{V_2}{V_1} = \frac{\rho_2}{\rho_2} = \frac{P_2 R T_2}{P_2 R T_1} = \frac{T_2}{T_1}$

$= \tau_b$

Es 2.16



$\tau_c = 0,79$ $\quad \frac{F_x}{P_1 A_1} = ?$

$\gamma = 1,4$

$V_1 = V_2$ $\quad P_0 = 0$ passoluto

$$\frac{F_x}{P_1 A_1} = \frac{I_{1x} - I_{2x}}{P_1 A_1} = \frac{\dot{m} V_1 + (P_1 - P_0) A_2 - \dot{m} V_2 - (P_2 - P_0) A_2}{P_1 A_1}$$

$$* = \frac{P_1 A_1 - P_2 A_2}{P_1 A_1} = 1 - \frac{P_2 A_2}{P_1 A_1} = 1 - \tau_c \frac{A_2}{A_1}$$

$\dot{m} cost \Rightarrow \rho_1 V_1 A_1 = \rho_2 V_2 A_2$

$V_1 = V_2$, $\quad \rho_1 A_1 = \rho_2 A_2 \Rightarrow \frac{A_2}{A_1} = \frac{\rho_1}{\rho_2} = \left(\frac{T_1}{T_2}\right)^{\frac{1}{\gamma - 1}} = (\tau_c)^{-2,5}$

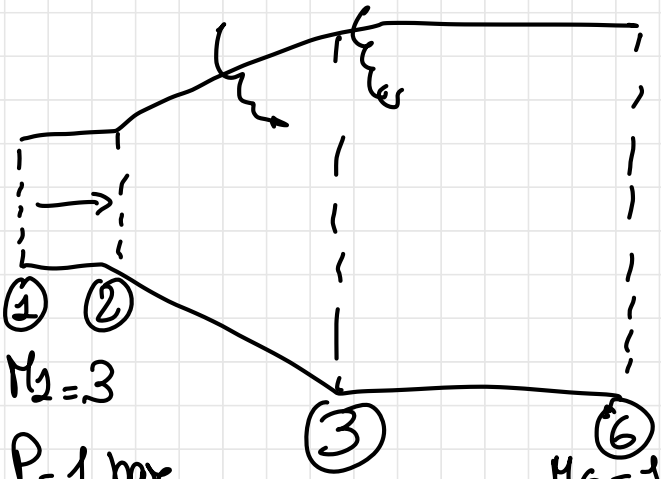
$= (0,79)^{-2,5}$

$= 1,803$

$\pi_c = (\tau_c)^{\frac{1}{\gamma}} = (0,79)^{3,5} = 0,438$

$* = 1 - 0,438 \cdot 1,803 = 0,210 \xrightarrow{F_x}$

Camera di comb SC ramjet ⇒ ingresso aereo



condotto diverge in modo che in questo modo si allontana da 1 così che non avere condizioni di

$M_1 = 3$

$P_1 = 1$ bar

$T_1 = 1000 K$

$A_1 = 1 m^2$

$M_6 = 1,2$ ipersonico

$A_6 = 1,4$

$\gamma = 1,4$

$R = 287 \frac{J}{Kg \cdot K}$

Flusso termico ?

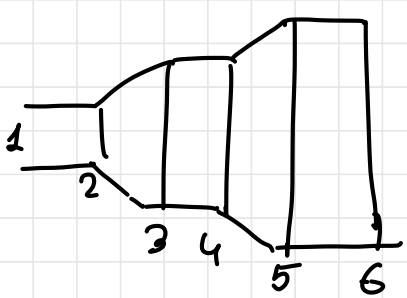
Da una parte aggiungo calore da altra parte sottraggo aria posso considerare come somma di tanti postazioni

Da 1 e 2 considero aggiungo calore

2 e 3

3 a 4

etc



una cosa da questo devo sottrarre ⇒ ipersonico

$\dot{q}_{1,2} = 500 \frac{kJ}{kg} = Q_{3,4} = Q_{5,6}$ dove $\frac{A_3}{A_2}$ è 1,2

$M_1 = 3$ comando $\frac{T_0}{T_0^*}$

ISO $\rightarrow \frac{T_1}{T_{01}} = 0,357$ $\quad T_{01} = \frac{T_1}{0,357} = \frac{1000}{0,357} = 2800\,K$

R $\rightarrow \frac{T_{01}}{T_0^*} = 0,054$ $\quad T_{02} = T_{01} + \frac{Q_{12}}{c_p} = 2800 + \frac{500}{1,004} = 3300K$

$\frac{T_{02}}{T_0^*} = \frac{T_{02}}{T_{01}} \cdot \frac{T_{01}}{T_0^*} = \frac{3300}{2800} \cdot 0,057 = 0,471 \xrightarrow{RA} M_2 = 2.12$

$\rightarrow \frac{A_2}{A^*} = 1,869$

$\frac{A_3}{A^*} = \frac{A_3}{A_2}\frac{A_2}{A^*} = 1.2 \cdot 1,869 = 2,24 \xrightarrow{ISO} M_3 = 2,32$

$\xrightarrow{RA} \frac{T_{03}}{T_0^*} = 0,736$

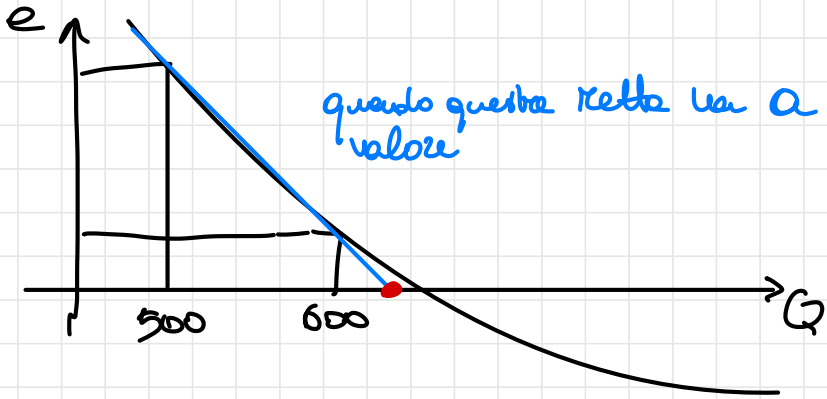
$T_{04} = T_{03} + \frac{Q_{34}}{c_p} = 3300 + \frac{500}{1,004} = 3788\,K$

$\frac{T_{04}}{T_0^*} = \frac{T_{04}}{T_{03}}\frac{T_{03}}{T_0^*} = \frac{3788}{3300} \cdot 0,736 = 0,847$

Di nuovo gli stessi proc

A RA finale mi trovo 1.505 $\rightarrow$ devo aumentare flusso

se metto 600 mi trovo comunque numero $\rightarrow$ falso positivo



quando questa retta va a 0 ho valore

$L > \Delta x$

formula finale: $Q^2 = \dfrac{Q_0 e_1 - Q_1 e_0}{e_1 - e_0}$

$$\psi = \frac{A^*}{A}\varphi^* = \gamma M\left(1+\frac{\gamma-1}{2}M^2\right)^{-\frac{(\gamma+1)}{2(\gamma-1)}} = \gamma M \varphi^{-K}$$

$$\psi = 1+\frac{\gamma-1}{2}M^2 \qquad K = \frac{\gamma+1}{2(\gamma-1)} \qquad \psi^* = \gamma\left(\frac{\gamma+1}{2}\right)^{-K}$$

$\dot{m} = 1030\ \frac{lbm}{s} = 1030 \cdot 0{,}453 = 467\ kg/s$

$P_0 = 3000\ P_{s1} = 3000 \cdot 6895 = 207\ bar$ (→ $\cdot 10^5$ conversione)

$T_t = 7350\ R = \frac{7350}{1.8} = 4080 K$

$R = 3800\ \frac{g^2}{a^2 R} = 3800 \cdot 0{,}3048^2 \cdot 1{,}8 = 635\ \frac{J}{kg\,K}$

Razzo è H_2O

$\frac{A_2}{A_1} = 77 \qquad \gamma = 1{,}25 \qquad M$ ad uscita ugelo = ?

Re iso $\quad M = 5{,}09$

devo scegliere un M iniziale e ideo

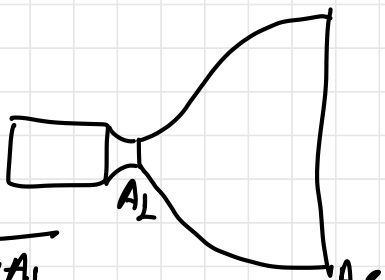
$K = \frac{1{,}25+1}{2(1{,}25-1)} = 4{,}5 \qquad \psi^* = 1{,}25\left(\frac{1{,}25+1}{2}\right)^{-4{,}50} = 0{,}736$

$\psi = 1 + 0{,}125 \cdot M^2 \qquad a_0 = \sqrt{\gamma R T_0} = 1000\ m/s$

A_1 è di gola

$\dot{m} = \frac{P_0 \cdot A_1 \psi^*}{a_0} = \frac{207 \cdot 10^5 \cdot A_1 \cdot 0{,}736}{1000} = 8464 \cdot A_1$

$A_1 = \frac{\dot{m}}{8464} = \frac{464}{8464} = 0{,}055$



$A_1 = \pi\left(\frac{d_1}{2}\right)^2 = \frac{\pi d_1^2}{4} \qquad d_1 = \sqrt{\frac{4A_1}{\pi}}$

$= \sqrt{\frac{4 \cdot 0{,}055^2}{3{,}14}} = 0{,}265\ m$

$d_2 = 2{,}32\ m$ ottenuto con $\sqrt{77}$

Supp M=4

$\Psi = 1 + 0{,}125 \cdot 16 - 3$

$\Psi = 1{,}25 \cdot 4{,}00 \cdot 3^{-4{,}50} - 0{,}0356$

$\frac{A}{A^*} = \frac{\Psi^*}{\Psi} = \frac{0{,}736}{0{,}0356} = 20{,}7$

$e = \frac{77 - 20{,}7}{77} = 0{,}731$

Supp M=5

$\Psi = 1 + 0{,}125 \cdot 25 = 4{,}13$

$\Psi = 1{,}25 \cdot 5 \cdot 4{,}13^{-4{,}50} = 0{,}01062$

$\frac{A}{A^*} = \frac{\Psi^*}{\Psi} = \frac{0{,}736}{0{,}01062} = 69{,}2$

$e_1 = \frac{77 - 69{,}2}{77} = 0{,}101$

$Q_2 = \frac{Q_1 e_0 - Q_0 e_1}{e_0 - e_1}$

$M = 5{,}09$

$F_x = \dot{m} V_2 + A_2 (P_2 - P_0)$

$P_0 = 1{,}13$ bar

$A_2 = A_1 \cdot \frac{A_2}{A_1} = 4{,}26\ m^2$

$\frac{T_0}{T_{0S}} = \frac{1}{4{,}24} \longrightarrow T_S = \frac{T_{0S}}{4{,}24} = \frac{4080}{4{,}24} = 963\ K$

$\psi = 1 + 0{,}125 \cdot 5{,}09^2 = 4{,}24$

Ag de $a_{0S} \Rightarrow a_S = \sqrt{\gamma R T} = \sqrt{1{,}25 \cdot 635 \cdot 963} = 876\ m/s$

M_S si intende M_2

$\frac{V_S}{a_S} = M_S \Rightarrow V_S = M_S a_S = 446\ m/s$

$P_S = P_{AS} \cdot \psi^{-\frac{1}{K}} = 207 \cdot 4{,}24^{-5} = 0{,}1510$ bar

$F_x = 467 \cdot 446 + 4{,}26 (0{,}152 - 1{,}013) = 170\ kN$

$2{,}02 \cdot 10^6 - 3{,}67 \cdot 10^5$

Se $p_a = 0$ sarebbe solo levemente più del vuoto (nel vuoto)

a quota = 4600 uscito in modo corretto, se lavoro a quota fuori atmosfera devo togliere parte dovuta a pressione

$F_x (P_0 = 0) = 2140\ kN$

A livello del mare spinta minima, poi aumenta e poi aumenta ancora

Il fatto che la spinta aumenti dopo andamento corretto mai => sono in difficoltà, ma solo che nel vuoto se avessi espansione (e dunque ugello) ancora maggiore la spinta a corretto sarebbe maggiore

Tipicamente nei raggiungimento ho grandi variabili, ci sono quando compromesso delle varie quote, la spinta aumenta perché diminuisce pressione ambiente

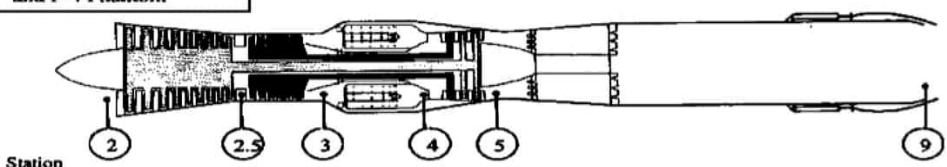
Lez 8 23/3/23

Farokhi problem 3.1

The total pressures and temperatures of the gas in an afterburning turbojet engine are shown (J57 "B" from Pratt & Whitney, 1988). The mass flow rates for the air and fuel are also indicated at two engine settings, the Maximum Power and the Military Power. Use the numbers specified in this engine to calculate:

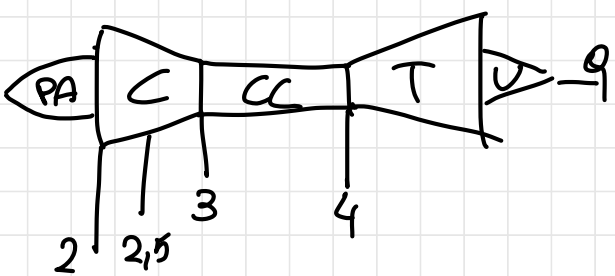
J57 "B" Series afterburning military turbojet sea level static internal pressures and temperatures (typical)

J57 powered many military aircraft including B-52, F-100, and F-4 Phantom



Station	2	2.5	3	4	5	9
P_t (psia)	14.7	54.0	167.0	158.0	36.0	31.9
T_t (°F)	59°	330°	660°	1570°	1013°	2540° (Maximum (A/B))
P_t (psia)	14.7	54.0	167.0	158.0	36.0	33.0
T_t (°F)	59°	330°	660°	1570°	1013°	1013° (Military)

Notes:
(1) Data for stations 1 through 7 also applies to a J57 "B" series nonafterburning turbojet
(2) Airflow: maximum w_a = 172 lb/s; Military w_a = 164 lb/s
(3) Fuel flow: maximum w_f = 33,650 lb/h; Military w_f = 8,520 lb/h
(4) Thrust: maximum F_n = 16,000 lb; Military F_n = 10,200 lb



$P_9 = 228$ kPa
$T_9 = 818$ K

$P_5 = 248$ kPa
$T_5 = 818$ K

$P_{t2} = 102$ kPa $P_{2,5} = 372$ kPa $P_3 = 115,2$ kPA $P_{t4} = 1059$ kPa

$T_{t2} = 228$ K $T_{2,5} = 448$ K $T_3 = 622$ K $T_4 = 1127$ K

a) f_{AB} e f ?

$f = \frac{\dot{m}_f}{\dot{m}_2} = \frac{2,073}{74,38} = 0,0144$ → AB OFF

$f_{AB} + f = \frac{\dot{m}_f}{m_2} = \frac{4,24}{76,0} = 0,0544$ → AB on

b) $\pi_{cL} = ?$ $\pi_{cH} = ?$ $\pi_t = ?$

$\pi_{cL} = \frac{P_{t2,5}}{P_{t2}} = 3,68$ (8 stadi)

$\pi_{cH} = \frac{P_{t3}}{P_{t2,5}} = 3,10$ (6 stadi)

$\pi_c = \pi_{cL} \cdot \pi_{cH} = 11,4$

$\pi_t = \frac{248}{1089} = 0,228$

c) $V_8 = ?$ velocità teorica possibile quando ugello adattato

$F = \dot{m}(V_8 - V_0) = \dot{m} V_8 \Rightarrow V_8 = \frac{F}{\dot{m}_8}$

a spento $F = 45.4\ kN \Rightarrow V_8 = \frac{45.4\ kN}{(74.4 + 1,073)} = 601\ m/s$

acceso $F = 71,2\ kN \Rightarrow V_8 = \frac{71,2}{78,0 + 4,24} = 866\ m/s$

d) η_{tH} con AB a spento che a acceso

$Q_R = 43,266\ cp$

$\eta_t = \frac{(1+f)V_8^2 - V_0^2}{2 f Q_R} = \frac{(0,14)(601)^2}{2(0,0144)(43,3 \cdot 10^6)}$

$= 0,235$ con spento

$\eta_t = \frac{(1,0544)(866)^2}{2(0,0544)(43,3 \cdot 10^6)} = 0,268$

$TSFC = \frac{\dot{m}_f}{F}$ $\quad AB_{OFF} = \frac{1,073\ kg/s}{45,4\ kN} = 0,0236\ \frac{kg}{kN \cdot s} = 23,6\ \frac{mg}{kN \cdot s}$

$AB_{ON} = \frac{4,24}{71,2} = 0,0596 = 59,6\ \frac{mg}{kN \cdot s}$

g) $\%F = \frac{F_{AB} - F}{F} \cdot 100 = 57\%$

$\%\dot{m}_f = \frac{\dot{m}_{f_{AB}} - \dot{m}}{\dot{m}} \cdot 100 = 235\%$

Non si ha aumento spinta prop al consumo perché rendimento del ciclo lavora a TIC più basso

h) η ciclo di Carnot con le stesse condizioni:

$\eta = 1 - \frac{T_{min}}{T_{max}} = \frac{AB_{OFF}}{} = 1 - \frac{288}{1128} \simeq 0,745$

$\frac{}{AB_{ON}} = 1 - \frac{288}{1167} = 0,827$

Altro es

$M_0 = 2$

$p_0/p_3 = 1$

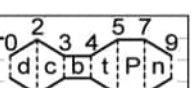
$Q_R = 42800\ kJ/kgK$

il resto sta tabella

TurboJet y Tom

Turbo Jet By TomLevel 4

	2		3	4	5	7	9		
	diff		comp	CC	Tur	AB	No		
c_p	1004				1152		1243	J/kg	
γ	1.4				1.33		1.3		
π	0.96		10	0.95		0.98	0.97		
$\eta, e_{c.t}$			0.9	0.99	0.9	0.99			
Tt				1750			2250		
M0	2			po/p9	1	QR	42800	kJ/kgK	
T0	250	K		p0	101,300	Pa	η_m		0.99



K, K_0, K_8 $\quad K = \frac{\gamma - 1}{\gamma} = \frac{1,4 - 1}{1,4} = 0,286$

$K_t = \frac{\gamma - 1}{\gamma} = \frac{1,33 - 1}{1,33} = 0,248$

R, R_c

$R = K \cdot c_p = 0,286 \cdot 1004 = 284 \ J/kg\,K$

$R_0 = K_0 \cdot c_p = 0,248 \cdot 1152 = 286 \ J/kg\,K$

Hp: p. bruciatore rimosso, uno estate pompa $\Rightarrow \Pi_{AB} = 1$

EFFETTO RAM

$a_0 = \sqrt{\gamma R T_0} = \sqrt{1,4 \cdot 287 \cdot 280} = 317 \ m/s$

$V_0 = M_0 a_0 = 2 \cdot 317 \ m/s = 634 \ m/s$

$\tau_r = \psi = 1 + \frac{\gamma - 1}{2} \cdot M_0^2 = 1 + 0,2 \cdot 4 = 1,8$

$P_{t0} = \Pi \cdot P = 791 \ kPa$

$\Pi_R = \tau_R^{\frac{1}{1K}} = 1,8^{3,5} = 7,81$

$T_{t0} = \tau_R \cdot T_0 = 450$

DIFFUSORE

$T_{t2} = T_{t0}$

$p_{02} = p_{t0} \cdot \Pi_d = 791 \cdot 0,96 = 753 \ kPa$

COMPRESSORE

$$\tau_c = \pi_c^{k_{rec}} = 10^{\frac{0,284}{0,9}} = 2,08$$

$$P_{t3} = \pi_c \cdot P_{t2} = 10 \cdot 759 = 7590 \text{ kPa}$$

$$T_{t3} = \tau_c \cdot T_{amb} = 2,08 \cdot 450 = 936 \text{ K}$$

CAM COMBUSTIONE

$$\tau_h = \frac{h_{t4}}{h_0} = \frac{c_p T_{t4}}{c_p T_0} = \frac{1102 \cdot 1750}{1004 \cdot 250} = 8,03$$

$$f = \frac{\tau_h - \tau_c \tau_r}{\frac{Q_{R4b}}{c_p T_0} - \tau_h} = \frac{8,03 - 2,08 \cdot 1,8}{\frac{42,8 \cdot 10^6 \cdot 0,98}{1004 \cdot 250} - 8,03} = 0,0266$$

$$\rightarrow 165,8$$

$$\tau_b = \frac{\tau_h}{\tau_R \tau_c} = \frac{8,03}{1,80 \cdot 2,08} = 2,14$$

$$P_{t4} = \pi_b \cdot P_{t3} = 7590 \cdot 0,95 = 7210 \text{ kPa}$$

TURBINA si adatta $\Rightarrow$ parlo di τ_c

$$\tau_t = 1 - \frac{(\tau_c - 1)\tau_r}{\eta_m (1+f)\tau_h} = \frac{1,08 \cdot 1,8}{0,99 (1,0271) 8,03} = 0,162$$

$$\pi_t = \tau_t^{\frac{1}{\epsilon_t \cdot k}} = 0,162^{\frac{1}{0,90 \cdot 0,248}} = 0,296$$

$$P_{t5} = \pi_t \cdot P = 0,296 \cdot 7210 = 2134 \text{ kPa}$$

$T_{t5} = \tau_6 \cdot T_{t4} = 0{,}762 \cdot 1750 = 1334\ K$

UGELLO

$T_{tg} = T_{t5} = 1334$ adiabatico $\Rightarrow$ T tot cost

$P_{tg} = P_{t5} \cdot \pi_M = 0{,}97 \cdot 2134 = 2070\ kPa$

$$\frac{T_g}{T_{tg}} = \left(\frac{P_g}{P_{tg}}\right)^{k_g} = \frac{1}{\psi_g} = \left(\frac{101{,}3}{2070}\right)^{0{,}268} = 0{,}673$$

