Lista N2 FT2

Ex 01.

Dados

Vaso de Pressão: $V = 10\ m^3$

Ar $\begin{cases} P = 20\ ATM = 20 \times 1{,}01 \times 10^5\ Pa \\ T = 300K \end{cases}$

a) massa de ar armazenada?

$$PV = mRT \rightarrow m = \frac{PV}{RT} = 20{,}2 \times 10^5 \frac{\cancel{N}}{\cancel{m^2}} \cdot \frac{10\ \cancel{m^3}}{287} \frac{kg\ \cancel{K}}{\cancel{J}} \cdot \frac{1}{300\ \cancel{K}} = \boxed{234{,}6\ kg}$$

$J = N \cdot m$

b) $U = ?$

$$C_v = \frac{R}{K-1} = \frac{287}{1{,}4-1} = 717{,}5 \frac{J}{kg\,K}$$

$$u = C_v T = 717{,}5 \frac{J}{kg\,K} \cdot 300K = 215250 \frac{J}{kg} \Rightarrow U = u \cdot m = \boxed{5{,}05 \times 10^7\ J}$$

c) $T_2 = 600K$

$\Delta s = ?$

$$PV = mRT \Rightarrow \frac{P}{T} = \frac{mR}{V} \Rightarrow \frac{P}{T} = \text{constante!}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \rightarrow P_2 = \frac{P_1}{T_1} \cdot T_2 = 20 \times 1{,}01 \times 10^5 \cdot \frac{600}{300} \Rightarrow \boxed{P_2 = 2 \times P_1}$$

$$S_2 - S_1 = c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} \rightarrow \Delta s = 1004{,}5 \frac{J}{kg\,K} \ln 2 - 287 \frac{J}{kg\,K} \ln 2$$

$$C_p = C_v + R = 717{,}5 + 287 = 1004{,}5 \frac{J}{kg\,K}$$

$$\Delta s = 497{,}3\ J/kg\,K$$

$$\boxed{\Delta S = 1{,}167 \times 10^5 \frac{J}{K}}$$

2) Bocal de foguete

Expansão isentrópica : $\Delta s = 0$

gás perfeito

Câmara de Combustão : $P = 15\,atm$

$T = 2500K$

$M = 12$

$C_p = 4157\ J/KgK$

Saída: $T = 1350K$

$$R = \frac{\bar{R}}{M} = \frac{8314}{12} = 692{,}8\ \frac{J}{KgK}$$

$$C_v = C_p - R = 4157 - 692{,}8 = 3464{,}1\ \frac{J}{KgK}$$

a) $P_2 = ?$ $\quad \Delta s = C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln \frac{P_2}{P_1} \Rightarrow R \ln \frac{P_2}{P_1} = C_p \ln\left(\frac{T_2}{T_1}\right) \rightarrow \ln \frac{P_2}{P_1} = \frac{C_p}{R} \ln\left(\frac{T_2}{T_1}\right)$

$$\ln\left(\frac{P_2}{P_1}\right) = \ln\left(\frac{T_2}{T_1}\right)^{C_p/R} \Rightarrow \frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{C_p/R} \Rightarrow P_2 = P_1 \left(\frac{T_2}{T_1}\right)^{C_p/R}$$

$$P_2 = 15 \times 1{,}01 \times 10^5 \frac{N}{m^2} \left(\frac{1350K}{2500K}\right)^{\frac{4157}{692{,}8}} \Rightarrow \boxed{P_2 = 37{,}56 \cdot 10^3 \frac{N}{m^2} = 0{,}372\ ATM}$$

ou

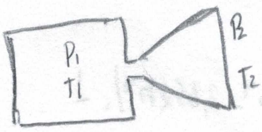
$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{k/k-1},\ k = \frac{C_p}{C_v} = 1{,}2 \rightarrow P_2 = P_1 \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} = 15\left(\frac{1350}{2500}\right)^{\frac{1{,}2}{1{,}2-1}} = 0{,}372A$$

$= 37{,}56.10$

2.b $M_2 = 2$

$V_2 = ?$

$$C = \sqrt{KRT} = \sqrt{1,2 \cdot 692,8 \cdot 1350} = 1059,4 \frac{m}{s}$$




$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

$$C_p T_1 + \frac{V_1^2}{2} = C_p T_2 + \frac{V_2^2}{2} \Rightarrow \frac{V_2^2}{2} = C_p (T_1 - T_2) \rightarrow V_2 = \sqrt{2 C_p (T_1 - T_2)}$$

$$V_2 = \sqrt{2 \cdot 4157 \cdot (2500 - 1350)} = \boxed{3092,1 \frac{m}{s}}$$

$$M_2 = \frac{V_2}{C_2} = \frac{3092,1}{1059,4} = \boxed{2,919}$$

Ou

$$\frac{P_0}{P} = \left(1 + \frac{K-1}{2} M^2\right)^{K/K-1} \Rightarrow \left(\frac{P_0}{P}\right)^{\frac{K-1}{K}} = 1 + \frac{K-1}{2} M^2 \Rightarrow M^2 = \left(\left(\frac{P_0}{P}\right)^{\frac{K-1}{K}} - 1\right) \frac{2}{K-1}$$

$$M = \sqrt{\left[\left(\frac{P_0}{P}\right)^{\frac{K-1}{K}} - 1\right] \frac{2}{K-1}} \Rightarrow M = \sqrt{\left[\left(\frac{15}{0,372}\right)^{\frac{1,2-1}{1,2}} - 1\right]\left(\frac{2}{1,2-1}\right)} \Rightarrow \boxed{M = 2,919}$$