$T_g = 0{,}673 \cdot 1334 = 631$

$a_g = \sqrt{\gamma R T_g} = \sqrt{1{,}33 \cdot 286 \cdot 631} = 490$

$$\psi_g = 1 + \frac{\gamma_g - 1}{2} M_g^2 \Rightarrow M_g = \sqrt{\frac{\psi_g - 1}{\frac{\gamma_g - 1}{2}}} = \sqrt{\left(\frac{1}{0{,}673} - 1\right) \cdot \frac{2}{1{,}33 - 1}} = 2{,}60$$

$V_g = M_g \cdot a_g = 2{,}6 \cdot 490 = 1274$

Se avessi rapp aree dovrei risolvere ugello: da $\frac{A}{A^*} \overset{ISO}{\Rightarrow} M_g \rightarrow T_{tg}$

e quindi anche spinta da pressione

$$\frac{V_g}{a_0} = \frac{1274}{317} = 4{,}02$$

$$\frac{F_{th}}{\dot{m} a_0} = (1 + f + \cancel{\beta_3}) \frac{V_g}{a_0} \left(1 + \underbrace{\frac{1 - P_0/P_g}{\gamma_g M_g^2}}_{\to 0}\right) - M_0$$

$$= (1{,}024) \cdot 4{,}02 - 2 = 2{,}13$$

$$B = a_0^2 \left[(1+f)\left(\frac{V_g}{a_0}\right)^2 - M_0^2\right] = 1{,}265 \cdot 10^6\ \frac{m^2}{s^2}$$

$$\eta_{th} = \frac{B}{2 g Q_R} = \frac{1,265 \cdot 10^6}{0,0266 \cdot 2 \cdot 42,8 \cdot 10^6} = 0,556$$

$$\eta_p = \frac{2 F_u \cdot V_0 / u_0 \cdot a_0 / a_0}{B} \quad \text{(prendo } F_u / u_0 \cdot a_0\text{)} = \frac{2 \cdot 2,13 \cdot 317 \cdot 634}{1,265 \cdot 10^6} = 0,677$$

$$\eta = \eta_{th} \cdot \eta_p = 0,556 \cdot 0,677 = 0,377$$

$$TSFC = \frac{f}{\frac{F_u}{u_0} \cdot \frac{a_0}{a_0}} = \frac{0,0266}{2,13 \cdot 317} = 3,94 \cdot 10^{-5} \frac{kg}{s \cdot N}$$

Confronto post bruciatore

$$p_{t7} = \frac{p_{t7}}{p_{t5}} \cdot p_{t5} = 0{,}98 \cdot 2134\,kPa = 2091\,kPa$$

$$\tau_{hAB} = \frac{h_{t7}}{h_0} = \frac{c_{p7} \cdot T_{t7}}{c_p \cdot T_0} = \frac{1243\,\frac{J}{kgK} \cdot 2350\,K}{1400\,\frac{J}{K \cdot kg} \cdot 250\,K} = 11{,}14$$

$$f_{AB} = \frac{(1+f)(\tau_{hAB} - \tau_h \tau_t)}{Q_{RAB} \cdot \frac{\eta_{AB}}{c_p \cdot T_0} - \tau_{hAB}} = \frac{(1+0{,}0247)(11{,}14 - 8{,}03 \cdot 0{,}767)}{\frac{42800 \cdot 0{,}98}{1{,}004 \cdot 250} - 11{,}14}$$

$$= 0{,}0318$$

$$p_{t8} = \frac{p_{t8}}{p_{t7}} \cdot p_{t7} = \pi_{MAB} \cdot p_{t7} = 0{,}97 \cdot 2091\,kPa = 2028\,kPa$$

$T_{t8} < T_{t7}$

$$k_8 = \frac{\gamma - 1}{\gamma} = \frac{1{,}3 - 1}{1{,}3} = 0{,}231$$

$$\frac{p_{t8}}{p_8} = \frac{p_{t8}}{p_0} \cdot \frac{p_0}{p_8} = \frac{2028}{101{,}3} \cdot 1 = 20{,}0$$

$$M_8 = \sqrt{\frac{2}{0{,}3}\left[\left(\frac{p_{t8}}{p_8}\right)^{k_8} - 1\right]} = \sqrt{\frac{2}{0{,}3}\left[(20)^{0{,}231} - 1\right]} = 2{,}58$$

$$\frac{T_{t8}}{T_8} = \left(\frac{p_{t8}}{p_8}\right)^{k_8} = 20^{0{,}231} = 1{,}998$$

$$T_S = \frac{T_S}{T_{tS}} \cdot T_{tS} = \frac{1}{1{,}958} \cdot 2250\,K = 1126\,K$$

$$a_S = \sqrt{\gamma R T_S} = \sqrt{1{,}3 \cdot 287 \cdot 1126} = 648\,\frac{m}{s}$$

$$V_S = M_S \cdot a_S = 2{,}58 \cdot 648\,\frac{m}{s} = 1672\,\frac{m}{s}$$

$$\frac{V_S}{a_0} = \frac{1672}{317} = 5{,}27$$

$$\frac{F_u}{\dot{m} a_0} = (1 + \zeta + \zeta_{AS}) \frac{V_S}{a_0} - M_0 =$$

$$= (1 + 0{,}0266 + 0{,}0318) \cdot 5{,}27 - 2 = 3{,}58$$

$$\eta_{th} = \frac{(1 + \zeta + \zeta_{AS}) V_S^2 - V_0^2}{2(\zeta + \zeta_{AS}) Q_e}$$

$$B = a_0^2 \left[(1 + \zeta + \zeta_{AS}) (V_S/a_0)^2 - (V_0/a_0)^2 \right]$$

$$= 317^2 \left[(1 + 0{,}0266 + 0{,}0318) \cdot 5{,}27^2 - 2^2 \right]$$

$$= 2{,}55 \cdot 10^6\,\frac{m^2}{s^2}$$

$$\eta_{th} = \frac{2{,}55 \cdot 10^6}{2(0{,}0266 + 0{,}0318) \cdot 42{,}8 \cdot 10^6} = 0{,}510$$

$$\eta_p = \frac{2 F V_0 / \dot{m}_0}{B} = \frac{2 \frac{F_0 V_0}{\dot{m}_0 a_0} \cdot a_0}{B} = \frac{2 \cdot 3{,}58 \cdot 317 \cdot 634}{2{,}55 \cdot 10^6} = 0{,}564$$

$\eta = \eta_{th} \cdot \eta_p = 0{,}288$

$TSFC = \frac{\dot{m}_f}{F} = \frac{\dot{m}_f}{\frac{F}{\dot{m}_0 a_0} \cdot \dot{m}_0 a_0} = \frac{(f + f_{AB})}{\frac{F}{\dot{m}_0 a_0} \cdot a_0} = 5{,}15 \cdot 10^{-5} \frac{kg}{Ns}$

Lez 10 28/03/23

Problema 3.2 Rolls JT3D-3B

$\alpha = \frac{\dot{m}_{13}}{\dot{m}_3} = \frac{120{,}2}{88{,}2} = 1{,}359$

$F = ?$ $\dot{m}_3 h_3$ $\dot{m}_4 h_{t4}$ $\dot{m}_f = \dot{m}_4 - \dot{m}_3$

$Q_R \dot{m}_f \eta_B$

$\frac{Q_R \dot{m}_f \eta_B}{\dot{m}_3} = \frac{\dot{m}_4 h_{t4} - \dot{m}_3 h_{t3}}{\dot{m}_3}$

$f = \frac{\dot{m}_f}{\dot{m}} \Rightarrow \dot{m}_f = f \cdot \dot{m}$

$= 0{,}01122 \cdot 88{,}5 =$

$= 0{,}954 \ kg/s$

$Q_R f \eta_B = (1+f) h_{t4} - h_{t3}$

$f = \frac{h_{t4} - h_{t3}}{Q_R \eta_B - h_{t4}} =$

$= \frac{0{,}26 \cdot 1860 - 0{,}24 \cdot 1175}{18600 \cdot 1 - 0{,}26 \cdot 1860}$

$= 0{,}01112$

Condizioni statiche sezione ventilatore zona

$F = \dot{m}_3 V_3 + \dot{m}_{13} V_{13} =$

$= 48{,}8 \ kN$

$$\eta_{th} = \frac{\dot{m}_3 \frac{V_3^2}{2} + \dot{m}_{13} \frac{V_{13}^2}{2}}{QR \cdot \dot{m}_f} = \frac{(58,5 + 0,984)\left(\frac{4,75}{2}\right)^2 + (120,2)\left(\frac{302}{2}\right)^2}{43,3 \cdot 10^6 \cdot 0,984}$$

$$= 0,366$$

$\pi_c = \frac{P_{t3}}{P_{t2}} = \frac{137,9}{102,4} = 13,6$ aumento leggermente perché è aumentato il π_c

$$TSFC = \frac{\dot{m}_f}{F} = \frac{0,954}{78,8\,kN} = 0,01250 \frac{kg}{s} \cdot \frac{1}{kN}$$

prima $TSFC = 3,94 \cdot 10^{-2}$ ⇒ ridotto

$$\frac{F}{\dot{m}_a} = \frac{78,8\,kN}{(120,2+88,5)\cdot 360} = 1,158$$

↳ $\dot{m}_{13} + \dot{m}_3$

$$a_0 = \sqrt{\gamma R T_0} = \sqrt{1,4 \cdot 287 \cdot 288} = 340$$

$$\eta_{compr} = 1 - \frac{T_0}{T_{t4}} = 1 - \frac{288}{1093} = 0,74$$

$$T_{t3} = T_3 + \frac{V_3^2}{2} \frac{1}{c_p}$$

$$T_{13} = T_{t,13} - \frac{V_{13}^2}{2c_p} = 350 - \frac{302^2}{2 \cdot 1005} = 305\,K$$

$$a_{13} = \sqrt{\gamma R T_{13}} = \sqrt{1,4 \cdot 287 \cdot 305} = 350$$

$M_{13} = \frac{V_{13}}{a_{13}}$ = un po' alto l'uno = 0,862

$T_8 = T_{t8} - \frac{v_8^2}{2cp} = 750 - \frac{475^2}{2 \cdot 1088} = 646K$

$a_8 = \sqrt{\gamma R T_8} = \sqrt{1,36 \cdot 287 \cdot 646} = 502$

$M_8 = \frac{v_8}{a_8} = \frac{475}{502} = 0,88$ ugo però $= 0,866$ (su mappa)

Lavoro su m_{13} perché T_{18} e $P_{18} = T_{13}$ e P_{13}

Ora 3.4

$\pi_c = \frac{p_{t3}}{p_{t2}} = \frac{2180 \text{ kPa}}{101,4 \text{ kPa}} = 21,5$

$F_{jet} = \dot{m}_{18} V_8 = 270 \cdot 566 = 152,7 kN$

$\dot{m}_{18} = \dot{m}_3$

$F_{core} = \dot{m}_3 \cdot V_8 = (\dot{m}_3 + \dot{m}_f) \cdot V_8 = 41,3 kN$

$f = \frac{cp_4 T_{t4} - cp_3 T_{t3}}{Q_{BVP} - cp_4 T_{t4}} = 0,0172$

$\dot{m}_f = f \cdot \dot{m}_2 = 0,0172 \cdot 112 = 1,9264$

$\frac{F_{jet}}{F_{core}} = \frac{152,7}{41,3} = 3,68$

$F_{tot} = F_{jet} + F_{core} = 194 kN$

$F_{jet} / F_{tot} = 78,7\%$

$$\lambda = \frac{\dot{m}_{19}}{\dot{m}_3} = \frac{566}{112} = 5{,}05$$

$$\eta_{th} = \frac{(\dot{m}_3 + \dot{m}_f) V_9^2/2 + \dot{m}_{19} \cdot V_{19}^2/2}{Q_B \, \dot{m}_f} =$$

$$= \frac{(112{,}0 + 1{,}926)\frac{363^2}{2} + 566 \cdot \frac{270^2}{2}}{43.3 \cdot 10^6 \cdot 1{,}926} = 33.5\%$$

$$TSFC = \frac{\dot{m}_f}{F_{TOT}} = \frac{1{,}926}{194{,}0} = 0{,}00997$$

$$\eta_{CARNOT} = 1 - \frac{T_0}{T_{t4}} = 1 - \frac{288}{1350} = 78{,}6\%$$

$$\pi_{C_{LP}} = \frac{221}{101.4} = 2{,}18 \qquad \pi_{C_{HP}} = \frac{P_{t3}}{P_{t2}} = \frac{2180}{221} = 9{,}84$$

HP > LP perché gira più vel e ha più stadi per bilanciare albero

$M_{19} = 0{,}788$

$M_9 = 0{,}711$

$$P_{LP} = \dot{m}_3 \cdot c_{p3} \cdot (T_{t2,5} - T_{t2})$$

$$= 112 \cdot 1005\,(372 - 288) = 9{,}44\,MW$$

$$P_{HP} = \dots = 41{,}2\,MW$$

cambiano solo le T

caduta in $P_{fan} = 22.4$ MW

$P_{HP} > P_{fan}$ perché poi deve andare a turbina che muove a sua volta fan e compressore

$P_{LP} = 73,8$ MW

$P_{TURBINA} = \dot{m}_4 c_{p4} \cdot \Delta T = 47,2$ MW

$P_{RESISTENZA} = \dot{Q} = \dot{m}_4 c_{p4} T_{t4} - \dot{m}_3 c_{p3} T_{t3} = 83,7$ MW

un po' turbina, un po' espansione nell'ugello e un po' perse

Es JTBd by Tom

$$K = \frac{\gamma - 1}{\gamma} = \frac{1,4-1}{1,4} = 0,286$$

$$K_t = \frac{\gamma_t - 1}{\gamma_t} = \frac{1,35-1}{1,35} = 0,259$$

$$R = K c_p = 286 J/Kg$$

$$R_t = K_t c_{pt} = 274 J/Kg$$

effetto RAM

$a_\infty = \sqrt{\gamma R T_\infty} = 340$ m/s $\quad V_0 = 0 \Rightarrow M_0 = 0$

$P_{t0} = \pi_R \cdot p_0 = p_0 = 101,3$ kPa $\quad \tau_r = 1 \rightarrow T_{t0} = T_0 = 288$ K

Diffusore

$T_{t2} = T_{t0} = T_0 = 288\,K$

$p_{t2} = \underset{1}{\pi_d} \cdot \underset{p_0}{p_{t0}} = p_0 = 101{,}3\,kPa$

Compressore

$\tau_c = \pi_c^{\frac{k}{e}} = 21{,}5^{\frac{0{,}286}{0{,}82}} = 2{,}58$

$\tau_c = 2{,}58$

$P_{t3} = \pi_c P_{t2} = 2180\,kPa$

$T_{t3} = \tau_c \cdot T_{t2} = 746{,}8\,K$

Camera combustione

$\tau_\lambda = \frac{c_{pcu} T_{t4}}{c_p T_0} = \frac{1057 \cdot 1350}{1005 \cdot 288} = 4{,}93$

$f = \frac{\frac{\tau_\lambda - \tau_c \tau_R}{Q_R \eta_B}}{c_p T_0} - \tau_\lambda = \frac{4{,}93 - 2{,}58 \cdot 1}{\frac{42818}{1004 \cdot 288} \cdot 0{,}95 - 4{,}93} = 0{,}01724$

$\tau_t = \frac{\tau_\lambda}{\tau_c \tau_R} = \frac{4{,}93}{2{,}58 \cdot 1} = 1{,}803$

$P_{t4} = \pi_B \cdot p_{t3} = 2080\,kPa$

TURBINA

τ_t depende de λ

$\pi_g = 1{,}53$

$\tau_g = \pi_g^{K_{leg}} = 1{,}135$

$P_{t3} = \pi_g \cdot p_{e2} = 155{,}0\ KPa$

$T_{T13} = \tau_g \cdot T_{t2} = 327\ K$

$$\eta_t = 1 - \frac{\tau_c [(\tau_c - 1) + \alpha (\tau_g - 1)]}{\eta_m (1+f)\tau_\lambda} = 0{,}537$$

$\pi_t = \tau_t^{\frac{1}{K_{et}}} = 0{,}689$

$\pi_T = 0{,}0688$

$\tau_t = 0{,}537$

$T_{T5} = \tau_t \cdot T_{T4} = 725\ K$

$P_{T5} = P_{T4} \cdot \pi_T = 2080\ kpa \cdot 0{,}0688 = 146{,}3\ kpa$

$\pi_M = 0{,}98$

$P_{T4} = \pi_M \cdot P_{T5} = 141{,}1\ KPa$

$T_{T3} = \tau_m T_{T5} = 725$

↳ 1, espansão adiabática

$$\frac{T_{Tg}}{T_g} = 1 + \frac{\gamma-1}{2} M_g^2 \Rightarrow M_g = \sqrt{\frac{\frac{T_{Tg}}{T_g} - 1}{\frac{\gamma-1}{2}}} = \sqrt{\frac{\left(\frac{p_{Tg}}{p_g}\right)^K - 1}{\frac{\gamma-1}{2}}}$$

ho assegnato $p_g/p_0 = 1 \Rightarrow \left(\frac{p_{Tg}}{p_g}\right)^K = \left(\frac{141{,}1}{101{,}3}\right) = 1{,}404^K$
$= 1{,}404^{0{,}259} =$
$= 1{,}092$

altrimenti dovevo valutarlo mediante rapporti

$$\Rightarrow M_g = \sqrt{(0{,}092) \cdot \frac{2}{0{,}35}} = 0{,}725 \Rightarrow p_g/p_0 \text{ è corretto.}$$

se era sonico o supersonico era un prob

$T_g = \frac{T_g}{T_{Tg}} \cdot T_{Tg} = 664\,K$ ci serve per a_g

$$a_g = \sqrt{\gamma R T_g} = \sqrt{1{,}35 \cdot 274 \cdot 664} = 486\ m/s$$

$$V_g = M_g \cdot a_g = 0{,}725 \cdot 486 = 360\ m/s$$

Per calcolare Spinta valuto $\frac{V_g}{a_0}$ volendo valutarla come specifica

$$\frac{V_8}{a_0} = \frac{360 m/s}{340 m/s} = 1{,}060$$

Ugello fan

$$T_{T18} = T_{T13} = 320 K$$

$$P_{T18} = \pi_{fg} \cdot P_{T13} = 0{,}98 \cdot 155 kPa = 153{,}5 kPa$$

$$\frac{P_{T18}}{P_0} = \frac{153{,}5 kPa}{101{,}3 kPa} = 1{,}515$$

$$\frac{T_{T18}}{T_8} = \left(\frac{P_{T18}}{P_8}\right)^{\kappa} = 1{,}515^{0{,}286} = 1{,}126$$

$$M_{18} = \sqrt{\left(\frac{T_{T18}}{T_8} - 1\right)\frac{2}{\gamma - 1}} = 0{,}794$$

$$V_{18} = M_{18}\, a_{18}$$

$$a_{18} = \sqrt{\gamma R T_{18}} = \sqrt{1{,}4 \cdot 287 \cdot 280} = 341 m/s$$

$$T_{18} = \frac{T_{18}}{T_{T18}} \cdot T_{T18} = 280 K$$

$$\frac{V_{18}}{a_0} = \frac{271}{340} = 0{,}797$$

$$\alpha = 5{,}05$$

$$f = 0{,}01724 = 0{,}017$$

$$\frac{\dot{F}_{id\ core}}{\dot{m}_{air} \cdot a_0} = \frac{(1+f)}{(1+\alpha)}\frac{V_8}{a_0} - \frac{1}{1+\alpha}\frac{V_0}{a_0} = \frac{1{,}017}{6{,}05} \cdot 1{,}060 = 0{,}178$$

$$\frac{\dot{F}_{id\ fan}}{\dot{m}_{air}\, a_0} = \frac{\alpha}{1+\alpha}\frac{V_{18}}{a_0} - \frac{\alpha}{1+\alpha}\frac{V_0}{a_0} = \frac{5{,}05}{6{,}05} \cdot 0{,}797 = 0{,}665$$

$\frac{Fu}{mair}$ = somma di queste due = 0,1782 + 0,665 = 0,843

% Fu cozze = $\frac{Fu\,cozze}{Fu} = \frac{0,1782}{0,843} \cdot 100 = 21,2\%$

% Fu fan = $\frac{Fu\,fan}{Fu} = 78,9\%$

$TSFC = \frac{\dot{m}_f}{Fu} = \frac{\dot{m}_{ao} \cdot f}{Fu} = \frac{f}{\frac{Fu}{m_{air}} \cdot \frac{\dot{m}_{ao}}{m_{air}}} = \frac{0,01724}{0,843 \cdot 340 \cdot 6,05} = 9,91 \cdot 10^{-6} = \frac{kg \cdot s}{N}$

$\dot{m}_{ao} \hookrightarrow 1+2$

$\eta_{TH} = \frac{(1+f) V_{9.e}^2 - V_0^2}{2 f Q_R} + \frac{2 V_{19.e}^2 - V_0^2}{2 f Q_R}$

$\eta_{TH} = \frac{N}{2 f Q_R} = \frac{5,03 \cdot 10^5}{2 \cdot 0,01724 \cdot 42,8 \cdot 10^6} = 0,340$

$N = 1,014 (360)^2 - 0 + 5,05 [(241)^2 - 0] = 5,03 \cdot 10^5 \frac{m^2}{s^2}$

$\eta_P = \frac{Fu\, v_0}{\Delta K \dot{E}} = \frac{2 Fu\, v_0}{N \cdot \dot{m}_{ao}} = \frac{2 \frac{Fu}{m_{air\,ao}} \cdot m_{air\,ao} \cdot v_0}{N} = 0$ $\quad v_0 = 0$

JT9d by Pau ma con $M_0 = 0{,}85$

$M_0 = 0{,}85 \quad a_0 = 340\ m/s \quad V_0 = M_0 a_0 = 289\ m/s$

Effetto RAM e presa d'aria

$\tau_r = \frac{T_0}{T_0} = 1 + \frac{\gamma - 1}{2} M_0^2 = \psi_0 = 1 + 0{,}2 \cdot 0{,}85^2 = 1{,}145$

$\Pi_R = \tau_r^{1/k} = (1{,}145)^{1/0{,}287} = 1{,}603$

$T_{t2} = T_{t0} = \frac{T_{t0}}{T_0} \cdot T_0 = 1{,}145 \cdot 288\ K = 330\ K$

$P_{t0} = \Pi_R \cdot P_0 = 1{,}603 \cdot 101{,}3\ kPa = 162{,}4\ kPa$

$P_{t2} = \Pi_d \cdot P_{t0} = 101{,}3\ kPa$

$\Pi_d = 1$

Compressore

$\Pi_c = 21{,}5$

$\tau_c = 2{,}58$

$P_{t3} = \Pi_c \cdot P_{t2} = 21{,}5 \cdot 162{,}4\ kPa = 3490\ kPa$

$T_{t3} = \tau_c \cdot T_{t2} = 2{,}58 \cdot 330\ K = 855\ K$

Camera di combustione:

$P_{T4} = \pi_b \cdot P_{T3} = 0{,}985 \cdot 3480 = 3330\,kPa$

$\tau_h = \frac{c_{pq} T_{T4}}{c_p T_0} = \frac{1057 \cdot 1350K}{1004 \cdot 288K} = 4{,}93$

$f = \frac{\tau_h - \tau_c \tau_R}{\frac{Q_R \eta_B}{c_p T_0} - \tau_h} = \frac{4{,}93 - 2{,}58 \cdot 1{,}145}{\frac{42{,}8 \cdot 10^6 \cdot 0{,}95}{1004 \cdot 280K} - 4{,}93} = 0{,}01448$

Fan (risolverla per fare Turbina)

$\tau_f = 2{,}135 \quad \pi_f = 1{,}53$

$P_{T13} = P_{t2} \cdot \pi_f = 162{,}4kPa \cdot 1{,}53 = 250kPa$

$T_{T13} = T_{T2} \cdot \tau_f = 330K \cdot 2{,}135 = 345$

Turbina

$\tau_t = 1 - \frac{\tau_r \left(\tau_c - 1 + 2(\tau_f - 1)\right)}{\eta_m (1+f) \tau_h} = \frac{1 - 1{,}05 \left(1{,}58 + 5{,}05(0{,}135)\right)}{0{,}98(1+0{,}14) \cdot 4{,}93} = 0{,}436$

$\pi_T = \tau_t^{\frac{1}{\kappa \epsilon t}} = (0{,}469)^{\frac{1}{0{,}259 \cdot 0{,}9}} = 0{,}0388$

$T_{T5} = \tau_t \cdot T_{T4} = 0{,}469 \cdot 1350 = 633K$

$P_{T5} = \pi_T \cdot P_{T4} = 0{,}0388 \cdot 3330 = 129{,}2\,kPa$

Ugello

$P_{t3} = \pi_M P_{t5} = 129,2 \cdot 0,98 = 126,6\ kPa$

$T_{t3} = T_{t5}$

$\frac{T_{t3}}{T_3} = \psi_3 = 1 + \frac{\gamma-1}{2} M_3^2$

$\frac{P_{t3}}{P_3} = \frac{P_{t3}}{P_0} \cdot \frac{P_0}{P_3} = \frac{126,6\ kPa}{101,3\ kPa} = 1,250$

con $\frac{T_{t3}}{T_3} = \left(\frac{P_{t3}}{P_3}\right)^{\kappa} = (1,250)^{0,259} =$

$= 1,059$

$M_3 = \sqrt{\left(\frac{T_{t3}}{T_3} - 1\right)\frac{2}{\gamma-1}} = 0,583$

$T_3 = \frac{T_3}{T_{t3}} \cdot T_{t3} = \frac{1}{1,059} \cdot 633\ K = 598\ K$

$a_3 = \sqrt{\gamma \cdot R \cdot T_3} = \sqrt{1,35 \cdot 274 \cdot 598} = 470\ K$

$V_3 = M_3 a_3 = 0,583 \cdot 470\ \frac{m}{s} = 274\ \frac{m}{s}$

$\frac{V_3}{a_0} = \frac{274\ m/s}{340\ m/s} = 0,806$

$\frac{V_3}{a_0} < M_0 \Rightarrow$ flusso vegetativo nel core

Ugello del fan

$P_{t13} = \pi_{Mf} \cdot P_{t13} = 250\ kPa \cdot 0,99 = 248\ kPa$

$T_{t13} = T_{t13} = 375\ K$

$$\frac{P_{T1S}}{P_{1S}} = \frac{P_{T1S}}{P_0} \cdot \frac{P_0}{P_{1S}} = \frac{248}{101,3} = 2,45 > 2$$

⇒ M_{S} invece supersonico che non può essere, per questo impongo M_{1S}

$$\frac{T_{T1S}}{T_{1S}} = \left(\frac{P_{T1S}}{P_{1S}}\right)^{k} = (2,45)^{0,286} = 1,292$$

$$M_S = \sqrt{\left(\frac{T_{T1S}}{T_{1S}} - 1\right)\frac{2}{\gamma - 1}} = 1,205$$

impongo $M_{1S} = 1$ ⇒ $\frac{T_{T1S}}{T_{1S}} = 1 + \frac{\gamma - 1}{2} \cdot M_{1S}^2 = 1,2$

$$T_{1S} = \frac{T_{1S}}{T_{T1S}} \cdot T_{T1S} = \frac{375}{1,2} = 313\,K$$

$$a_{1S} = \sqrt{\gamma R T_{1S}} = \sqrt{1,4 \cdot 287 \cdot 313} = 355\ m/s$$

$$V_{1S} = M_{1S}\, a_{1S} = 1 \cdot 355\ m/s$$

P_{1S} per calcolare spinta di pressione

$$P_{1S} = \frac{P_{1S}}{P_{T1S}} \cdot P_{T1S} = \left(\frac{1}{\psi}\right)^{\alpha} \cdot P_{T1S} = 0,528 \cdot 248\,kPa = 130,9\,kPa$$

$$V_{1S,e} = V_{1S}\left(1 + \frac{\left(1 - \frac{P_0}{P_{1S}}\right)}{\gamma M_{1S}^2}\right) = 412\ m/s$$

$$\frac{V_{1S,e}}{a_0} = \frac{412\ m/s}{340\ m/s} = 1,213$$

Spinta nel cuore

$$\frac{\text{Fu cuore}}{\text{uscita ao}} = \frac{(1+\beta)}{(1+\tau)} \cdot \frac{V_{3,e}}{a_0} - \frac{H_0}{1+\tau} = -0,00243$$

Spinta nel fan

$$\frac{\text{Fu fan}}{\text{uscita ao}} = \frac{\alpha}{1+\tau}\left(\frac{V_{3,e}}{a_0} - H_0\right) = \frac{5,05}{6,05}(1,213 - 0,85) = 0,299$$

Totale: somma dei due $\Rightarrow 0,299 - 0,00243 = 0,2963$

% core = -0,82 % % fan = 100,7 %

Rendimenti

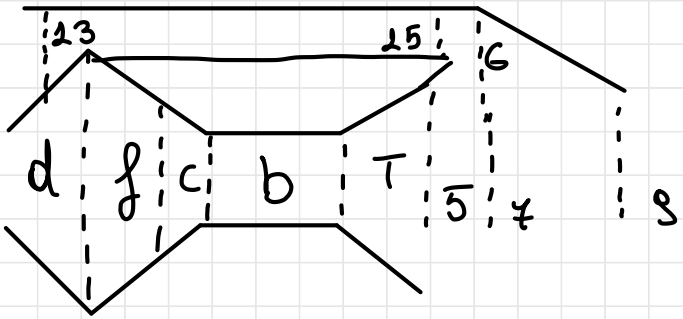
$$N = (1+\beta) V_{3,e}^2 + 2V_{3,e}^2 - (1+\tau) V_0^2 = 4,24 \cdot 10^5$$

Rend prop

$$\eta_p = \frac{2 \cdot Fu \cdot V}{N \cdot \dot{m}_0} = \frac{\frac{Fu}{\text{uscita ao}} \cdot a_0 \, \frac{\text{uscita } V_0}{\dot{m}_0}}{N} = 83\%$$

rend tot = 28%

ESERCIZIO TURBOFAN FLUSSI MISCELATI (ES 3.3)



$\dot{m}_{fuel} = ?$

$$f = \frac{c_{p4} T_{t4} - c_{pT3} T_{t3}}{\eta_B Q_R - c_{p4} T_{t4}} = \frac{1088 \cdot 1211K - 1005 \cdot 700K}{1 \cdot 43{,}3 \cdot 10^6 J - 1088 \cdot 1211K}$$

$$\Rightarrow 0{,}0146 \; (6)$$

$$\dot{m}_f = f \dot{m}_3 = 0{,}0146 \cdot 68 \, kg/s = 0{,}996 \frac{kg}{s}$$

$$F = (\dot{m}_3 + \dot{m}_f + \dot{m}_{13}) V_9 = (68.0 + 0.996 + 74{,}8) 442 \frac{m}{s}$$

$$=$$

$$\eta_{Th} = \frac{(\dot{m}_3 + \dot{m}_f + \dot{m}_{13}) V_9^2/2}{\dot{m}_f Q_R} = \frac{(68.0 + 0{,}996 + 74{,}8) \cdot 442^2/2}{0{,}996 \cdot 43{,}3 \cdot 10^6}$$

$$= 0{,}326 = 32{,}6\%$$

$$\eta_C = 1 - \frac{T_c}{T_n} = 1 - \frac{T_0}{T_{t4}} = 76{,}2\%$$

$$\pi_C = \frac{P_{T3}}{P_{T2}} = \frac{1607}{102.4} = 15{,}85$$ più o meno gli stessi del turbofan

$$TSFC = \frac{\dot{m}_f}{F_u} = \frac{0,936}{63,6} = 0,01566 \ \frac{kg}{kN \cdot s}$$

$$\alpha - \frac{\dot{m}_{13}}{\dot{m}_3} = \frac{74,8}{68} = 1,1$$

$$M_9 = \frac{V_9}{a_9} = \frac{642}{507} = 0,872$$

$$R = c_{p9} \cdot \kappa = 1088 \cdot \frac{0,358}{1,358} = 287$$

$$a_9 = \sqrt{\gamma R T_9} = \sqrt{1,358 \cdot 287 \cdot 660} = 507 \ m/s$$

$$T_{T9} = T_9 + \frac{V_9^2}{2c_p} \Rightarrow T_9 = T_{T9} - \frac{V_9^2}{2c_p} = 750 - \frac{(642)^2}{2 \cdot 1088} = 660 \ K$$

$$\pi_{C\,LOW} = \frac{P_{t25}}{P_{t2}} = \frac{414}{102,4} = 4,08$$

$$\pi_{C\,HIGH} = \frac{P_{t3}}{P_{t25}} = \frac{1607}{414} = 3,88$$

$$\pi_f = \frac{P_{t13}}{P_{t2}} = \frac{193}{102,4} = 1,804$$

FAROKHI 4.16

$$k = \frac{\gamma - 1}{\gamma} = \frac{1,4 - 1}{1,4} = \frac{0,4}{1,4} = 0,286$$

$$k_t = \frac{\gamma_t - 1}{\gamma_t} = \frac{1,33 - 1}{1,33} = \frac{0,33}{1,33} = 0,248$$

$$k_s = \frac{\gamma_s - 1}{\gamma_s} = \frac{1,3 - 1}{1,3} = \frac{0,3}{1,3} = 0,231$$

$$R = k\, c_p = 0,286 \cdot 1004 = 287 \ \frac{J}{kg \cdot K}$$

$$R_t = k_t\, c_{p_t} = 0,248 \cdot 1152 = 286 \ \frac{J}{kg \cdot K}$$

$$R_s = k_s\, c_{p_s} = 1241 \cdot 0,231 = 287 \ \frac{J}{kg \cdot K}$$

EFFETTO RAM

$T_0 = 223\,K$

$$a_0 = \sqrt{\gamma R T_0} = \sqrt{1,4 \cdot 287 \cdot 223} = 299 \ m/s$$

$M_0 = 2$

$$V_0 = M_0\, a_0 = 2 \cdot 299 = 598 \ m/s$$

$$\tau_r = \psi_0 = 1 + \frac{\gamma - 1}{2} M_0^2 = 1 + 0.2 \cdot M_0^2 = 1,8$$

$$T_{t_0} = T_0\, \tau_r = 223\,K \cdot 1,8 = 401$$

$$P_{t_0} = p_0\, \tau_r^{\frac{1}{k}} = 10 \cdot 1,8^{\frac{1}{0,286}} = 78,2\,kPa$$

DIFFUSORE

$p_{t2} = p_{t0} \cdot \Pi_d = 78{,}2 \cdot 0{,}9 = 70{,}4\ kPa \qquad T_{T2} = T_{T0}$

COMPRESSORE

$\tau_c = \Pi_c^{\frac{k}{e_c}} = 13^{\frac{0{,}286}{0{,}80}} = 2{,}26$

$p_{t3} = \Pi_c\, p_{t2} = 13 \cdot 70{,}4\ kPa = 915\ kPa$

$T_{T3} = \tau_c \cdot T_{T2} = 2{,}26 \cdot 401 = 906\ K$

CAMERA DI COMBUSTIONE

$\tau_\lambda = \frac{c_{pt} T_{T4}}{c_p T_0} = \frac{1152 \cdot 1600}{1004 \cdot 223} = 8{,}23$

$f = \frac{\tau_\lambda - \tau_c \tau_r}{Q_R \eta_b / (c_p T_0) - \tau_\lambda} = \frac{8{,}23 - 2{,}26 \cdot 1{,}8}{\frac{42 \cdot 10^6 \cdot 0{,}98}{(1004 \cdot 223)} - 8{,}23} = 0{,}0237$

$\tau_b = \frac{\tau_\lambda}{\tau_c \tau_r} = \frac{8{,}23}{2{,}26 \cdot 1{,}8} = 2{,}02$

$p_{t4} = p_{t3}\, \Pi_b = 915\ kPa \cdot 0{,}95 = 869\ kPa$

FAN

$\tau_f = \Pi_f^{\frac{k}{e_f}} = 1{,}80^{\frac{0{,}286}{0{,}80}} = 1{,}226$

$T_{T13} = \tau_f\, T_{T2} = 401\ K \cdot 1{,}226 = 492\ K$

$P_{T13} = \Pi_f\, P_{T2} = 1{,}80 \cdot 70{,}4\ kPa = 133{,}7\ kPa$

TURBINA

$$\pi_T = \frac{\pi_{fd} \cdot \pi_f}{\pi_b \cdot \pi_c} = \frac{0,98 \cdot 1,80}{0,95 \cdot 13} = 0,1523$$

$$\tau_t = \pi_t^{k_{et}} = 0,1523^{0,241 \cdot 0,8} = 0,688$$

$$P_{t5} = P_{t4}\,\pi_T = 868\ kPa \cdot 0,1523 = 132,3\ kPa$$

$$T_{t5} = T_{t4}\,\tau_T = 1600\ K \cdot 0,688 = 1101\ K$$

MIXER

$$\alpha = \frac{\eta_M (1+f)(1-\tau_T)\,\tau_h - \tau_r (C_c - 1)}{\tau_r (\tau_f - 1)} \qquad \pi_T = \frac{\pi_{fd}\,\pi_f}{\pi_b \pi_c}$$

$$\tau_M = \frac{2\,\tau_f\,\tau_r}{\tau_T\,\tau_h} + (1+f) \qquad f_{AB} = \left(1 + \frac{f}{1+2}\right) \frac{\tau_{hAB} - \tau_M\,\tau_T\,\tau_h}{\frac{Q_{RAB}\,\eta_{AB}}{c_p T_0} - \tau_{hAB}}$$

$$1 + 2 + f$$

$$f_{TOT} = \frac{f}{1+2} + f_{AB}$$

$$\alpha = \frac{0,95\,(1,024)(1-0,688)\,8,23 - 1,8\,(1,26)}{1,8\,(0,226)} = 0,565$$

$$\tau_M = \frac{0,565 \cdot 1,226 \cdot 1,8}{0,688 \cdot 8,23} + (1,024) = 0,783$$

$$1,024 + 0,565$$

$P_{T6} = P_{T5} \cdot \pi_M = 1323 \cdot 0{,}971 = 128{,}5\ kPa$

$T_{T6} \cong T_{T5} \cdot \tau_M = 1101 \cdot 0{,}783 = 862\ K$

POST BRUCIATORE

$$\tau_{MAB} = \frac{c_{pB} T_{T7}}{c_p T_0} = \frac{1261 \cdot 2000}{1004 \cdot 223} = 11{,}08$$

$$f_{AB} = \left(1 + \frac{f}{1+f}\right) \frac{\tau_{MAB} - \tau_M \tau_r \tau_m}{\frac{Q_R \eta_B}{c_p T_0} - \tau_{MAB}} = \left(1 + \frac{0{,}0237}{1+0{,}565}\right) \cdot$$

$$\cdot \frac{11{,}08 - 0{,}783 \cdot 0{,}688 \cdot 8{,}23}{\frac{42 \cdot 10^6 \cdot 0{,}88}{1004 \cdot 223} - 11{,}08}$$

$$\Rightarrow f_{AB} = 0{,}0391$$

$P_{T7} = P_{T6}\, \pi_{AB} = 128{,}5\ kPa \cdot 0{,}82 = 118{,}2\ kPa$

$$f_{TOT} = \frac{f}{1+f} + f_{AB} = \frac{0{,}0237}{1+0{,}565} + 0{,}0391 = 0{,}0542$$

UGELLO

$P_{T8} = P_{T7} \cdot \pi_M = 118{,}2\ kPa \cdot 0{,}95 = 112{,}3\ kPa$

$T_{T8} = T_{T7} = 2000\ K$

$$\frac{P_{T8}}{P_8} = \frac{P_{T8}}{P_0} \cdot \frac{P_0}{P_8} = \frac{112{,}3}{10} \cdot \frac{1}{3{,}8} = 2{,}96$$

$$\frac{T_{T8}}{T_8} = \left(\frac{P_{T8}}{P_8}\right)^{k_8} = 2{,}96^{0{,}231} = 1{,}285$$

$$M_8 = \sqrt{\frac{2}{\gamma-1}\left[\frac{T_{T8}}{T_8} - 1\right]} = \sqrt{\frac{2}{0,3}\left[0,285\right]} = 1,378$$

$$T_8 = \frac{T_8}{T_{T8}} \cdot T_{T8} = \frac{2000}{1,285} = 1556\ K$$

$$a_8 = \sqrt{\gamma_8 R_8 T_8} = \sqrt{1,3 \cdot 287 \cdot 1556} = 762\ m/s$$

$$V_8 = M_8 a_8 = 1,378 \cdot 762\ m/s = 1050\ m/s$$

$$V_{8,e} = V_8\left(1 + \frac{1 - \frac{p_0}{p_8}}{\gamma_8 M_8^2}\right) = 1050\left(1 + \frac{1 - \frac{1}{3,8}}{1,3 \cdot 1,378^2}\right) = 1363\ m/s$$

$$\frac{V_{8,e}}{a_0} = \frac{1363}{288} = 4,56$$

SPINTA e RENDIMENTI

$$\frac{F_u}{\dot{m}_{air}\, a_0} = (1 + f_{tot})\frac{V_{8,e}}{a_0} - M_0 = (1,054) \cdot 4,56 - 2 = 2,81$$

$$TSFC = \frac{\dot{m}_f}{F_u} = \frac{\dot{m}_f}{\dot{m}_{air}\frac{F_u}{\dot{m}_{air} a_0} \cdot a_0} = \frac{f_{tot}}{\frac{F_u}{\dot{m}_{air} a_0} \cdot a_0} =$$

$$= \frac{0,0542}{2,81 \cdot 288} = 6,45 \cdot 10^{-5}\ \frac{kg}{s \cdot N}$$

$$\eta_{TH} = \frac{\Delta \dot{KE}}{P_t} = \frac{a_0^2\left[(1+f_{tot})\left(\frac{V_{8e}}{a_0}\right)^2 - M_0^2\right]}{2 f_{tot} Q_R} = \frac{B}{2 f_{tot} Q_R} = \frac{1,602 \cdot 10^6}{2 \cdot 0,0542 \cdot 42 \cdot 10^6}$$

$$B = 288^2\left[(1,054)\ 4,56^2 - 2^2\right] = 1,602 \cdot 10^6\ m^2/s^2$$

$\eta_{TH} = 0,353 = 35,3\%$

$\eta_p = \frac{F_u \cdot V_0}{\dot{DKE}} = 2 \cdot \frac{F_u \cdot V_0}{\frac{\dot{m}_{air} \cdot a_0}{B}} \cdot a_0 = \frac{2 \cdot 2,81 \cdot 288 \cdot 558}{1,602 \cdot 10^6}$

$= 0,624 = 62,4\%$

$\eta_p = \eta_{TH} \cdot \eta_p = 0,353 \cdot 0,624 = 0,221 = 22,1\%$

$B = \frac{2 \cdot \dot{DKE}}{\dot{m}_{air}}$

Lez 15 20/04/23
FAROKHI 4.38

$K = \frac{\gamma - 1}{\gamma} = 0,286$

$K_T = \frac{\gamma_t - 1}{\gamma_t} = 0,248$

$R = 287\ J \cdot kg/K$

$R_T = 286\ J \cdot kg/K$

EFFETTO RAM

$a_0 = \sqrt{\gamma R T_0} = \sqrt{1,4 \cdot 287 \cdot 258} = 322\ m/s$

$V_0 = M_0 a_0 = 0,82 \cdot 322\ m/s = 264\ m/s$

$\tau_r = \psi_0 = 1 + \frac{\gamma - 1}{2} M_0^2 = 1 + 0,2 \cdot 0,82^2 = 1,134$

$T_{i0} = T_0 \cdot \tau_r = 258K \cdot 1,134 = 293K$ $\quad T_{ir} = \tau_r^{\frac{1}{K}} = 1,352$

$P_{T0} = P_0 \cdot \tau_r = 30\,kPa \cdot 1{,}552 = 46{,}6\,kPa$

DIFFUSORE (PRESA D'ARIA)

$p_{T2} = \tau_d \cdot p_{T0} = 0{,}99 \cdot 46{,}6\,kPa = 46.1\,kPa$

$T_{T2} = T_{T0} = 293K$

COMPRESSORE

$\tau_c = \pi_c^{\frac{k}{e_c}} = 35^{\frac{0{,}286}{0{,}82}} = 3{,}02$

$P_{T3} = \pi_c P_{T2} = 35 \cdot 46{,}1 = 1614\,kPa$

$T_{T3} = \tau_c T_{T2} = 3{,}02 \cdot 293K = 885\,K$

CAMERA DI COMBUSTIONE

$T_{T4} = 1650$

$p_{T4} = p_{T3} \pi_B = 1614 \cdot 0{,}96 = 1548\,kPa$

$\tau_h = \frac{c_{pT} T_{T4}}{c_p T_0} = \frac{1152 \cdot 1650}{1004 \cdot 288} = 7{,}34$

$f = \frac{\tau_h - \tau_c \tau_r}{\frac{Q_R \cdot \eta_B}{c_p T_0} - \tau_h} = \frac{7{,}34 - 3{,}02 \cdot 1{,}134}{\frac{42 \cdot 10^6 \cdot 0{,}99}{1004 \cdot 288} - 7{,}34} = 0{,}0256$

TURBINA HP

$\tau_{TH} = 1 - \frac{\tau_r \cdot (\tau_c - 1)}{\eta_{m_H} \cdot (1+f) \cdot \tau_h} = \frac{1{,}134 \cdot (2{,}02)}{0{,}99\,(1+0{,}0256) \cdot 7{,}34} = 0{,}693$

$$\pi_{TH} = (\tau_{TH})^{\frac{1}{k \cdot e_{TH}}} = 0{,}683^{\frac{1}{0{,}248 \cdot 0{,}8}} = 0{,}1575$$

$$P_{T45} = P_{T4} \cdot \pi_{TH} = 1548\,kPa \cdot 0{,}1575 = 244\,kPa$$

$$T_{T45} = T_{T4} \cdot \tau_{TH} = 1650 \cdot 0{,}683 = 1143\,K$$

TURBINA LP

$\Delta p = 0{,}75$ $\qquad \tau_{TL} = 1 - \eta_{TL}\,\Delta p \left[1 - \left(\frac{P_0}{P_{T45}}\right)^{k_T}\right]$

$$= 1 - \eta_{TL} \cdot 0{,}75 \left[1 - \left(\frac{30}{244}\right)^{0{,}248}\right]$$

$$\tau_{TL} = 1 - \eta_{TL} \cdot 0{,}304$$

Supponiamo $\eta_{TL} = 1 \Rightarrow \tau_{TL} = 1 - 0{,}304 = 0{,}696$

$$\eta_{TL} = \frac{1 - \tau_{TL}}{1 - \tau_{TL}^{\frac{1}{e_{TL}}}} = \frac{1 - 0{,}696}{1 - 0696^{1{,}164}} = 0{,}883$$

$$\frac{1}{e_{TL}} = \frac{1}{0{,}853} = 1{,}164$$

$$\tau_{TL} = 1 - 0{,}883 \cdot 0{,}304 = 0{,}731$$

$$\eta_{TL} = \frac{1 - 0{,}731}{1 - 0{,}731^{1{,}164}} = 0{,}880$$

$$\tau_{TL} = 1 - 0{,}880 \cdot 0{,}304 = 0{,}732 \Rightarrow \eta_{TL} = 0{,}880$$

$$\pi_{TL} = (\tau_{TL})^{1/k\eta_{TL}} = 0{,}732^{\frac{1}{0{,}248 \cdot 0{,}833}} = 0{,}231$$

$$P_{T5} = P_{T45}\,\pi_{TL} = 244\ kPa \cdot 0{,}231 = 56{,}4\ kPa$$

$$T_{T5} = T_{T45} \cdot \tau_{TL} = 1143\ K \cdot 0{,}732 = 837\ K$$

UGELLO

$$\eta_M = \frac{\left(\frac{P_{T5}}{P_3}\right)^{k_T} - \pi_M^{-k_T}}{\left(\frac{P_{T5}}{P_3}\right)^{k_T} - 1} = \frac{x - \pi_M^{-k_T}}{x-1} \Rightarrow \eta_M(x-1) = x - \pi_M^{-k_T}$$

$$\pi_M^{-k_T} = x - \eta_M(x-1)$$

$$\pi_M = \left(x - \eta_M(x-1)\right)^{-\frac{1}{k_T}}$$

$$\left(\frac{P_{T5}}{P_3}\right)^{k_T} = x = \left(\frac{56{,}4}{30}\right)^{0{,}248} = 1{,}169$$

↳ P_0

$$\pi_M = \left[1{,}169 - 0{,}95\,(1{,}169-1)\right]^{-\frac{1}{0{,}248}} = 0{,}967$$

$$P_{T3} = P_{T5} \cdot \pi_M = 56{,}4 \cdot 0{,}967 = 54{,}5\ kPa$$

$$\frac{P_{T3}}{P_3} = \frac{54{,}5}{30} = 1{,}817$$

$$\psi_3 = \frac{T_{T3}}{T_3} = \left(\frac{P_{T3}}{P_3}\right)^{k_6} = 1{,}817^{0{,}248} = 1{,}160$$

$$M_3 = \sqrt{\frac{2}{\gamma_{E1}}\left(\psi_3 - 1\right)} = \sqrt{\frac{2}{0{,}33} \cdot 0{,}160} = 0{,}985$$

essendo $M_3 \simeq 1$ $p_3 = p_0$ ha senso $\qquad T_{T3} = T_{T5}$

$$T_9 = \frac{T_{T9}}{\tau_9} = \frac{837\,K}{1,160} = 722\,K$$

$$a_9 = \sqrt{\gamma_t R T_9} = \sqrt{1,33 \cdot 286 \cdot 722} = 524\,m/s$$

$$V_9 = M_9 a_9 = 0,985 \cdot 524 = 516\,m/s$$

$$\frac{V_9}{a_0} = \frac{516\,m/s}{322\,m/s} = 1,602 > M_0 \quad \text{HA SENSO !!}$$

PROPELLER

$$\frac{P_S}{\dot{m}_0} = (1+f) \cdot M_{GB} \cdot \eta_{M_{LP}} \cdot (1 - \chi_{tL}) c_{pT} T_{T45}$$

$$= 1,026 \cdot 0,995 \cdot 0,99 \cdot (1 - 0,732)\, 1152 \cdot 1143 = 357\,\frac{kJ}{kg}$$

SPINTA e RENDIMENTO

$$\frac{F_{u.c}}{\dot{m}_0 \cdot a_0} = (1+f)\frac{V_9}{a_0} - M_0 = 1,026 \cdot 1,602 - 0,82 = 0,824$$

$$\frac{F_{u.p}}{\dot{m}_0 a_0} = \frac{\eta_{prop} P_S}{\dot{m}_0 V_0 a_0} = \frac{0,85 \cdot 357 \cdot 10^3}{264 \cdot 322} = 3,57$$

$$\frac{F_{TOT}}{\dot{m}_0 a_0} = 0,824 + 3,57 = 4,40$$

$$TSFC = \frac{f}{F_u/\dot{m}_0} \cdot \frac{a_0}{a_0} = 1,807 \cdot 10^{-5}\,\frac{kg}{s \cdot N}$$

$$\eta_{TH} = \frac{a_0^2 \left[(1+f)(V_9/a_0)^2 - M_0^2\right] + 2 P_S/\dot{m}_0}{2 f Q_R} = 42,6\%$$

$$B = a_0^2 \left[(1+f)(V_9/a_0)^2 - M_0^2\right]$$

MATTINGLY 4.3 (o 4.1)

$A_1 = 6\ m^2 \qquad M_1 = 0,6$

DADO con $M=0 \quad p_0 = 1,013 \cdot 10^5\ Pa$

DADO $h = 12\ km$ e $M_0 = 0,8$

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

$$\frac{p_1}{p_{t1}} \frac{p_{t1}}{p_0} \cdot p_0 = \psi_1^{-\frac{1}{k}} \cdot 1 \cdot 1,013 \cdot 10^5 = 1,072^{-\frac{1}{0,286}} \cdot 1 \cdot 1,013 \cdot 10^5$$

$$\Rightarrow p_1 = 78,4\ kPa$$

$$\psi_1 = 1 + \frac{\gamma - 1}{2} M_1^2 = 1 + 0,2 \cdot 0,6^2 = 1,072 \qquad k = 0,286$$

$$\dot{m}_1 V_1 = \rho_1 V_1 A_1 \cdot V_1 = \frac{p_1}{p_1} \frac{\gamma}{\gamma} V_1^2 A_1 \rho_1 = \frac{\gamma p_1 V_1^2 A_1}{\frac{\gamma p_1}{\rho_1}} =$$

$$= \frac{\gamma p_1 V_1^2 A_1}{a_1^2} = \gamma p_1 M_1^2 A_1$$

$$= 1,4 \cdot 78,4\ kPa \cdot 0,6^2 \cdot 6\ m^2 =$$

$$= 240\ kN$$

$$(p_1 - p_0) A_1 = (78,4\ kPa - 101,3\ kPa)\, 6\ m^2 = -131,4\ kN$$

$$D_{ADD} = \dot{m}_1 V_1 - \cancel{\dot{m}_0 V_0}^{=0} + (p_1 - p_0) A_1 = 240 - 131,4 = 108,6\ kN$$

$$\frac{D_{ADD}}{p_0 A_1} = \frac{108,6}{101,3 \cdot 6} = 0,1787$$

$$\gamma M_1 \left(\frac{\psi_0}{\psi_1}\right)^K \left(M_1 \sqrt{\frac{\psi_0}{\psi_1}} - M_0\right) + \left(\frac{\psi_0}{\psi_1}\right)^{\frac{\gamma}{\gamma-1}} - 1 =$$

$K = \frac{\gamma+1}{2(\gamma-1)} = 3 \quad \psi_0 = 1 \quad (M_0 = 0) \quad \psi_1 = 1{,}072$

$$1{,}4 \cdot 0{,}6 \cdot \left(\frac{1}{1{,}072}\right)^3 \left(0{,}6 \sqrt{\frac{1}{1{,}072}} - 0\right) + \left(\frac{1}{1{,}072}\right)^{3{,}5} - 1 = 0{,}1791$$

$$\gamma M_1 \left(\frac{\psi_0}{\psi_1}\right)^K \left(M_1 \sqrt{\frac{\psi_0}{\psi_1}} - M_0\right) = 0{,}395$$

$$\left(\frac{\psi_0}{\psi_1}\right)^{\frac{\gamma}{\gamma-1}} - 1 = -0{,}216$$

$$\frac{D_{a00}}{p_0 A_1} = 0{,}395 - 0{,}216 = 0{,}179$$

$M_0 = 0{,}8 \quad h = 12\,km \Rightarrow p_0 = 18{,}4\,kPa$

$$p_1 = \frac{p_1}{p_{T1}} \frac{p_{T1}}{p_{T0}} \frac{p_{T0}}{p_0} \cdot p_0 = 0{,}784 \cdot 1 \cdot \frac{1}{0{,}650} \cdot 18{,}4\,kPa = 23{,}2\,kPa$$

$$\frac{p_1}{p_{T1}} = \psi_1^{-\frac{1}{K}} = 1{,}072^{-\frac{1}{0{,}286}} = 0{,}784$$

$M_1 = 0{,}6 \xrightarrow{ISO} \frac{A_1}{A^*} = 1{,}188$

$M_0 = 0{,}8 \xrightarrow{ISO} \frac{A_0}{A^*} = 1{,}038$

$$\frac{p_0}{p_{T0}} = 0{,}656$$

$$D_{ADD} = \dot{m}_2 V_2 - \dot{m}_0 V_0 + (p_2 - p_0) A_2$$

$$\dot{m}_1 V_1 = \gamma p_1 M_1^2 A_1 = 1,4 \cdot 23,2 \cdot 0,6^2 \cdot 6 = 70,2 \text{ kN}$$

$$A_0 = \frac{A_0}{A^*} \frac{A^*}{A_1} \cdot A_2 = \frac{1,038}{1,188} \cdot 6 = 5,24 \text{ m}^2$$

$$\dot{m}_0 V_0 = \gamma p_0 M_0^2 A_0 = 1,4 \cdot 18,4 \cdot 0,8^2 \cdot 5,24 = 81,1 \text{ kN}$$

$$(p_2 - p_0) A_2 = (23,2 - 18,4) \cdot 6 = 22,8 \text{ kN}$$

$$D_{ADD} = 70,2 - 81,1 + 22,8 = 1,9 \text{ kN}$$

$$\frac{D_{ADD}}{p_0 A_2} = \frac{1,9}{18,4 \cdot 6} = 0,016$$

$$\gamma M_1 \left(\frac{\psi_0}{\psi_1}\right)^K \left(M_1 \sqrt{\frac{\psi_0}{\psi_1}} - M_0\right) + \left(\frac{\psi_0}{\psi_1}\right)^{\frac{\gamma}{\gamma-1}} - 1$$

$$\psi_0 = 1 + \frac{\gamma - 1}{2} M_0^2 = 1 + 0,2 \cdot 0,8^2 = 1,128$$

$$\gamma M_1 \left(\frac{\psi_0}{\psi_1}\right)^K \left(M_1 \sqrt{\frac{\psi_0}{\psi_1}} - M_0\right) = 1,4 \cdot 0,6 \left(\frac{1,128}{1,072}\right)^3 \left(0,6 \sqrt{\frac{1,128}{1,072}} - 0,8\right)$$

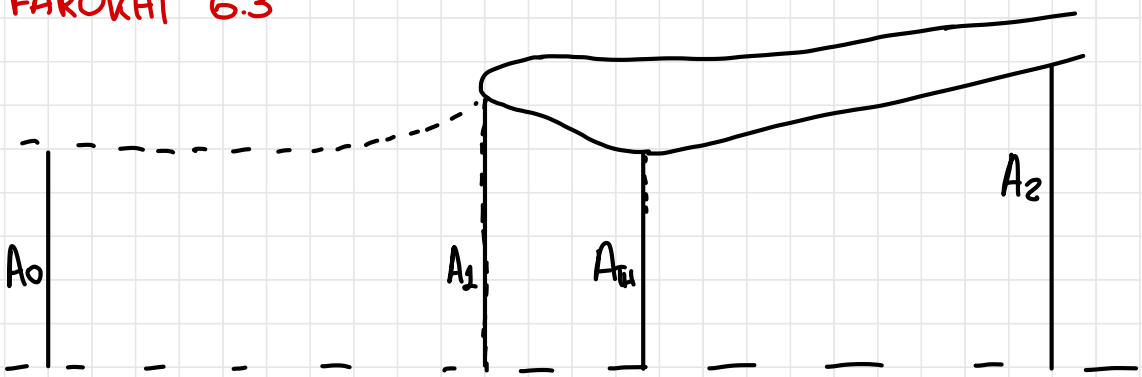
$$= -0,1806$$

$$\left(\frac{\psi_0}{\psi_1}\right)^{\frac{\gamma}{\gamma-1}} - 1 = \left(\frac{1,128}{1,072}\right)^{3,5} - 1 = 0,1951$$

$$\frac{D_{ADD}}{p_0 A_2} = -0,1806 + 0,1951 = 0,0145$$

più precisa e corretta per cifre significative

FAROKHI 6.3



$M_0 = 0{,}8 \qquad \frac{A_0}{A_1} = 0{,}92$

$$c_{p_0} = \frac{p_{t_0} - p_0}{\frac{1}{2}\rho_0 v_0^2} = \frac{\frac{p_{t_0}}{p_0} - 1}{\frac{1}{2}\gamma \frac{p_0 V_0^2}{p_0 \gamma}} = \frac{\frac{p_{t_0}}{p_0} - 1}{\frac{1}{2}\gamma M_0^2}$$

$$\psi_0 = 1 + \frac{\gamma - 1}{2} M_0^2 = 1 + 0{,}2 \cdot 0{,}8^2 = 1{,}128$$

$$\frac{p_0}{p_{t_0}} = \psi_0^{-\frac{1}{\kappa}} = 1{,}128^{-\frac{1}{0{,}286}} = 0{,}656 \qquad \frac{p_{t_0}}{p_0} = \frac{1}{0{,}656} = 1{,}524$$

$$c_{p_0} = \frac{1{,}524 - 1}{\frac{1}{2} \cdot 1{,}4 \cdot 0{,}8^2} = 1{,}170$$

$M_1 = ?$

$$\frac{A_1}{A^*} = \frac{A_1}{A_0} \cdot \frac{A_0}{A^*} = \frac{1{,}038}{0{,}82} = 1{,}128$$

$M_0 \xrightarrow{\text{ISO}} \frac{A_0}{A^*} = 1{,}038$

$\frac{A_1}{A^*}$ $\xrightarrow{\text{ISO}}$ $M_1 = 0{,}658$

$\frac{A_1}{A_{TH}}$ per $M_{TH} = 0{,}45$ $\quad P_{T\,TH} = P_{T1}$ OK avendo ugello convergente

$$\frac{A_1}{A_{TH}} = \frac{A_1}{A^*}\,\frac{A^*}{A_{TH}} = \frac{1{,}128}{1{,}062} = 1{,}062$$

M_{TH} $\xrightarrow{\text{ISO}}$ $\frac{A_{TH}}{A^*} = 1{,}062$

$\frac{A_2}{A_{TH}}$ con $M_2 = 0{,}5$ $\quad \frac{P_{T2}}{P_{TTH}} = \frac{P_{T2}}{P_{T1}} = 0{,}98$

CASO IDEALE ISO

$$\left.\frac{A_2}{A_{TH}}\right|_{IDEALE} = \frac{A_2}{A^*}\,\frac{A^*}{A_{TH}} = \frac{1{,}340}{1{,}062} = 1{,}262$$

M_2 $\xrightarrow{\text{ISO}}$ $\frac{A_2}{A^*} = 1{,}340$

$$P_{TTH} \cdot A_{2\,IDEALE} = P_{T2} \cdot A_{2\,REALE}$$

$$\Rightarrow \left.\frac{A_2}{A_{TH}}\right|_{REALE} = \frac{\left.\frac{A_2}{A_{TH}}\right|_{IDEALE}}{\frac{P_{T2}}{P_{TTH}}} = \frac{1{,}262}{0{,}98} = 1{,}288$$

$$\frac{DADD}{\rho A_1} = \frac{\dot{m}_1 V_1 - \dot{m}_0 V_0 + (p_1 - p_0) A_1}{\rho A_2} \qquad \dot{m}_1 = \dot{m}_0$$

$$= \frac{\dot{m}_0 (V_1 - V_0)}{p_0 A_1} + \frac{p_1 - p_0}{p_0} = \frac{\rho_0 V_0 A_0}{\gamma} \frac{\gamma (V_1 - V_0)}{p_0 A_1} + \frac{p_1 - p_0}{p_0}$$

$$= \frac{V_0 A_0 \gamma (V_1 - V_0)}{a_0^2} = \frac{V_0 A_0 \gamma}{a_0} \left(\frac{V_1}{a_0} - \frac{V_0}{a_0} \right) + \frac{p_1 - p_0}{p_0}$$

$$= \frac{\gamma M_0 A_0}{A_1} \left(\frac{V_1}{a_1} \cdot \frac{a_1}{a_0} - M_0 \right) + \frac{p_1 - p_0}{p_0}$$

$$* = \frac{\gamma M_0 A_0}{A_1} \left(M_1 \cdot \frac{a_1}{a_0} - M_0 \right) + \frac{p_1 - p_0}{p_0}$$

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

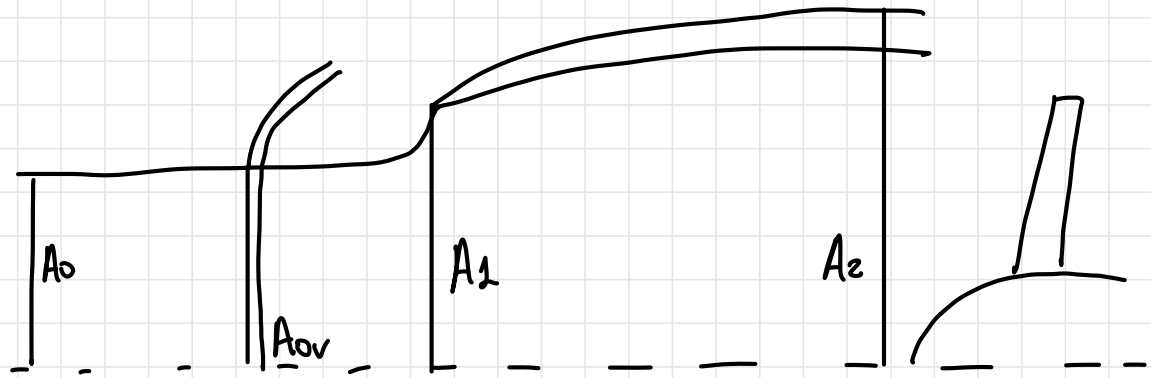
$\psi_0 = 1{,}128$ $\qquad \psi_1 = 1 + \frac{\gamma - 1}{2} M_1^2 = 1 + 0{,}2 \cdot 0{,}658^2 = 1{,}087$

$\Psi = \gamma M \psi^{-K}$ $\qquad \frac{\Psi}{\Psi^*} = \frac{A^*}{A} \Rightarrow \frac{\Psi_1}{\Psi_0} = \frac{A_0}{A_1} = \frac{M_1 \psi_1^{-K}}{M_0 \psi_0^{-K}} = \frac{M_1}{M_0} \left(\frac{\psi_0}{\psi_1} \right)^K$

$$* = 1{,}4 \cdot 0{,}8 \cdot \left(\frac{1{,}128}{1{,}087} \right)^3 \cdot \left(0{,}658 \cdot \sqrt{\frac{1{,}128}{1{,}087}} - 0{,}8 \right) + \left(\frac{1{,}128}{1{,}087} \right)^{3{,}5} - 1$$

$$= 5{,}88 \cdot 10^{-3}$$

FAROKHI 6,17



$M_0 = 1,6 \quad \frac{A_0}{A_2} = 0,80 \Rightarrow$ spillamento $\quad \frac{A_2}{A_1} = 1,2 \quad \frac{P_{t2}}{P_{t1}} = 0,95$

$M_1 = ? \quad M_2 = ? \quad \Pi_D = \frac{P_{t2}}{P_{t0}}$

$M_0 = 1,6 \xrightarrow{NSW} M_{ov} = 0,668$

$$\frac{P_{tov}}{P_{t0}} = 0,855$$

$M_{ov} = 0,668 \xrightarrow{ISO} \frac{A_{ov}}{A^*_{ov}} = 1,120$

$$\frac{A_1}{A_1^*} = \frac{A_1}{A_0}\frac{A_0}{A_{ov}}\frac{A_{ov}}{A_{ov}^*} = \frac{1}{0,80} \cdot 1,120 = 1,244$$

$\frac{A_1}{A_1^*} = 1,244 \xrightarrow{ISO} M_1 = 0,557$

$$\frac{A_2}{A_2^*} = \frac{A_2}{A_1}\cdot\frac{A_1}{A_1^*}\cdot\frac{A_1^*}{A_2^*} = 1,2 \cdot 1,244 \cdot 0,95 = 1,418$$

$$A_2^* P_{t2} = A_1^* \cdot P_{t1} \Rightarrow \frac{A_2^*}{A_1^*} = \frac{P_{t1}}{P_{t2}} = \frac{1}{0,95}$$

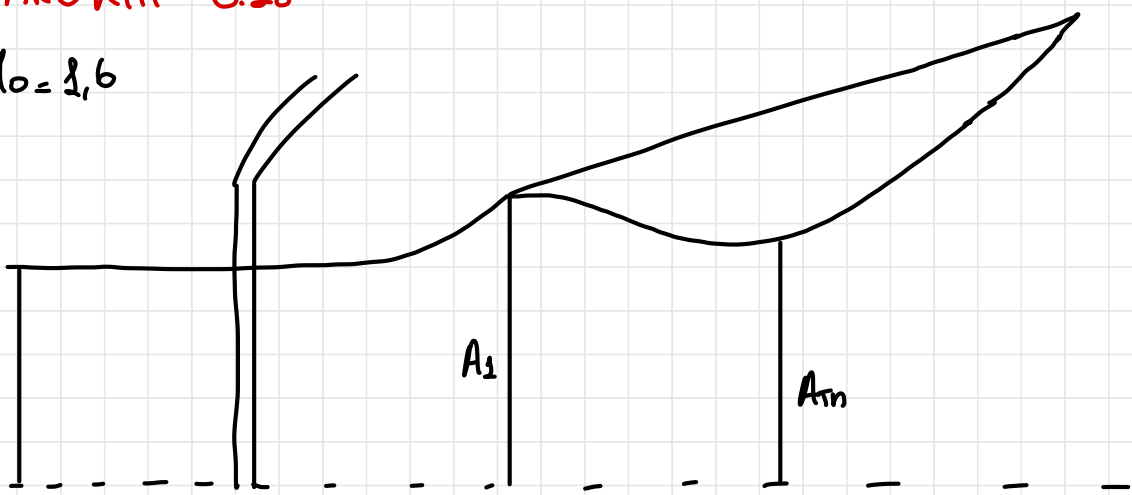
$$\frac{A_2}{A_2^*} = 1,418 \xrightarrow{150} M_2 = 0,463$$

$$\pi_D = \frac{P_{t2}}{P_{t0}} = \frac{P_{t2}}{P_{t1}} \cdot \frac{P_{t1}}{P_{t0v}} \cdot \frac{P_{t0v}}{P_{t0}} = 0,95 \cdot 0,895 = 0,850$$

1

FAROKHI 6.18

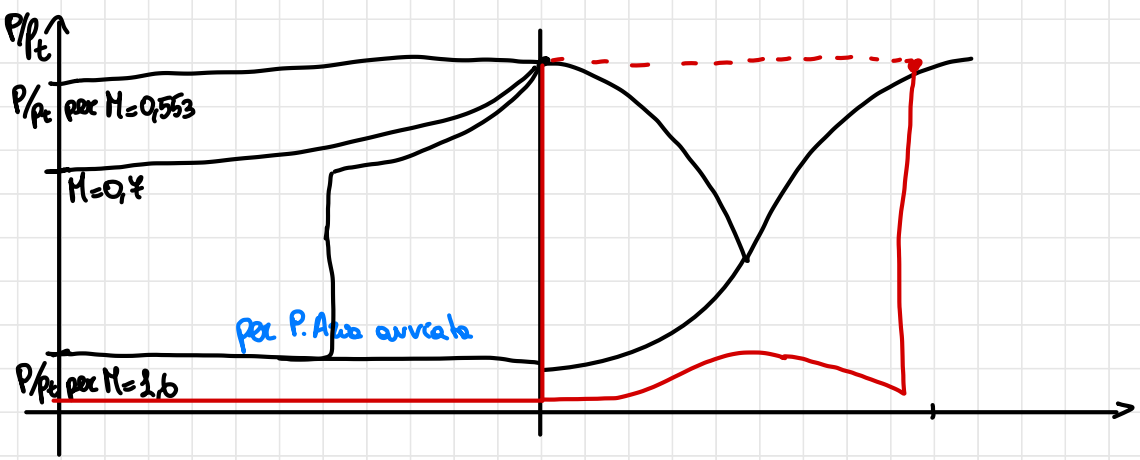
$M_0 = 1,6$



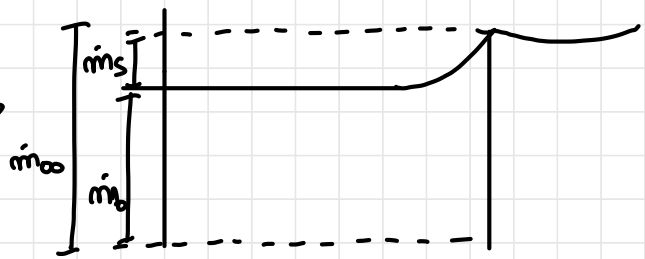
$$\frac{A_1}{A_{tn}} = ?$$

$$M_0 = 1,6 \xrightarrow{150} \frac{A_0}{A_0^*} = \frac{A_1}{A_{tn}} = 1,250$$

$$\frac{A_1}{A_{tn}} = 1,250 \xrightarrow{150} M = 0,553$$



% SP per M=0,7 M=1,6 $\frac{\dot{m}_s}{\dot{m}_\infty}$



$$\%SP = \frac{\dot{m}_\infty - \dot{m}_0}{\dot{m}_\infty} = 1 - \frac{\dot{m}_0}{\dot{m}_\infty}$$

$$\dot{m}_0 = \dot{m}_1 = \frac{P_{t1} \cdot A_1^* \cdot \Psi^*}{a_{t1}}$$

$$\frac{\dot{m}_0}{\dot{m}_\infty} = \frac{A_0}{A_1} = \frac{A_0}{A_0^*} \cdot \frac{A_0^*}{A_1^*} \cdot \frac{A_1^*}{A_1} = \frac{1,084}{1,250} = 0,875$$

($\frac{A_0^*}{A_1^*} = 1$)

$$M_1 = 0,553 \xrightarrow{ISO} \frac{A_1}{A_1^*} = 1,250$$

$$M_0 = 0,4 \xrightarrow{ISO} \frac{A_0}{A_0^*} = 1,084$$

$$\%SP = 1 - \frac{\dot{m}_0}{\dot{m}_\infty} = 1 - 0,875 = 0,125 = 12,5\%$$

$$\frac{\dot{m}_{ideale}}{\dot{m}_{reale}} = \frac{A_0}{A_2} = \frac{A_0}{A_0^*} \cdot \frac{A_0^*}{A_j^*} \cdot \frac{A_j^*}{A_2} = \frac{1,250 \cdot 0,885}{1,250} = 0,885$$

$M_0 = 1,6 \xrightarrow{ISO} \frac{A_0}{A_0^*} = 1,250$

$\xrightarrow{NSW} \frac{p_{t1}}{p_{t0}} = 0,885 = \frac{A_0^*}{A_j^*}$

$M_1 = 0,553 \xrightarrow{ISO} \frac{A_1}{A_j^*} = 1,250$

$\%\,SP = 1 - 0,885 = 0,105 = 10,5\%$

$M_{over} = ?$

$M_{1(SUB)} = 0,553 \xrightarrow{NSW} M_{over} = 2,16$

M_{th} dopo avviamento con $M_0 = M_{over}$

$M_{over} = 2,16 \xrightarrow{ISO} \frac{A_1}{A^*} = 1,935$

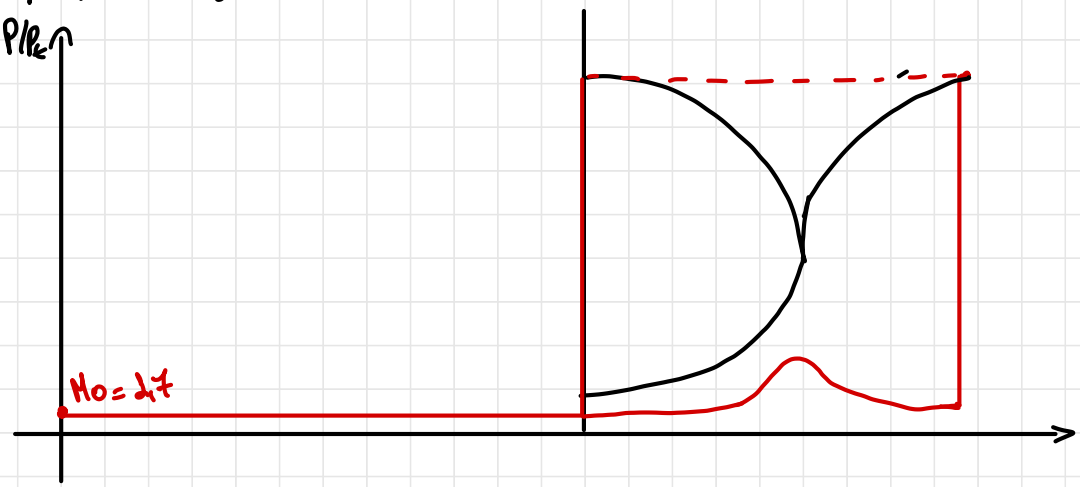
$\frac{A_{th}}{A^*} = \frac{A_{th}}{A_1} \cdot \frac{A_1}{A^*} = \frac{1}{1,250} \cdot 1,935 = 1,548$

$\frac{A_{th}}{A^*} \xrightarrow{ISO} M_{th} = 1,834 \xrightarrow{NSW} \frac{p_{t2}}{p_{t1}} = 0,728$

FAROKHI 6.23

$M_0 = 1{,}7$

$\frac{A_1}{A_{th}} = ?$ $\frac{P_{t2}}{P_{t1}} = ?$ $M_{th} = ?$



$M_0 = 1{,}7 \xrightarrow{\text{NSW}} M_1 = 0{,}641$

$M_1 \xrightarrow{\text{ISO}} \frac{A_1}{A^*} = 1{,}144 = \frac{A_{1SUB}}{A_{th}}$

$\frac{A_{th}}{A^*} = \frac{A_{th}}{A_{1SUB}} \cdot \frac{A_{1SUP}}{A^*} = \frac{1}{1{,}144} \cdot 1{,}338 = 1{,}170$

$M = 1{,}7 \xrightarrow{\text{ISO}} \frac{A_{1SUP}}{A^*} = 1{,}338$

$\frac{A_{th}}{A^*} \xrightarrow{\text{ISO}} M_{th} = 1{,}481$

$M_{th} \xrightarrow{\text{NSW}} \frac{P_{t2}}{P_{t1}} = 0{,}833 \quad \simeq 7\%$

$M_0 \xrightarrow{NSW} \frac{P_{t2}}{P_{t1}} = 0{,}856 \simeq 14\%$

FARO KHI 6.63

$\pi_M = 0{,}88$

$\gamma = 1{,}3$

$R = 281 \frac{J}{kgK}$

$NPR_{critico} = \frac{P_{t7}}{P_8}$ con $M=1$

$NPR = \frac{P_{T7}}{P_8} = \frac{P_{t7}}{P_{t8}} \cdot \frac{P_{t8}}{P_8} = \frac{1}{0{,}88} \cdot 1{,}831 = 1{,}868$

$\frac{P_t}{P^*}$

$\psi^* = 1 + \frac{\gamma-1}{2} M^2 = 1 + \frac{1{,}3-1}{2} \cdot 1^2 = 1{,}150$

$K = \frac{\gamma-1}{\gamma} = \frac{1{,}3-1}{1{,}3} = 0{,}231$

$\frac{P_t}{P^*} = (\psi^*)^{\frac{1}{K}} = 1{,}150^{\frac{1}{0{,}231}} = 1{,}831$

ho NPR 4,2 > 1,868 $\Rightarrow$ sottoespanso

$T_{T7} = 333K$

$P_{t7} = P_0 \cdot NPR = 100kPa \cdot 4{,}2 = 420kPa$

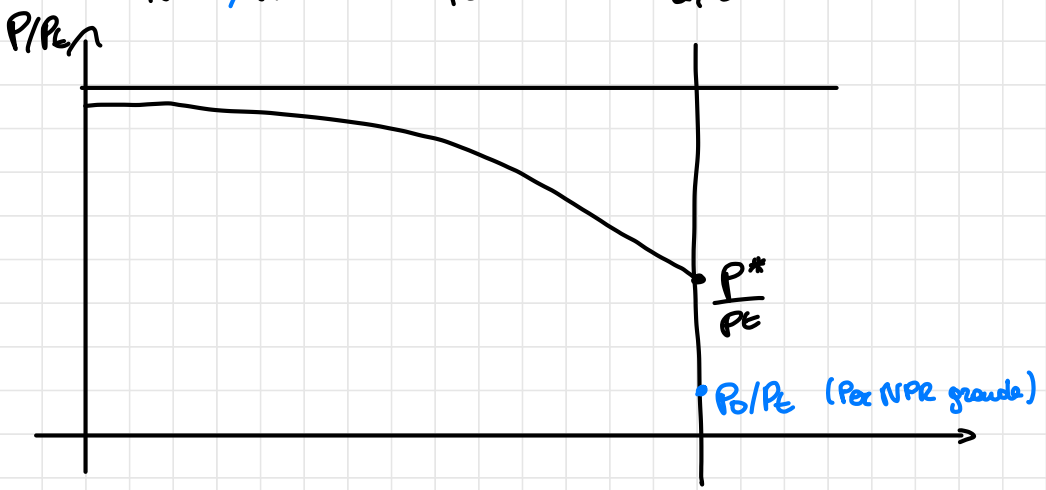
$P_0 = 100kPa$

$P_8 = ?$ $T_8 = ?$

$$P_8 = \frac{P_8}{P_{t8}} \cdot \underbrace{\frac{P_{t8}}{P_{t7}}}_{\pi_{t8}} \cdot P_{t7} = \frac{1}{1{,}831} \cdot 412\,kPa = 225\,kPa$$

$$P_{t8} = \frac{P_{t8}}{P_{t7}} \cdot P_{t7} = 0{,}98 \cdot 420 = 412\,kPa$$

$$T_8 = \frac{T_8}{T_{t8}} \cdot \frac{\cancel{T_{t8}}^{1}}{\cancel{T_{t7}}} \cdot T_{t7} = \frac{1}{\psi_8} \cdot 1 \cdot T_{t7} = \frac{938}{1{,}150} = 817\,K$$



$V_8 = ?$

$$V_8 = a_8 \cdot \sqrt{\gamma R T_8} = \sqrt{1{,}3 \cdot 291 \cdot 817} = 556\ m/s$$

$$\eta = \frac{h_{t7} - h_8}{h_{t7} - h_{8s}} = \frac{\frac{V_8^2}{2}}{\frac{V_{8s}^2}{2}} = \frac{\left(NPR \cdot \frac{P_0}{P_8}\right)^{k8} - \tau_m^{-k8}}{\left(NPR \cdot \frac{P_0}{P_8}\right)^{k8} - 1}$$

$$= \frac{NPR_{cr}^{\ k8} - \tau_m^{-k8}}{NPR_{cr}^{\ k8} - 1} =$$

$$= \frac{1,868^{0,231} - 0,88^{-0,231}}{1,868^{0,231} - 1}$$

$$= 0,870$$

$$V_{8s} = ? = \frac{V_8}{\sqrt{\gamma}} = \frac{556}{\sqrt{0,870}} = 565 \text{ m/s}$$

$$\%F = \frac{F_{CD} - F_C}{F_C}$$

$$\frac{F_C}{\dot{m}_8 a_8} = \frac{V_8}{a_8} + \frac{A_8 (p_8 - p_0)}{\dot{m}_8 a_8} = \frac{V_8}{a_8} + \frac{A_8 \left(1 - \frac{p_0}{p_8}\right)}{\gamma \frac{p_8}{\gamma} A_8 V_8 a_8}$$

$$= \frac{V_8}{a_8} + \frac{\left(1 - \frac{p_0}{p_8}\right)}{\gamma \frac{V_8 a_8}{2}}$$

$$= M_8 + \frac{\left(1 - \frac{p_0}{p_8}\right)}{\gamma M_8}$$

$$= 1 + \frac{\left(1 - \frac{100}{225}\right)}{1,3 \cdot 1} = 1,427$$

$$\frac{F_{CD}}{\dot{m}_8 a_8} = \frac{\overline{V_8}}{a_8}$$

$$\frac{\overline{p_8}}{p_{t8}} = \frac{\overline{p_0}}{p_{t8}} = \frac{100}{412} = 0,243$$

$$\frac{\overline{T_8}}{T_{t8}} = \left(\frac{\overline{p_8}}{p_{t8}}\right)^{\kappa} = 0,243^{0,231} = 0,721$$

$$\overline{T_8} = \frac{\overline{T_8}}{\overline{T_{T8}}} \cdot \overline{T_{T8}} = 0{,}721 \cdot 939 = 677\,K$$

$\overline{T_{T8}} \downarrow \overline{T_{T7}}$

$$\overline{a_8} = \sqrt{\gamma R T_8} = \sqrt{1{,}3 \cdot 281 \cdot 677} = 506\,m/s$$

$$\overline{\psi_8} = 1 + \frac{\gamma - 1}{2} M_8^2 \Rightarrow M_8 = \sqrt{\frac{2}{\gamma - 1} \cdot (\psi_8 - 1)}$$

$$= \sqrt{\frac{2}{0{,}3} \cdot \left(\frac{1}{0{,}721} - 1\right)} = 1{,}606$$

$$\overline{V_8} = M_8 \overline{a_8} = 1{,}606 \cdot 506 = 813\,m/s$$

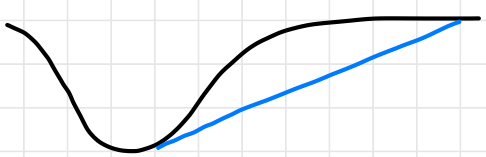
$$\frac{F_{CD}}{\dot{m} a_8} = \frac{\overline{V_8}}{a_8} = \frac{813}{556} = 1{,}462$$

$$\%F = \frac{F_{CD} - F_C}{F_C} = \frac{1{,}462 - 1{,}424}{1{,}424} = 0{,}0265 = 2{,}4\%$$

FAROKHI 6.64

$\alpha = 25°$

$C_A = ?$



$$C_A = \frac{1 + \cos\alpha}{2} = \frac{1 + \cos 25°}{2} = 0{,}953 \Rightarrow 4{,}7\%$$

In 2D

$$C_{A_{2D}} = \frac{\sin\alpha}{2} = \frac{\sin 25°}{\frac{25 \cdot \pi}{180}} = 0{,}963 \Rightarrow 3{,}1\%$$

MATTINGLY 9.12

$$K = \frac{\gamma - 1}{\gamma} = \frac{1,4 - 1}{1,4} = 0,286$$

SEZIONE 1 $M_1 = 0,5$ $P_{T1} = 101,3$ kPa $T_{T1} = 290$ K $\dot{m} = 50$ kg/s

$$\psi_1 = 1 + \frac{\gamma - 1}{2} M_1^2 = 1 + 0,2 \cdot 0,5^2 = 1,050$$

$$T_1 = \frac{T_{T1}}{\psi_1} = \frac{280}{1,050} = 276\ K$$

$$a_1 = \sqrt{\gamma R T_1} = \sqrt{1,4 \cdot 287 \cdot 276} = 333\ m/s$$

$$C_1 = M_1 \cdot a_1 = 0,5 \cdot 333\ m/s = 166,5\ m/s$$

$$p_1 = \frac{p_{T1}}{\psi_1^{1/K}} = \frac{101,3}{1,050^{1/0,286}} = 85,4\ kPa$$

$$C_{z_1} = C_1 \cos\alpha = 166,5\ m/s \cdot \cos 40 = 127,5\ m/s$$

$$C_{\theta_1} = C_1 \operatorname{sen}\alpha = 166,5\ m/s \cdot \operatorname{sen} 40 = 107,0\ m/s$$

$$a_{T2} = \sqrt{\gamma R T_{T1}} = \sqrt{1,4 \cdot 287 \cdot 290} = 341\ m/s$$

$$\dot{m} = \frac{p_{T1} A^*_{R_1} \psi^*}{a_{T1}} = \frac{p_{T1} \frac{A^*_{R_1}}{A_{R_1}} A_1 \psi^*}{a_{T1}} \Rightarrow A_{R_1} = \frac{\dot{m} \cdot a_{T1}}{p_{T1} \psi^*} \cdot \frac{A_{R_1}}{A^*_{R_1}}$$

$$M_1 \xrightarrow{\text{tab}} \frac{A_{R_1}}{A^*_{R_1}} = 1,340 \Rightarrow A_{R_1} = \frac{50 \cdot 341}{1,013 \cdot 10^5 \cdot 0,81} \cdot 1,340$$

$$A_{R_1} = 0,278\ m^2$$

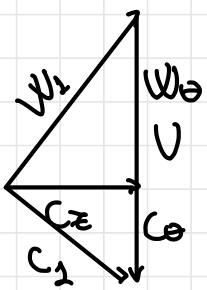
$$A_1 = \frac{A_{e_1}}{\cos\alpha} = \frac{0{,}248}{\cos 40} = 0{,}363\ m^2$$

SEZ 1R $\quad T_{T3} = T_{T2}$

$T_{T3} - T_{T1} = 45\ K$

$W_{\theta 1} = C_{\theta 1} - U = 107{,}0 - 400 = -293\ m/s$

$\omega = 800\ rad/s \quad r = 0{,}5\ m \Rightarrow U = \omega \cdot r = 0{,}5 \cdot 800 = 400\ m/s$



$$W_1 = \sqrt{W_{\theta 1}^2 + W_{z1}^2} = \sqrt{293^2 + 127{,}5^2} = 320\ m/s$$

$W_{z1} = C_{z1}$

$$M_{1R} = \frac{W_1}{a_1} = \frac{320}{333} = 0{,}961$$

$$\beta_1 = \operatorname{arctan}\frac{W_\theta}{W_z} = \operatorname{arctan}\left(-\frac{293}{127{,}5}\right) = -66{,}5$$

$$\psi_{1R} = 1 + \frac{\gamma - 1}{2} M_{1R}^2 = 1 + 0{,}2 \cdot 0{,}961^2 = 1{,}185$$

$$T_{T1R} = T_{1R}\psi_{1R} = 276 \cdot 1{,}185 = 327\ K$$

$$p_{T1R} = p_{1R}\psi_{1R}^{1/K} = 85{,}4 \cdot 1{,}185^{\frac{1}{0{,}286}} = 154{,}6\ kPa$$

Secteur 2R $\omega_R = 0{,}1$ $\Delta T = 45\,K$

$$\omega_R = \frac{p_{t1R} - p_{t2R}}{\frac{1}{2}\rho_1 w_{1R}^2} = \frac{p_{t1R} - p_{t2R}}{\frac{1}{2}\cdot\frac{\rho_1}{p_1}\,p_{1R}\,\frac{\gamma_1}{\gamma_1}\,M_{1R}^2} = \frac{p_{t1R} - p_{t2R}}{\frac{1}{2}\gamma p_{1R} M_{1R}^2}$$

a^2

$$\Rightarrow p_{t2} = p_{t1R} - \omega_R\left(\frac{1}{2}\gamma p_{1R} M_{1R}^2\right) =$$

$$= 154{,}6\,kPa - 0{,}1\left(\frac{1}{2}\cdot 1{,}4\cdot 85{,}4\cdot 0{,}861^2\right) =$$

$$= 148{,}1\,kPa$$

$$T_{t2} = T_{t1} + \Delta T = 290 + 45 = 335\,K$$

$$\frac{T_{t2}}{T_{t1}} = 1 + \frac{U^2}{c_p T_{t1}}\left[1 + \frac{c_{z1}}{U}\left(\tan\beta_2 - \tan\alpha_1\right)\right]$$

$$c_p\left(T_{t2} - T_{t1}\right) - U^2 = c_{z1}\cdot U\left(\tan\beta_2 - \tan\alpha_1\right)$$

$$\tan\beta_2 = \tan\alpha_1 + \frac{c_p\left(T_{t2} - T_{t1}\right) - U^2}{c_{z1}\cdot U} = \tan 40^\circ + \frac{1004\cdot 45 - 400^2}{127{,}5\cdot 400}$$

$$= 1{,}412$$

$$\Rightarrow \beta_2 = \tan^{-1}(-1{,}412) = -54{,}7^\circ$$

$$w_{\theta 2} = c_{z2}\cdot\tan\beta_2 = 127{,}5\cdot(-1{,}412) = -180{,}0\ m/s$$

$$W_2 = \sqrt{W_{\theta 2}^2 + W_{z_2}^2} = \sqrt{180^2 + 127{,}5^2} = 221 \text{ m/s}$$

$$T_2 = T_{T2R} - \frac{W_2^2}{2c_p} = 327 - \frac{221^2}{2 \cdot 1004} = 303 \text{ K}$$

T_2 = T_{T2R}

$$a_2 = \sqrt{\gamma R T_2} = \sqrt{1{,}4 \cdot 287 \cdot 303} = 348 \text{ m/s}$$

$$M_{2_R} = \frac{W_2}{a_2} = \frac{221 \text{ m/s}}{348 \text{ m/s}} = 0{,}633$$

$$p_2 = p_{t2R} \left(\frac{T_2}{T_{T2R}}\right)^{1/K} = 149{,}1 \cdot \left(\frac{303}{327}\right)^{\frac{1}{0{,}286}} = 114{,}2 \text{ kPa}$$

p_2 = p_{2R}

SEZIONE 2

$$C_{\theta 2} = W_{\theta 2} + U = -180 + 400 = 220 \text{ m/s}$$

$$C_2 = \sqrt{C_{\theta 2}^2 + C_{z_2}^2} = \sqrt{220^2 + 127{,}5^2} = 254 \text{ m/s}$$

$$\alpha_2 = \text{arctan} \frac{C_{\theta 2}}{C_{z_2}} = \tan^{-1} \frac{220}{127{,}5} = 59{,}8°$$

$$M_2 = \frac{C_2}{a_2} = \frac{254}{348} = 0{,}728$$

$$\psi_2 = 1 + \frac{\gamma - 1}{2} M_2^2 = 1 + 0{,}2 \cdot 0{,}428^2 = 1{,}106$$

$$P_{T2} = p_2 \psi_2^{1/K} = 114{,}2 \cdot (1{,}106)^{1/0{,}286} = 162{,}4 \text{ kPa}$$

$$a_{T2} = \sqrt{\gamma R T_{T2}} = \sqrt{1{,}4 \cdot 287 \cdot 335} = 367 \text{ m/s}$$

$$A_{R2} = \frac{\dot{m}\, a_{T2}}{P_{T2} \cdot \frac{A_2^*}{A_{R2}} \cdot q^*} = \frac{50 \cdot 367}{162{,}4 \cdot 10^3 \cdot \frac{0{,}810}{1{,}075}} = 0{,}1500 \text{ m}^2$$

$$M_2 \xrightarrow{\text{ISO}} \frac{A_{R2}}{A^*_2} = 1{,}075$$

$$A_2 = \frac{A_{R2}}{\cos\alpha_2} = \frac{0{,}1500}{\cos 58{,}9} = 0{,}289$$

Sez 3 $\omega_s = 0{,}03$

$$T_{T3} = T_{T2} = 335 \text{ K}$$

$$P_{T3} = P_{T2} - \omega_s \cdot \frac{1}{2} \gamma p_2 M_2^2 = 162.4 - 0{,}03 \cdot \frac{1{,}4}{2} \cdot 114{,}2 \cdot 0{,}428^2 =$$

$$= 161{,}1 \text{ kPa}$$

$M_3 = M_1 = 0{,}5$

$\psi_3 = \psi_1 = 1{,}050$

$$T_3 = \frac{T_{T3}}{\psi_3} = \frac{335}{1{,}050} = 318 \text{ K}$$

$$P_3 = \frac{P_{T3}}{\psi_3^{1/K}} = \frac{161{,}1}{1{,}050^{1/0{,}286}} = 135{,}8 \text{ kPa}$$

$$a_3 = \sqrt{\gamma R T_3} = \sqrt{1{,}4 \cdot 287 \cdot 318} = 358 \text{ m/s}$$

$$C_3 = M_3 a_3 = 0{,}5 \cdot 358 = 178 \text{ m/s}$$

$$\alpha_3 = \alpha_1 = 60°$$

$$C_{z3} = C_3 \cos\alpha_3 = 178 \cdot \cos 60 = 137{,}1 \text{ m/s}$$

$$C_{\theta 3} = C_3 \sin\alpha_3 = 178 \cdot \sin 60 = 115{,}1 \text{ m/s}$$

$$M_3 \xrightarrow{\text{tab}} \frac{A_{R3}}{A^*} = 1{,}360$$

$$A_{R3} = \frac{\dot{m}\, a_{T3}}{P_{T3} \cdot \frac{A^*}{A_{R3}} \cdot \varphi^*} = \frac{50 \cdot 367}{161{,}1 \cdot 10^3 \cdot \frac{0{,}810}{1{,}360}} = 0{,}1884 \text{ m}^2$$

$$A_3 = \frac{A_{R3}}{\cos\alpha_1} = \frac{0{,}1884}{\cos 60} = 0{,}246 \text{ m}^2$$

$$^{\circ}R = \frac{T_2 - T_1}{T_3 - T_1} = \frac{303 - 266}{313 - 266} = 0{,}628$$

$$D_R = 1 - \frac{W_2}{W_1} + \frac{|W_{\theta 2} - W_{\theta 1}|}{2\sigma_R \cdot W_1} = 1 - \frac{221}{320} + \frac{293 - 173{,}9}{2 \cdot 1 \cdot 320} = 0{,}486 \quad < 0{,}6 \text{ OK}$$

$\sigma_R = 1$

$$D_S = 1 - \frac{C_3}{C_2} + \frac{|C_{\theta 3} - C_{\theta 2}|}{2\sigma_S \cdot C_2} = 1 - \frac{178}{254} + \frac{220 - 115}{2 \cdot 1 \cdot 254} = 0{,}503 \quad < 0{,}6 \text{ OK}$$

$\sigma_S = 1$

$$\pi_c = \frac{p_{t3}}{p_{t1}} = \frac{161,1}{101,3} = 1,590$$

$$\tau_c = \pi_c^{\frac{k}{e_c}} = \frac{335}{290} = 1,155$$

$$\eta_c = \frac{\pi_c^{k} - 1}{\tau_c - 1} = \frac{(1,590)^{0,286} - 1}{1,155 - 1} = 0,815$$

$$e_c = \frac{e_u \pi_c}{e_u \tau_c} \cdot k = \frac{\ln 1,155}{\ln 1,590} \cdot 0,286 = 0,820$$

$$\psi_c = \frac{c_p \Delta T_T}{U^2} = \frac{1004 \cdot 65}{400^2} = 0,282 \qquad \phi = \frac{C_z}{U} = \frac{127,5}{400} = 0,319$$

	SEZ 1	SEZ 1R	SEZ 2R	SEZ 2	SEZ 3
T_T	290 K	327	327	335 K	335 K
T	276 K	276	303	303 K	318 K
P_T	101,3 KPa	154,6	148,1	162,4 KPa	161,1 KPa
P	85,4 KPa	85,4	114,2	114,2 KPa	135,8 KPa
M	0,5	0,861	0,633	0,728	0,5
C/W	166,5 m/s	320 m/s	221	254 m/s	179 m/s
C_z/W_z	127,5 m/s	127,5 m/s	127,5 m/s	127,5 m/s	137,2 m/s
C_θ/W_θ	107,0 m/s	-293 m/s	-180	220 m/s	115,1 m/s
α/β	40°	-66,5	-54,7	58,8	40
A	0,363 m^2			0,289 m^2	0,246 m^2

MISCELE BY TOM

SPECIE	MASSA KG	MW	N freedom	T
N_2	8	28	5	300
CO_2	2	44	7	800

$$n_{N_2} = \frac{m_{N_2}}{MW_{N_2}} = \frac{8}{28} = 0{,}286 \text{ Kmol}$$

$$n_{CO_2} = \frac{m_{CO_2}}{MW_{CO_2}} = \frac{2}{44} = 0{,}0455 \text{ Kmol}$$

$$n_m = n_{N_2} + n_{CO_2} = 0{,}286 + 0{,}0455 = 0{,}332 \text{ Kmol}$$

$$x_{N_2} = \frac{n_{N_2}}{n_m} = \frac{0{,}286}{0{,}332} = 0{,}861$$

$m_m = 2 + 8 = 10$ Kg

$$x_{CO_2} = 1 - x_{N_2} = 1 - 0{,}861 = 0{,}139$$

$$MW_m = x_{N_2} \cdot MW_{N_2} + x_{CO_2} \cdot MW_{CO_2} = \frac{m_m}{n_m} = 30{,}1 \frac{Kg}{Kmol}$$

$$w_{N_2} = \frac{m_{N_2}}{m_m} = \frac{8}{10} = 0{,}800$$

$$\overline{cv}_{N_2} = \overline{R} \cdot \frac{5}{2} = 8320 \cdot \frac{5}{2} = 20800 \frac{J}{Kmol \cdot K} = 20{,}8 \frac{KJ}{Kmol \cdot K}$$

$$\overline{cv}_{CO_2} = \overline{R} \cdot \frac{7}{2} = 8320 \cdot \frac{7}{2} = 29{,}1 \frac{KJ}{Kmol \cdot K}$$

$$\overline{cv}_m = x_{N_2} \cdot \overline{cv}_{N_2} + x_{CO_2} \cdot \overline{cv}_{CO_2} = 0{,}861 \cdot 20{,}8 + 0{,}139 \cdot 29{,}1$$

$$= 21{,}9 \frac{KJ}{Kmol\,K}$$

$$c_{v_{N_2}} = \frac{\bar{c}_{v_{N_2}}}{MW_{N_2}} = \frac{20,8}{28} = 0,743 \ \frac{kJ}{kg\,K}$$

$$c_{v_m} = \frac{\bar{c}_{v_m}}{MW_m} = \frac{21,9}{30,1} = 0,728 \ \frac{kJ}{kg\,K}$$

$$R = \frac{\bar{R}}{MW_m} = \frac{8320}{30,1} = 276 \ \frac{J}{kg \cdot K}$$

$$c_{v_{CO_2}} = 661 \ \frac{J}{kg \cdot K}$$

$$c_{v_m} T_m = \frac{w_{N_2} \cdot c_{v_{N_2}} \cdot T_{N_2} + w_{CO_2} \cdot c_{v_{CO_2}} \cdot T_{CO_2}}{c_{v_m}}$$

$$T_m = \frac{0,8 \cdot 743 \cdot 300 + 0,2 \cdot 661 \cdot 800}{728} = 390 \ K$$

$$\bar{c}_{p_m} = \bar{c}_{v_m} + \bar{R} = 21,9 + 8,320 = 30,2 \ \frac{kJ}{kmol \cdot K}$$

$$p_{N_2} = p_m \cdot x_{N_2} = 101,3 \ kPa \cdot 0,861 = 87,2 \ kPa \quad (p_m \to 101,3 \ kPa)$$

$$V_m = \frac{n_m \cdot R \cdot T_m}{p_m} = \frac{n_{N_2} \cdot R \cdot T_m}{p_{N_2}}$$

(1) (2)

$$(1) \Rightarrow \frac{0,332 \cdot 8320 \cdot 390}{101,3 \cdot 10^3} = 10,63 \ m^3$$

$$V_{N_2} = x_{N_2} \cdot V_m = \frac{n_{N_2} \cdot R \cdot T_m}{p_m} = 0,861 \cdot 10,63 = 9,15$$

$$\gamma_m = \frac{\bar{c}_{p_m}}{\bar{c}_{v_m}} = \frac{30,2}{21,9} = 1,379$$

FAROKHI 7.4

$$CH_{1,93} + x(O_2 + 3,76\,N_2) \rightarrow CO_2 + y\,H_2O + z\,3,76\,N_2$$

$$x \cdot 3,76 = z \cdot 3,76 \Rightarrow x = z$$

$$1,93 = 2y \Rightarrow y = 0,965 \qquad y = \frac{1,93}{2}$$

$$2x = 2 + y \qquad x = \frac{2 + 0,965}{2} = 1,483 \qquad x = \frac{5,93}{9}$$

$$CH_{1,93} + 1,483(O_2 + 3,76\,N_2) \rightarrow CO_2 + 0,965\,H_2O + 1,483 \cdot 3,76 \cdot N_2$$

$$\phi = \frac{\dot{m}_g}{\dot{m}_0} = \frac{m_g}{m_0} = \frac{1 \cdot 12 + 1 \cdot 1,93}{1,483(2 \cdot 16 + 3,76 \cdot 2 \cdot 14)} = 0,0684$$

FAROKHI 7.5

$$C_8H_{18} + \frac{25}{2}O_2 \rightarrow 8CO_2 + 9H_2O$$

$$Q_{ext} = \sum_J \left[m_J \overline{c_p}_J (\bar{T}_2 - T_g) \right]_{prod} - \sum_i \left[n_i \overline{c_p}_i (\bar{T}_1 - T_g) \right]_{Reg} + \Delta H_{RPF}$$

$$\Delta H_{RPF} = \sum_J \left[m_J \Delta \bar{h}^\circ_{g_J} \right]_{prod} - \sum_i \left[n_i \Delta \bar{h}^\circ_{g_i} \right]_{reag}$$

$\Delta \bar{h}^\circ_g$ (kJ/gmol):

- $C_8H_{18} \rightarrow -208$
- $CO_2 \rightarrow -393,522$
- $H_2O \rightarrow -241,827$

$$Q_{ext} = \Delta H_{RPF} = n_{CO_2} \cdot \overline{\Delta h_f^\circ}_{CO_2} \dots - n_{C_8H_{18}} \cdot \overline{\Delta h_f^\circ}_{C_8H_{18}} \dots$$

$$= 8 \cdot (-394) + 9 \cdot (-242) - 1 \cdot (-208)$$

$$= -5120 \ \frac{kJ}{8\ mol}\ kmol = -5120\ MJ$$

$$LHV = -\frac{Q_{ext}}{m_f} = \frac{5120 \cdot 10^3\ kJ}{\underbrace{12 \cdot 8}_{C_8} + \underbrace{1 \cdot 18}_{H_{18}}} = 44912\ \frac{kJ}{kg} = 44,9\ \frac{MJ}{kg}$$

$$HHV = LHV + \frac{m_{H_2O}}{m_{C_8H_{18}}} \cdot h_{vap\,H_2O} = 44,9 \cdot 10^3 + \frac{9 \cdot (16+2)}{12 \cdot 8 + 1 \cdot 18} \cdot 2260$$

$\hookrightarrow 2240\ \frac{kJ}{kg}$

$$= 48,1\ \frac{MJ}{kg}$$

FAROKHI 7.3

$\overline{cp}_{CO_2} = 61,3\ \frac{kJ}{kmol \cdot K}$ $\overline{cp}_{O_2} = 37.8\ \frac{kJ}{kmol \cdot K}$ $\overline{cp}_{N_2} = 33.6\ \frac{kJ}{kmol \cdot K}$

$\overline{cp}_{H_2O} = 52,3\ \frac{kJ}{kmol \cdot K}$

$$C_8H_{18} + (1+2)x\,(O_2 + 3,76\,N_2) \rightarrow 8CO_2 + 9H_2O + y\,O_2 + (1+2)x \cdot 3.76\,N_2$$

$2 = 0,2 \quad x = \frac{25}{2}$

$y = 2x = \frac{25}{2} \cdot 0,2 = 2.5 \qquad (1+2)x = 1.2 \cdot \frac{25}{2} = 15$

$$C_8H_{18} + 15\,(O_2 + 3,76\,N_2) \rightarrow 8CO_2 + 9H_2O + 2.5O_2 + \underbrace{15 \cdot 3,76}_{56,4} \cdot N_2$$

$$f = \frac{\dot{m}_f}{\dot{m}_O} = \frac{m_f}{m_O} = \frac{8 \cdot 12 + 18 \cdot 1}{15\,(2 \cdot 16 + 3{,}76 \cdot 2 \cdot 14)} = 0{,}0554$$

$$\Phi = \frac{f}{f_{st}} = \frac{0{,}0554}{\frac{8 \cdot 12 + 18 \cdot 1}{12.5\,(2 \cdot 16 + 3{,}76 \cdot 2 \cdot 14)}} = \frac{1}{1+2} = 0{,}833$$

$$Q_{ext} = \sum_J \left[m_J \overline{c_{pJ}} (T_2 - T_f) \right]_{prod} - \sum_i \left[m_i \overline{c_{pi}} (T_1 - T_f) \right]_{Reg} + \Delta H_{RPF}$$

($T_1 = T_f$)

$$\Delta H_{RPF} = \sum_J \left[m_J \overline{\Delta h^\circ_{fJ}} \right]_{prod} - \sum_i \left[m_i \overline{\Delta h^\circ_{fi}} \right]_{reag}$$

$\overline{\Delta h^\circ_f}$ { $C_8H_{18} \rightarrow -208$; $CO_2 \rightarrow -393{,}522$; $H_2O \rightarrow -241{,}827$ } $\frac{KJ}{g\,mol}$ $\qquad T_1 = T_f$

$$Q_{ext} = \sum_J \left[m_J \overline{c_{pJ}} (T_2 - T_f) \right] + \Delta H_{RPF}$$

($\Delta H_{RPF} = -5120$ MJ)

$$= m_m \cdot \overline{c_{pm}} (T_2 - T_f) + \Delta H_{RPF} = 0$$

$$m_m = 8 + 9 + 2.5 + 15 \cdot 3{,}76 = 75{,}9 \text{ Kmol}$$

$$\overline{c_{pm}} = \sum_i X_i \cdot \overline{c_{pi}} = \sum_i \frac{n_i \cdot \overline{c_{pi}}}{m_m}$$

Cp medio miscela (mediato su T_m) $= \frac{8 \cdot 61{,}9 + 9 \cdot 52{,}3 + 2{,}5 \cdot 37{,}8 + 56{,}4 \cdot 33{,}6}{75{,}9} = 35.9 \ \frac{KJ}{Kmol \cdot K}$

$$m_m \cdot \overline{c_{pm}} \,(T_2 - T_f) + \Delta H_{RPF} = 0$$

$$\Rightarrow T_2 = T_f - \frac{\Delta H_{RPF}}{m_m \, c_{pm}} = 298{,}15\,K + \frac{5120 \cdot 10^3}{75{,}9 \cdot 38{,}9} = 2030\,K$$

$$\overline{h_J} = \int_{T_f}^{T_2} \overline{c_{pJ}}\, dT + \overline{\Delta h^\circ_{fJ}}$$

$$\overline{c_{pJ}} = \frac{\int_{T_f}^{T_2} \overline{c_{pJ}} dT}{T_2 - T_f} = \frac{\overline{h_{J\,T_2}} - \overline{h_{J\,T_f}}}{T_2 - T_f} \qquad \theta = \frac{T}{100}$$

$$CO_2 \Rightarrow \overline{c_{p0}} = -3{,}74 + 30.5\theta^{0.5} - 4.10\,\theta + 0{,}242 \cdot \theta^2$$

$$\overline{c_{pJ}} = \frac{\int_{T_f}^{T_2} \overline{c_{pJ}} dT}{T_2 - T_f} = \frac{1}{T_2 - T_f} \int_{T_f}^{T_2} 100 \sum a_i \cdot \theta^{e_i} \frac{d\theta}{dT}$$

$$= \frac{1}{T_2 - T_f} \left[\frac{100 \sum a_i \theta^{e_i+1}}{e_i + 1} \right]_{T_2}^{T_f}$$

$$= \frac{1}{T_2 - T_f} \cdot T \, \frac{\sum a_i \theta^{e_i}}{e_i + 1}$$

$$\overline{c_{pCO_2}} = \frac{1}{T_2 - T_f} \left[-3{,}74 \cdot T + \frac{30{,}5 \cdot T}{1{,}5} \left(\frac{T}{100}\right)^{0{,}5} + \frac{(-4.10)\,T}{2} \left(\frac{T}{100}\right)^{1} \dots \right]$$

FAROKHI 7.10

4000 K $\quad O_2 \rightarrow 2O \quad K_p = 2.19$ atm

$\frac{1}{2} O_2 \leftrightarrow O \quad \log_{10} K = 0{,}170 \Rightarrow K_P = 1{,}479$

$K = \frac{X_O}{X_{O_2}^{1/2}} P^{1/2} = 1{,}479 \qquad K_p = \frac{X_O^2}{X_{O_2}} P = K^2 = 2{,}19$ atm

$O_2 \longrightarrow (1-x)O_2 + 2xO$

$X_O = ?$ $\qquad n_m = 1 - x + 2x = 1 + x$

$X_{O_2} = ?$

$X_O = \frac{2x}{1+x}$

$X_{O_2} = \frac{1-x}{1+x}$

$\frac{X_O^2}{X_{O_2}} P = K^2 = \left(\frac{2x}{1+x}\right)^2 \cdot \frac{1+x}{1-x} \cdot P = \frac{4x^2}{1-x^2} \cdot P = 2{,}19$

$4x^2 \cdot P = 2{,}19 (1-x^2)$

$\Rightarrow x^2 (4P + 2{,}19) = 2.19$

$x = \sqrt{\frac{2{,}19}{4P + 2{,}19}}$

$P = 1$ atm $\Rightarrow x = 0{,}595$

$P = 10$ atm $\Rightarrow x = 0{,}228$

	1 atm	10 atm
X_0	0,746	0,371
X_{O_2}	0,254	0,629

$$X_0 = \frac{2x}{1+x} \rightarrow \begin{cases} 1\,atm \rightarrow \frac{2 \cdot 0{,}535}{1+0{,}535} = 0{,}746 \\ 10\,atm \rightarrow = 0{,}371 \end{cases}$$

$$X_{O_2} = 1 - 0{,}746 = 0{,}254$$

$$X_{O_2} = 1 - 0{,}371 = 0{,}629$$

MA 8.35

$$\gamma = 1{,}3 \Rightarrow K = \frac{\gamma - 1}{\gamma} = \frac{1{,}3-1}{1{,}3} = 0{,}231$$

$$K = \frac{\gamma+1}{2(\gamma-1)} = \frac{2{,}3}{0{,}6} = 3{,}83$$

SEZIONE 1 $M_1 = 0{,}3$ $T_{T_1} = 1780\,K$ $P_{T_1} = 1400\,kPa$

$$\psi_1 = 1 + \frac{\gamma-1}{2} M_1^2 = 1 + \frac{0{,}3}{2} \cdot 0{,}3^2 = 1{,}014$$

$$T_1 = \frac{T_{T_1}}{\psi} = \frac{1780}{1{,}014} = 1755\,K$$

$$P_1 = \frac{P_{T_1}}{\psi^{1/K}} = \frac{1400}{1{,}014^{1/0{,}231}} = 1318\,kPa$$

$R = 287\ J/kg\,K$

$$a_{T_1} = \sqrt{\gamma R T_{T_1}} = \sqrt{1{,}3 \cdot 287 \cdot 1780} = 815\ m/s$$

$$a_1 = \sqrt{\gamma R T_1} = \sqrt{1{,}3 \cdot 287 \cdot 1755} = 808\ m/s$$

$C_1 = M_1 a_1 = 0{,}3 \cdot 808 = 243 \text{ m/s}$ $\quad \alpha_1 = 0°$

$C_{z_1} = C_1 = 243 \text{ m/s}$ $\quad C_{\theta 1} = 0 \text{ m/s}$ $\quad \omega = 1000 \text{ rad/s}$ $\quad r_0 = 0{,}4 \text{ m}$

$U = \omega \cdot r_0 = 1000 \cdot 0{,}4 = 400 \text{ m/s}$

$\dot{m} = \dfrac{p_{t1} A_{1R} \cdot \Psi_1}{a_{t1}}$ $\quad \dot{m} = 40 \text{ kg/s}$

$\Psi_1 = \gamma M \psi_1^{-K} = 1{,}3 \cdot 0{,}3 \cdot 1{,}014^{-3{,}83} = 0{,}370$

$A_{1R} = \dfrac{\dot{m} a_{T1}}{p_{t1} \Psi_1} = \dfrac{40 \cdot 815}{1400 \cdot 10^3 \cdot 0{,}370} = 0{,}0629 \text{ m}^2 = A_1$ essendo $\alpha_1 = 0$

SEZIONE 2 $T_{T2} = T_{T1}$ $\quad M_2 = 1{,}15$ $\quad \omega s = 0.04$

$\Psi_2 = 1 + \dfrac{\gamma - 1}{2} M_2^2 = 1 + \dfrac{0{,}3}{2} 1{,}15^2 = 1{,}188$

$T_2 = \dfrac{T_{T2}}{\Psi_2} = \dfrac{1400 \text{ K}}{1{,}188} = 1486 \text{ K}$

$a_{T2} = a_{T1} = 815 \text{ m/s}$

$a_2 = \sqrt{\gamma R T_2} = \sqrt{1{,}3 \cdot 287 \cdot 1486} = 745 \text{ m/s}$

$C_2 = M_2 a_2 = 1{,}15 \cdot 745 \text{ m/s} = 857 \text{ m/s}$

$\omega s = \dfrac{p_{T1} - p_{T2}}{p_{T2} - p_2} = \dfrac{1 - \dfrac{p_{T2}}{p_{T1}}}{\dfrac{p_{T2}}{p_{T1}} \left(1 - \dfrac{p_2}{p_{T2}}\right)}$

$$\Rightarrow 1 - \frac{p_{t2}}{p_{t1}} = \omega s \left[\frac{p_{t2}}{p_{t1}} \left(1 - \frac{p_2}{p_{t2}} \right) \right]$$

$$\frac{p_{t2}}{p_{t1}} = \frac{1}{1 + \omega s \left(1 - \frac{p_2}{p_{t2}} \right)} \qquad \psi_2^{-\frac{1}{k}} = 1{,}198^{(-1/0{,}231)} = 0{,}457$$

$$p_{t2} = \frac{p_{t1}}{1 + \omega s \left(1 - \psi_2^{-1/k} \right)} = \frac{1400}{1 + 0.04 \left(1 - 0{,}457 \right)} = 1370 \text{ kPa}$$

$$P_2 = P_{t2} \cdot \psi^{-1/k} = 1370 \cdot 0{,}457 = 626 \text{ kPa}$$

$\Delta T_{tot} = 230 \text{ K}$

$c_p = 1244 \text{ J/kg K}$

$$\Delta h_{tot} = -U \Delta c_\theta = -U \left(\underbrace{c_{\theta 3}}_{=0 \text{ per } \alpha = 0} - c_{\theta 2} \right) = U c_{\theta 2} \Rightarrow c_{\theta 2} = \frac{\Delta h_{tot}}{U}$$

$$c_{\theta 2} = \frac{c_p \Delta T_{tot}}{U} =$$

$$= \frac{1244 \cdot 230}{400} = 715 \text{ m/s}$$

$$\alpha_2 = \sin^{-1} \frac{c_{\theta 2}}{c_2} = \sin^{-1} \frac{715}{857} = 56{,}5$$

$$c_{z_2} = c_2 \cos \alpha_2 = 857 \cdot \cos(56{,}5) = 473 \text{ m/s}$$

$$\dot{m} = \frac{p_{t2} \cdot A_{2R} \cdot \psi_2}{a_{t2}}$$

$$\psi_2^T = \gamma M_2 \psi_2^{-K} = 1{,}3 \cdot 1{,}15 \cdot 1{,}138^{(-3{,}82)} = 0{,}748$$

$$A_{2R} = \frac{\dot{m}\, a_{T2}}{p_{i2} \cdot \psi_2^T} = \frac{40 \cdot 815}{1360 \cdot 10^2 \cdot 0{,}748} = 0{,}0318$$

$$A_2 = \frac{A_{2R}}{\cos \lambda_2} = \frac{0{,}0318}{\cos 56{,}5} = 0{,}0576\ m^2$$

SEZIONE 2R

$$W_{\theta 2} = C_{\theta 2} - U = 715 - 400 = 315\ m/s$$

$$W_2 = \sqrt{W_{\theta 2}^2 + W_{z2}^2} = \sqrt{315^2 + 473^2} = 568\ m/s$$

$$\beta = \tan^{-1} \frac{W_{\theta 2}}{W_{z2}} = \tan^{-1} \frac{315}{473} = 33{,}7$$

$$M_{2R} = \frac{W_2}{a_2} = \frac{568}{745} = 0{,}762$$

$$\psi_{2R} = 1 + \frac{\gamma - 1}{2} M_{2R}^2 = 1 + 0{,}15 \cdot 0{,}762^2 = 1{,}087$$

$$T_{T2R} = T_{2R} \cdot \psi_{2R} = 1486 \cdot 1{,}087 = 1615\ K$$

$$P_{T2R} = P_{2R} \cdot \psi_{2R}^{1/K} = 626 \cdot 1{,}087^{1/0{,}231} = 898\ kPa$$

SEZIONE 3

$C_{z3} = C_{z2} = 473\ m/s \qquad \alpha_3 = 0 \Rightarrow C_3 = C_{z3}$

$C_{\theta 3} = 0$

$\Delta T_{tot} = 230\ K \Rightarrow T_{T3} = T_{T2} - \Delta T_{TOT} =$

$= 1780 - 230 = 1550\ K$

$$T_3 = T_{T3} - \frac{C_3^2}{2c_p} = 1550 - \frac{473}{2 \cdot 1244} = 1460\ K$$

$$a_3 = \sqrt{\gamma R T_3} = \sqrt{1{,}3 \cdot 287 \cdot 1460} = 738\ m/s$$

$$a_{T3} = \sqrt{\gamma R T_{T3}} = \sqrt{1{,}3 \cdot 287 \cdot 1550} = 760\ m/s$$

$$\psi_3 = \frac{T_{T3}}{T_3} = \frac{1550}{1460} = 1{,}062$$

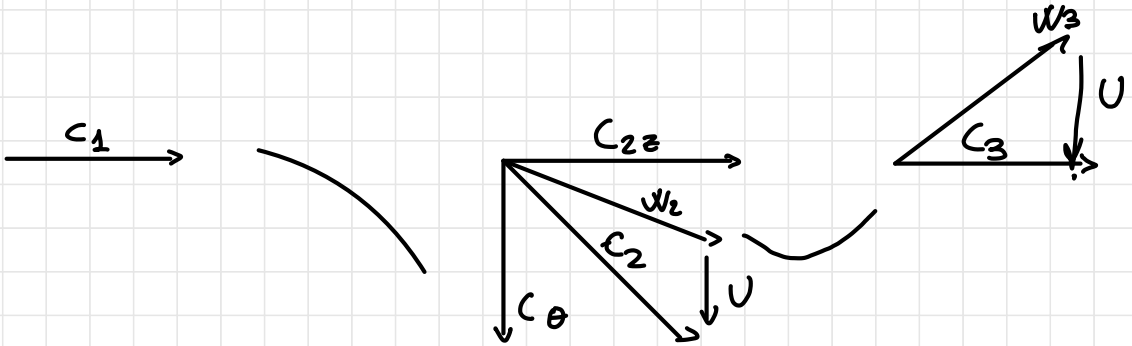
$$\frac{C_3}{a_3} = M_3 = \frac{473}{738} = 0{,}641$$

SEZIONE 3R

$$W_{\theta 3} = C_{\theta 3} - U = -400\ m/s \quad (C_{\theta 3} = 0)$$

$$W_3 = \sqrt{W_{\theta 3}^2 + W_{z3}^2} = \sqrt{400^2 + 473^2} = 619\ m/s$$

$$\beta_3 = \tan^{-1}\frac{W_{\theta 3}}{W_{z3}} = \tan^{-1}\left(\frac{-400}{473}\right) = -40{,}2°$$



$$M_{3R} = \frac{W_3}{a_3} = \frac{619}{738} = 0{,}839$$

$$\psi_{3R} = 1 + \frac{\gamma-1}{2} M_{3R}^2 = 1 + \frac{0{,}3}{2} \cdot 0{,}839^2 = 1{,}106$$

$$T_{t3R} = T_{t2R} = 1615\,K$$

$$p_{t3R} = \frac{p_{t2R}}{1 + \omega_R \left(1 - \psi_{3R}^{-1/k}\right)} = \frac{888\,kPa}{1 + 0{,}08\left(1 - 1{,}106^{-1/0{,}231}\right)} = 873\,kPa$$

$$p_{3R} = p_{t3R} \cdot \psi_{3R}^{-1/k} = 873\,kPa \cdot 1{,}106^{-1/0{,}231} = 564\,kPa$$

SEZIONE 3 (camera)

$$p_{t3} = p_3 \cdot \psi_3^{1/k} = 564\,kPa \cdot 1{,}062^{1/0.231} = 732\,kPa$$

$$\Psi_3 = \gamma M_3 \psi_3^{-\frac{k}{}} = 1{,}3 \cdot 0{,}661 \cdot 1{,}062^{-3{,}83} = 0{,}662$$

$$A_{3R} = \frac{\dot{m}\, a_{t3}}{p_{t3} \Psi_3} = \frac{40 \cdot 760}{732 \cdot 10^3 \cdot 0{,}662} = 0{,}0624\,m^2 = A_3$$

$$^{o}R = \frac{h_2 - h_3}{h_1 - h_3} = \frac{1486 - 1460}{1755 - 1460} = 0{,}0881$$

$$\eta = \frac{1 - \tau_t}{1 - \pi_t^{k}} = \frac{1 - \frac{1550}{1780}}{1 - \left(\frac{732}{1400}\right)^{0{,}231}} = 0.829$$

$$e_c = \frac{\ln \tau_t}{k \ln \pi_t} = \frac{\ln\left(\frac{1550}{1780}\right)}{0{,}231 \ln\left(\frac{732}{1400}\right)} = 0{,}825 \qquad \Psi_c = \frac{c_p \Delta T_c}{U^2} = \frac{1244 \cdot 230}{400^2} = 1{,}788$$

MATTINGLY ES 3.3

$m_{pay} = 900\ kg$

$c = 4115\ m/s$

$\Delta V_{tot} = 14{,}3\ km/s$

$\delta = \frac{m_s}{m_0} = 0{,}03$

$m_0 = m_p + m_g = m_p + m_{pay} + m_s$

$MR = \frac{m_g}{m_0}$ $\qquad MR = h + \delta$

$h = \frac{m_{pay}}{m_0}$

$\delta = \frac{m_s}{m_0}$

$\Delta V = -c \ln \frac{m_g}{m_0} = c \ln \frac{1}{MR} \Rightarrow MR = e^{-\frac{\Delta V}{c}}$

$MR = e^{-\frac{14300}{4115}} = 0{,}0310$

$h = MR - \delta = 0{,}0310 - 0{,}03 = 0{,}0010$

$m_0 = \frac{m_{pay}}{h} = \frac{900}{0{,}0010} = 900 \cdot 10^3\ kg$

$m_0 = \frac{m_{pay}}{e^{-\frac{\Delta V}{c}} - \delta}$

$m_p = m_0 (1 - MR) = 900 \cdot 10^3 (1 - 0{,}0320) = 872 \cdot 10^3$ kg

$m_S = \delta \cdot m_0 = 0{,}03 \cdot 900 \cdot 10^3 = 27 \cdot 10^3$

2 STADI (stadio finale è 1)

$\frac{\Delta V}{2} = -c \ln \frac{m_f}{m_0} = c \ln \frac{1}{MR_1} \Rightarrow MR_1 = e^{-\frac{\Delta V/2}{c}} = MR_1 = e^{-\frac{7160}{4115}} =$

$= 0{,}1760$

$h_1 = MR_1 - \delta = 0{,}1760 - 0{,}03 = 0{,}1460$

$m_{0_1} = \frac{m_{pay}}{h} = \frac{900}{0{,}1460} = 6160$ kg

$m_{0_1} = \frac{m_{pay}}{e^{-\frac{\Delta V/2}{c}} - \delta}$

$m_{p_1} = m_{0_1}(1 - MR_1) = 6160(1 - 0{,}1760) = 5080$ kg

$m_{S_1} = \delta \cdot m_{0_1} = 0{,}03 \cdot 6160 = 185$ kg

$m_{pay\,2} = m_{0_1}$

$m_{0_2} = \frac{m_{pay_2}}{h} = \frac{6160}{0{,}1460} = 42200$ kg

$m_{0_2} = \frac{m_{pay}}{(e^{-\frac{\Delta V/2}{c}} - \delta)^2}$

$m_{p_2} = m_{0_2}(1 - MR_1) = 42200(1 - 0{,}1760) = 34800$ kg

$m_{S_2} = \delta \cdot m_{0_2} = 0{,}03 \cdot 42200 = 1266$ kg

HATTINGLY 3.7

$t_g = 520\ s$

$\epsilon = 77:1$

$D_e = 2{,}3\ m$

$\gamma = 1.25$

$p_c = 2.07 \cdot 10^6\ Pa$

$T_c = 4083\ K$

$R = 602{,}6\ J/kg\,K$

$M_2 = 5.08$

VELOCITA' CARATTERISTICA (c^*)

$$c^* = \frac{p_c A_{TH}}{\dot{m}_p} = \frac{p_c A_{TH}}{\frac{p_c A_{TH} \cdot \Psi^*}{a_c}} = \frac{a_c}{\Psi^*}$$

$$a_c = \sqrt{\gamma R T_c} = \sqrt{1{,}25 \cdot 603 \cdot 4083} = 1754\ m/s$$

$$k = \frac{\gamma - 1}{\gamma} = \frac{0{,}25}{1{,}25} = 0{,}2 \qquad K = \frac{\gamma + 1}{2(\gamma - 1)} = \frac{2.25}{0{,}5} = 4{,}5$$

$$\psi^* = 1 + \frac{\gamma - 1}{2} = 1 + 0{,}125 = 1{,}125$$

$$\Psi^* = \gamma \psi^{*-K} = 1{,}25 \cdot 1{,}125^{-4{,}5} = 0{,}736$$

$$c^* = \frac{ac}{\Psi^*} = \frac{1754}{0{,}736} = 2383 \text{ m/s}$$

PORTATA

$$\dot{m}_p = \frac{p_c \cdot A_{tn} \cdot \Psi^*}{ac} = \frac{p_c A_{tn}}{c^*} = \frac{2{,}07 \cdot 10^6 \cdot 0{,}0539}{2383} = 46{,}8 \text{ kg/s}$$

$$A_{tn} = 0{,}0538 \text{ m}^2$$

PRESSIONE in uscita Design

$$\Psi_2 = 1 + \frac{\gamma - 1}{2} M_2^2 = 1 + 0{,}125 \cdot 5{,}05^2 = 4{,}24$$

$$P_2 = p_c \cdot \Psi_2^{-\frac{1}{K}} = 2{,}07 \cdot 10^6 \cdot 4{,}24^{-5} = 15{,}11 \text{ kPa}$$

PRESSIONE SEPARAZIONE

$$P_s = P_2 \cdot 3{,}5 = 15{,}11 \cdot 3{,}5 = 52{,}9 \text{ kPa}$$

C_F, I_s e F per $P_0 = 0$ o $P_0 = P_s$

$$C_F = \sqrt{\frac{2\gamma^2}{\gamma - 1} \cdot \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{\gamma-1}} \cdot \left[1 - \left(\frac{P_2}{P_c}\right)^K\right]} + \frac{P_2 - P_0}{P_c} \cdot \frac{A_2}{A_{tn}}$$

$$C_F = 1{,}819 + \frac{P_2 - P_0}{P_c} \cdot \frac{A_2}{A_{tn}}$$

$P_0 = 0 \Rightarrow = 1{,}875$

$P_0 = P_s \Rightarrow = 1{,}679$

$\frac{F}{\dot{m}} = C^* \cdot C_F$ → $P_0 = 0$ → 4480 $\frac{N \cdot s}{kg}$; $P_0 = P_3$ → 3380 $\frac{N \cdot s}{kg}$

$I_s = \frac{F}{\dot{m} g_0}$ → $P_0 = 0$ → 455 s; $P_0 = P_3$ → 407 s

FAROKHII 11.10

$K = \frac{\gamma - 1}{\gamma} = \frac{1,4 - 1}{1,4} = 0,286$ $\quad K_T = 0,248$

$R = K c_p = 287 \frac{J}{kg\,K} = R_T$ $\quad c_{p_c} = 1004 \frac{J}{kg\,K}$ $\quad c_{p_T} = 1156 \frac{J}{kg\,K}$

EFFETTO RAM $\quad T_0 = 288K \quad P_0 = 101,3\ kPa$

$T_{t0} = T_0 \quad P_{t0} = P_0$ poiché $M_0 = 0$

DIFFUSORE $\quad \pi_d = 0,95$

$T_{t2} = T_{t0} \quad P_{t2} = P_{t0} \pi_d = 101,3 \cdot 10^3 \cdot 0,95 = 96,2\ kPa$

COMPRESSORE $\quad \pi_c = 30 \quad e_c = 0,80$

$\gamma_c = \pi_c^{\frac{K}{e_c}} = 30^{\frac{0,286}{0,8}} = 2,95$

$P_{t3} = P_{t2} \pi_c = 96,2 \cdot 30 = 2890\ kPa$

$T_{t3} = T_{t2} \gamma_c = 288K \cdot 2,95 = 850K$

CAMERA DI COMBUSTIONE $Q_R = 42{,}6 \frac{MJ}{kg}$ $\eta_B = 0{,}98$ $\tau_r = 1$ $\pi_B = 0{,}95$

$$\tau_h = \frac{c_{pT} T_{T4}}{c_p T_0} = \frac{1156 \cdot 1873}{1004 \cdot 288} = 7{,}89$$

$$f = \frac{\tau_h - \tau_c \tau_r}{\frac{Q_r \eta_B}{c_p T_0} - \tau_h} = \frac{7{,}89 - 2{,}95 \cdot 1}{\frac{42{,}6 \cdot 10^6 \cdot 0{,}98}{1004 \cdot 288} - 7{,}89} = 0{,}0362$$

$$\tau_b = \frac{\tau_h}{\tau_c \tau_r} = \frac{7{,}89}{2{,}95 \cdot 1} = 2{,}67$$

$$P_{T4} = \pi_B P_{T3} = 2880 \cdot 0{,}95 = 2750 \text{ kPa}$$

TURBINA $\eta_m = 0{,}98$ $e_t = 0{,}85$

$$\tau_t = 1 - \frac{(\tau_c - 1)\tau_r}{\eta_m (1+f) \tau_h} = 1 - \frac{1{,}95 \cdot 1}{0{,}98\,(1{,}036) \cdot 7{,}89} = 0{,}757$$

$$\pi_T = \tau_t^{\frac{1}{k_c e_t}} = 0{,}757^{\frac{1}{0{,}248 \cdot 0{,}85}} = 0{,}267$$

$$P_{T5} = P_{T4} \cdot \pi_T = 2750 \cdot 0{,}267 = 734 \text{ kPa}$$

$$T_{T5} = T_{T4} \cdot \tau_T = 1873 \cdot 0{,}757 = 1494 \text{ K}$$

UGELLO $\pi_m = 0{,}90$

$$P_8 = P_{T5} \cdot \pi_m = 734 \cdot 0{,}90 = 661 \text{ kPa} \qquad T_{T8} = T_{T5} = 1494 \text{ K}$$

$$\frac{P_{T8}}{P_8} = \frac{P_{T8}}{P_0} = \frac{661}{101{,}3} = 6{,}53$$

esp ugello

$$M_9 = \sqrt{\frac{2}{(\gamma-1)}\left[\frac{T_{T9}}{T_9} - 1\right]} = \sqrt{\frac{2}{0,33}\left[1,583 - 1\right]} = 1,895$$

$$\psi_9 = \frac{T_{T9}}{T_9} = \left(\frac{P_{T9}}{P_9}\right)^{k_c} = 6,53^{0,248} = 1,583$$

$$T_9 = \frac{T_9}{T_{T9}} \cdot T_{T9} = \frac{1}{1,583} \cdot 1496 = 938 K$$

$$a_9 = \sqrt{\gamma_9 T_9 R_9} = \sqrt{1,33 \cdot 938 \cdot 287} = 588 \, m/s$$

$$V_9 = M_9 a_9 = 1,895 \cdot 588 = 1133 \, m/s$$

$V_{9eff} = V_9$ (espansione corretta)

$$a_0 = \sqrt{\gamma T_0 R} = \sqrt{1,4 \cdot 288 \cdot 287} = 340 \, m/s$$

$$\frac{V_{9eff}}{a_0} = \frac{1133}{340} = 3,33$$

SPINTA e RENDIMENTI

$$\frac{F_u}{\dot{m}_0 a_0} = (1+f)\frac{V_{9eff}}{a_0} - M_0 = 1,036 \cdot 3,33 - 0 = 3,65$$

$$\eta_T = \frac{\Delta \dot{K}E}{\dot{m}_f Q_R} = \frac{a_0^2\left[(1+f)(V_9/a_0)^2 - M_0^2\right]}{2 f Q_R} = \frac{B}{2 f Q_R} = \frac{1,330 \cdot 10^6}{2 \cdot 0,0362 \cdot 42,6 \cdot 10^6} = 0,431$$

$$B = a_0^2\left[(1+f)(V_9/a_0)^2 - M_0^2\right] = 1,036 \cdot 1133^2 = 1,330 \cdot 10^6 \, m^2/s^2$$

$$\eta_p = \frac{F \cdot V_0}{\Delta \dot{K}E} = \frac{2F \cdot V_0 / \dot{m}_0}{B} = \frac{2F \cdot V_0 a_0}{a_0 \dot{m}_0 B} = \frac{F}{\dot{m}_0 a_0} \cdot \frac{2 V_0 a_0}{B} = 0$$

($V_0 = 0$)

$$TSFC = \frac{\dot{m}_f}{Fu} = \frac{f}{\frac{Fu\dot{m}_0 \cdot a_0}{a_0}} = \frac{f}{\frac{Fu}{\dot{m}_0 a_0} \cdot a_0} = \frac{0{,}0362}{3{,}45 \cdot 360} = 3{,}09 \cdot 10^{-5} \frac{kg}{N \cdot s}$$

PARAMETRI CORRETTI

$$\delta_2 = \frac{P_{t2}}{P_{2g}} = \frac{96{,}2}{101{,}3} = 0{,}950 \qquad \theta_2 = \frac{T_{t2}}{T_{2g}} = \frac{288}{288} = 1$$

$$\theta = \frac{T_{t4}}{T_{t2}} = \frac{1873}{288} = 6.85$$

$$\theta_4 = \frac{T_{t4}}{T_{2g}} = \frac{1873}{288} = 6{,}85$$

$M_{z2} = 0{,}5 \qquad N = 7460 \text{ rpm} \qquad \dot{m}_2 = 74 \frac{kg}{s}$

$$\dot{m}_{c2} = \frac{\dot{m}_2 \sqrt{\theta_2}}{\delta_2} = \frac{74\sqrt{1}}{0{,}95} = 81{,}0 \frac{kg}{s}$$

$$N_{c2} = N_2 / \sqrt{\theta_2} = \frac{7460}{\sqrt{1}} = 7460 \text{ rpm}$$

$$N_{c4} = N_4 / \sqrt{\theta_4} = \frac{7460}{\sqrt{6{,}85}} = 2850 \text{ rpm}$$

OFF DESIGN

$M_0 = 0{,}8 \qquad T_0 = -35C = -35 + 273 = 238 K$

$P_0 = 20 kPa \qquad T_{t4} = 1500°C = 1773 K$

EFFETTO RAM

$$a_0 = \sqrt{\gamma R T_0} = \sqrt{1{,}4 \cdot 287 \cdot 238} = 308 \text{ m/s}$$

$V_0 = M_0 a_0 = 0{,}8 \cdot 305 = 244\ m/s$

$\tau_r = 1 + \frac{\gamma - 1}{2} M_0^2 = \psi_0 = 1 + 0{,}2 \cdot 0{,}8^2 = 1{,}128$

$T_{t0} = T_{t2} = T_0 \tau_r = 238 \cdot 1{,}128 = 268\ K$

$P_{t0} = P_0 \cdot \tau_r^{\frac{1}{K}} = 20 \cdot 1{,}128^{\frac{1}{0{,}286}} = 30{,}5\ kPa$

DIFFUSORE

$P_{t2} = P_{t0} \cdot \pi_d = 30{,}5 \cdot 0{,}95 = 29\ kPa$

PARAMETRI CORRETTI OFF DESIGN

$\delta_2 = \frac{P_{t2}}{P_{ref}} = \frac{29}{101{,}3} = 0{,}286$

$\theta_2 = \frac{T_{t2}}{T_{ref}} = \frac{268}{288} = 0{,}931$ $\quad \Theta = \frac{T_{t4}}{T_{t2}} = \frac{1773}{268} = 6{,}62$

$\theta_4 = \frac{T_{t4}}{T_{ref}} = \frac{1773}{288} = 6{,}15$

$\tau_h = \frac{c_{pt} T_{t4}}{c_p T_0} = \frac{1156 \cdot 1773}{1004 \cdot 238} = 8{,}58$

OFF DESIGN

$\tau_c - 1 = \eta_m (1+f) \frac{c_{pt}}{c_{p2}} \frac{T_{t4}}{T_{t2}} (1 - \tau_t) =$

$f = \frac{\tau_h - \tau_c \tau_r}{\frac{c_{pt} \eta_B}{c_p T_0} - \tau_h}$ $\quad$ stimo $f = 0{,}0362$

$$\pi_c = 1 + 0{,}88\,(1+\varepsilon)\,\frac{1156}{2004}\,6{,}62\cdot(1-0{,}757) = 1 + 1{,}815\,(1+\varepsilon)$$

$$= 1 + 1{,}815\,(1{,}036) =$$

$$= 2{,}88$$

$$\varepsilon = \frac{8{,}58 - \pi_c \cdot 1{,}128}{\frac{42{,}6\cdot 10^6 \cdot 0{,}88}{2004\cdot 238} - 8{,}58} = \frac{8{,}58 - \pi_c \cdot 1{,}128}{166{,}1} = 5{,}17\cdot 10^{-2} - 6{,}79\cdot 10^{-3}\cdot \pi_c$$

$$\varepsilon_1 = 5{,}17\cdot 10^{-2} - 6{,}79\cdot 10^{-3}\cdot 2{,}88$$

$$= 0{,}0321$$

$$\pi_{c2} = 1 + 1{,}815\,(1{,}032) = 2{,}87 \Rightarrow \varepsilon_2 \cong \varepsilon_1$$

$$\frac{\dot{m}c_{2OD}}{\dot{m}c_2} = \frac{\Pi c_{OD}}{\Pi c}\cdot\sqrt{\frac{\Theta}{\Theta_{OD}}} \Rightarrow \dot{m}c_{2OD} = 81{,}0\cdot\frac{2{,}6}{30}\cdot\sqrt{\frac{6{,}55}{6{,}62}} = 75{,}8\ \text{kg/s}$$

$$\dot{m}_{2OD} = \frac{\dot{m}c_{2OD}\cdot\delta_2}{\sqrt{\Theta_2}} = \frac{75{,}8\cdot 0{,}286}{\sqrt{0{,}930}} = 22{,}5\ \frac{\text{kg}}{\text{s}}$$ (correct: $\frac{\text{kg}\sqrt{\text{K}}}{\text{J}}$)

$$N_{4OD} = N_{4D} = 2850\ \text{rpm} \Rightarrow N_{4OD} = N_{4OD}\cdot\sqrt{\Theta_4} =$$

$$= 2850\cdot\sqrt{6{,}15} = 7070\ \text{rpm}$$

(7640 rpm)

$$\frac{\dot{m}c_{2OD}}{\dot{m}c_{2D}} = \frac{\Psi_{2OD}}{\Psi_{2D}} = \frac{M_{z2OD}\cdot\psi_{z2OD}^{-K_2}}{M_{z2}\cdot\psi_{z2}^{-K_2}}$$

$$K_2 = \frac{\gamma+1}{2(\gamma-1)} = \frac{2{,}4}{0{,}8} = 3 \Rightarrow M_{z2}\cdot\psi_{z2}^{-K_2} =$$

$$= 0{,}5\cdot\left(1+0{,}2\cdot 0{,}95^2\right)^{-3} = 0{,}632$$

$$M_{z2} \cdot \psi_{z2}^{-k_2} \cdot \frac{\dot{m}c_{2DD}}{\dot{m}c_{2D}} = 0{,}432 \cdot \frac{75{,}8}{82} = 0{,}404$$

valuto $M_{z2DD} = 0{,}5 \Rightarrow e = 0{,}432 - 0{,}404 = 0{,}028$

$$M_{z2DD} = 0{,}4 \Rightarrow M_{z2DD} \cdot \psi_{z2DD}^{-k_2} = 0{,}364$$

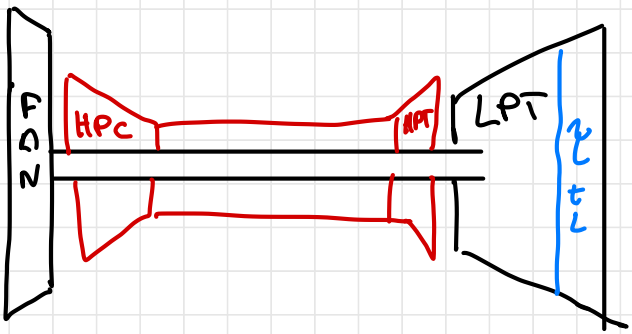
$$e = 0{,}364 - 0{,}404 = -0{,}040$$

$$M_{z2DD} = \frac{0{,}5 \cdot (-0{,}040) - 0{,}4\,(0{,}028)}{-0{,}040 - 0{,}028} = 0{,}459$$

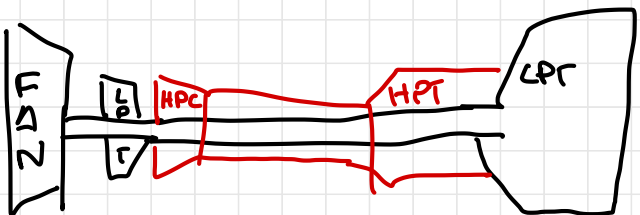
Con questi dati rifaccio gli stessi passaggi per ogni zona del motore

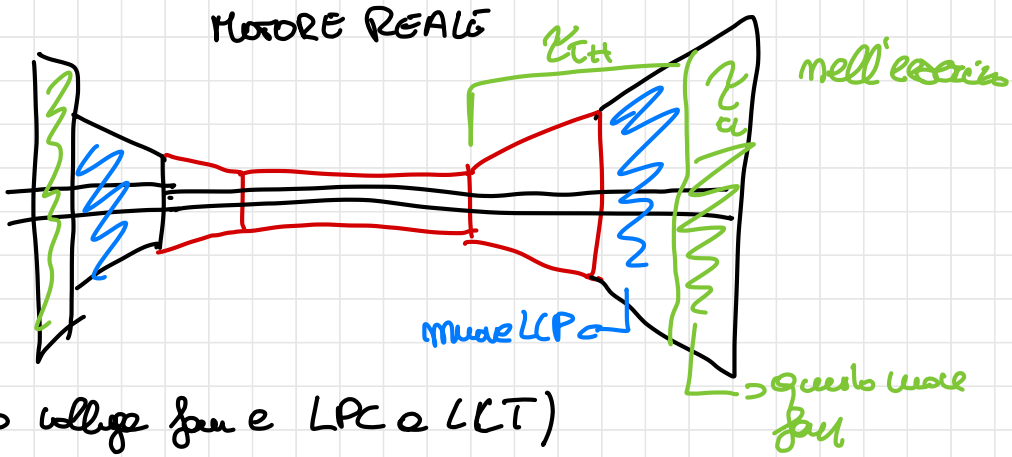
Poi 11.18 (VEDI FILE EXCEL)

Doppio albero



Il reale è





(albero collega fan e LPC a LCT)

lo facciamo per ricordare esattamente dove vogliamo

FAROKHI 12.2

$$\alpha_p = \frac{1}{\dot{v}} \cdot \left(\frac{\partial \dot{v}}{\partial T}\right)_p = 0{,}002 \ K^{-1}$$

$$\pi_K = \frac{1}{p}\left(\frac{\partial p}{\partial T}\right) = 0{,}005 \ K^{-1}$$

$T_{c1} = 15°C \qquad T_{c2} = 75° \Rightarrow \Delta T = T_{c2} - T_{c1} = 60°C$

$\Delta P = P_{c1}\, \pi_K\, \Delta T = 10 \cdot 0{,}005 \cdot 60 = 3 \text{ MPa}$

$P_{c2} = P_{c1} + \Delta P = 10 + 3 = 13 \text{ MPa}$

$\dot{v}_{2p} = \left(\frac{p_{c2}}{p_{c1}}\right)^n \cdot \dot{v}_1 = \left(\frac{13}{10}\right)^{0{,}4} \cdot 3 = 3{,}33 \text{ m}^3/\text{s} \qquad \dot{v}_1 = Q\, p_{cj}^m = 3 \text{ m}^3/\text{s} \qquad n = 0{,}4$

$\dot{v}_2 = \dot{v}_{2p}\,(1 + \alpha_p \Delta T) = 3{,}33\,(1 + 0{,}002 \cdot 60) = 3{,}43 \text{ m}^3/\text{s}$

$t_1 = 120 \text{ s}$

$t_2 = ?$

$h = \dot{v} \cdot t_1 = 3 \text{ m}^3/\text{s} \cdot 120 = 360 \text{ m}$

$t_2 = \frac{h}{\dot{v}_2} = \frac{360}{3{,}43} = 96{,}5 \text{ s}$

MATTINGLY ES 3.3

$m_{pay} = 900\ kg$

$c = 4115\ m/s$

$\Delta V_{tot} = 14{,}3\ km/s$

$\delta = \frac{m_s}{m_0} = 0{,}03$

$m_0 = m_p + m_g = m_p + m_{pay} + m_s$

$MR = \frac{m_g}{m_0}$ $\qquad MR = h + \delta$

$h = \frac{m_{pay}}{m_0}$

$\delta = \frac{m_s}{m_0}$

$\Delta V = -c \ln \frac{m_g}{m_0} = c \ln \frac{1}{MR} \Rightarrow MR = e^{-\frac{\Delta V}{c}}$

$MR = e^{-\frac{14300}{4115}} = 0{,}0310$

$h = MR - \delta = 0{,}0310 - 0{,}03 = 0{,}0010$

$m_0 = \frac{m_{pay}}{h} = \frac{900}{0{,}0010} = 900 \cdot 10^3\ kg$

$m_0 = \frac{m_{pay}}{e^{-\frac{\Delta V}{c}} - \delta}$

$m_p = m_0 (1 - MR) = 900 \cdot 10^3 (1 - 0{,}0320) = 872 \cdot 10^3$ kg

$m_S = \delta \cdot m_0 = 0{,}03 \cdot 900 \cdot 10^3 = 27 \cdot 10^3$

2 STADI (stadio finale è 1)

$\frac{\Delta V}{2} = -c \ln \frac{m_f}{m_0} = c \ln \frac{1}{MR_1} \Rightarrow MR_1 = e^{-\frac{\Delta V/2}{c}} = MR_1 = e^{-\frac{7160}{4115}} =$

$= 0{,}1760$

$h_1 = MR_1 - \delta = 0{,}1760 - 0{,}03 = 0{,}1460$

$m_{0_1} = \frac{m_{pay}}{h} = \frac{900}{0{,}1460} = 6160$ kg

$m_{0_1} = \frac{m_{pay}}{e^{-\frac{\Delta V/2}{c}} - \delta}$

$m_{p_1} = m_{0_1}(1 - MR_1) = 6160(1 - 0{,}1760) = 5080$ kg

$m_{S_1} = \delta \cdot m_{0_1} = 0{,}03 \cdot 6160 = 185$ kg

$m_{pay\,2} = m_{0_1}$

$m_{0_2} = \frac{m_{pay_2}}{h} = \frac{6160}{0{,}1460} = 42200$ kg

$m_{0_2} = \frac{m_{pay}}{(e^{-\frac{\Delta V/2}{c}} - \delta)^2}$

$m_{p_2} = m_{0_2}(1 - MR_1) = 42200(1 - 0{,}1760) = 34800$ kg

$m_{S_2} = \delta \cdot m_{0_2} = 0{,}03 \cdot 42200 = 1266$ kg

HATTINGLY 3.7

$t_g = 520\ s$

$\epsilon = 77:1$

$D_e = 2{,}3\ m$

$\gamma = 1.25$

$p_c = 2.07 \cdot 10^6\ Pa$

$T_c = 4083\ K$

$R = 602{,}6\ J/kg\,K$

$M_2 = 5.08$

VELOCITA' CARATTERISTICA (c^*)

$$c^* = \frac{p_c A_{TH}}{\dot{m}_p} = \frac{p_c A_{TH}}{\frac{p_c A_{TH} \cdot \Psi^*}{a_c}} = \frac{a_c}{\Psi^*}$$

$$a_c = \sqrt{\gamma R T_c} = \sqrt{1{,}25 \cdot 603 \cdot 4083} = 1754\ m/s$$

$$k = \frac{\gamma - 1}{\gamma} = \frac{0{,}25}{1{,}25} = 0{,}2 \qquad K = \frac{\gamma + 1}{2(\gamma - 1)} = \frac{2.25}{0{,}5} = 4{,}5$$

$$\psi^* = 1 + \frac{\gamma - 1}{2} = 1 + 0{,}125 = 1{,}125$$

$$\Psi^* = \gamma \psi^{*-K} = 1{,}25 \cdot 1{,}125^{-4{,}5} = 0{,}736$$

$$c^* = \frac{ac}{\Psi^*} = \frac{1754}{0{,}736} = 2383 \text{ m/s}$$

PORTATA

$$\dot{m}_p = \frac{p_c \cdot A_{tn} \cdot \Psi^*}{ac} = \frac{p_c A_{tn}}{c^*} = \frac{2{,}07 \cdot 10^6 \cdot 0{,}0539}{2383} = 46{,}8 \text{ kg/s}$$

$$A_{tn} = 0{,}0538 \text{ m}^2$$

PRESSIONE in uscita Design

$$\Psi_2 = 1 + \frac{\gamma - 1}{2} M_2^2 = 1 + 0{,}125 \cdot 5{,}05^2 = 4{,}24$$

$$P_2 = p_c \cdot \Psi_2^{-\frac{1}{K}} = 2{,}07 \cdot 10^6 \cdot 4{,}24^{-5} = 15{,}11 \text{ kPa}$$

PRESSIONE SEPARAZIONE

$$P_s = P_2 \cdot 3{,}5 = 15{,}11 \cdot 3{,}5 = 52{,}9 \text{ kPa}$$

C_F, I_s e F per $P_0 = 0$ o $P_0 = P_s$

$$C_F = \sqrt{\frac{2\gamma^2}{\gamma - 1} \cdot \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{\gamma-1}} \cdot \left[1 - \left(\frac{P_2}{P_c}\right)^K\right]} + \frac{P_2 - P_0}{P_c} \cdot \frac{A_2}{A_{tn}}$$

$$C_F = 1{,}819 + \frac{P_2 - P_0}{P_c} \cdot \frac{A_2}{A_{tn}}$$

$P_0 = 0 \Rightarrow = 1{,}875$

$P_0 = P_s \Rightarrow = 1{,}679$

$\frac{F}{\dot{m}} = C^* \cdot C_F$

$P_0 = 0 \rightarrow 4480 \ \frac{N \cdot s}{kg}$

$P_0 = P_3 \rightarrow 3380 \ \frac{N \cdot s}{kg}$

$I_s = \frac{F}{\dot{m} g_0} =$

$P_0 = 0 \rightarrow 455 \ s$

$P_0 = P_3 \rightarrow 407 \ s$