$V_2 = C_2 \cdot M_2$

c) $E = 4,5 \times 10^5 N$

$P_{amb} = 0,372$ ATM

$\dot{m}_s = ?$

$A_s = ?$

$$E = \dot{m}_s V_s - \dot{m}_e \cancel{V_\infty}^{0} + (P_s - P_\infty) A_s$$

$P_s = 0,372$, $P_\infty = 0,372$

$$E = \dot{m}_s V_s$$

$$\dot{m}_s = \frac{4,5 \times 10^5 N}{3092,1\ m} s \Rightarrow \dot{m}_s = 145,5 \left[\frac{kg \cdot m}{s^2} \frac{s}{m}\right] \Rightarrow \dot{m}_s = 145,5 \frac{kg}{s}$$

$$\left.\begin{array}{l}\dot{m} = \rho V A \\ \rho = \frac{P}{RT}\end{array}\right\} A_2 = \frac{\dot{m}}{\rho_2 V_2} = \frac{\dot{m}}{V_2} \frac{R T_2}{P_2} \Rightarrow A_2 = \frac{145,5}{3092,1} \frac{692,8 \cdot 1350}{37,56 \cdot 10^3} \Rightarrow A_2 = 1,1$$

Ex03 $V_1 = 300 m/s$

$h = 10 km$

$P_1 = 2,65 \times 10^4 Pa$

$\rho_1 = 0,414 \frac{kg}{m^3}$

$A_1 = 2 m^2$

$A_2 = 1 m^2$

$V_2 = 500 m/s$

$P_2 = 2,3 \times 10^4 Pa$

$\frac{Combustível}{ar} = 0,05$

$$E = \dot{m}_s V_s - \dot{m}_e V_{\infty} + (P_s - P_{\infty}) A_s$$

$$\dot{m}_e = \rho V_e A_e = 0,414 \cdot 300 \cdot 2 \Rightarrow \dot{m}_e = 248,4 \frac{kg}{s}$$

$$\dot{m}_s = 1,05 \dot{m}_e = 260,82 \frac{kg}{s}$$

$$E = 260,82 \cdot 500 - 248,4 \cdot 300 + (2,3 \times 10^4 - 2,65 \times 10^4) \cdot 1$$

$$\boxed{E = 52390 \frac{kg \cdot m}{s^2} = N}$$

Ex04: $h_2 = 11 \frac{kg}{s}$

$O_2 = 89 \frac{kg}{s}$

$V_s = 4000 \frac{m}{s}$

$P_s = 1,2 \times 10^3 \frac{N}{m^2}$

$A_s = 12 m^2$

$E = ?$

$P_{\infty} = 0,584 \times 10^3 \frac{N}{m^2}$

$$E = \dot{m}_s V_s - \dot{m}_e V_{\infty} + (P_s - P_{\infty}) A_s$$

$$\dot{m}_e = 0$$

$$\dot{m}_s = 89 + 11 = 100 \frac{kg}{s}$$

$$E = 100 \cdot 4000 + (1,2 \times 10^3 - 0,584 \times 10^3) \cdot 12$$

$$\boxed{E = 4,074 \times 10^5 N}$$

Ex 05

$P = 1890 \frac{lb}{ft^2}$ tab A1: $\frac{P_0}{P}$ $\frac{\rho_0}{\rho}$ $\frac{T_0}{T}$

$M = 1,5$ $0,3671 \times 10$ $0,2532 \times 10$ $0,1450 \times 10$

$T = 450R = 250k$

$M = 1,5$

$\frac{T_0}{T} = 0,1450 \times 10 \rightarrow T_0 = 0,1450 \times 10 \times 450R \Rightarrow T_0 = 652,5R$

$T_0 = ?$

$P_0 = ?$

$P_0 = 0,3671 \times 10 P \Rightarrow P_0 = 0,3671 \times 10 \times 1890 \Rightarrow P_0 = 6938,19 \frac{lb}{ft^2}$

$T^* = ?$

$P^* = ?$

$V = ?$

ou

$\frac{T_0}{T} = 1 + \left(\frac{k-1}{2}\right) M^2 \rightarrow T_0 = 450 \left[1 + \left(\frac{1,4-1}{2}\right) 1,5^2\right] \Rightarrow T_0 = 652,5R$

$\frac{P_0}{P} = \left(1 + \frac{k-1}{2} M^2\right)^{k/k-1} \rightarrow \frac{P_0}{P} = \left(1 + \left(\frac{1,4-1}{2}\right) 1,5^2\right)^{\frac{1,4}{1,4-1}} \Rightarrow P_0 = 3,671P = 6938,25 \frac{lb}{ft^2}$

$\frac{T^*}{T_0} = 0,833 \rightarrow T^* = 543,53R$

$V = M \cdot c = M \cdot \sqrt{kRT}$

$V = 1,5\sqrt{1,4 \times 287 \times 250}$

$\frac{P^*}{P_0} = 0,528 \rightarrow P^* = 3663,36 \frac{lb}{ft^2}$

$V = 475,4 \frac{m}{s}$

$\frac{T_0}{T} = 1 + \frac{k-1}{2} M^2 \rightarrow \frac{T_0}{T^*} = 1 + \frac{k-1}{2} = 1 + \frac{1,4-1}{2} \Rightarrow \frac{T_0}{T^*} = 1,2 \Rightarrow \frac{T^*}{T_0} = 0,833$ (1560 ft/s)

$\frac{P_0}{P} = \left(1 + \frac{k-1}{2} M^2\right)^{k/k-1} \rightarrow \frac{P_0}{P^*} = \left(1 + \frac{k-1}{2}\right)^{\frac{k}{k-1}} \Rightarrow \frac{P_0}{P^*} = 1,89 \rightarrow \frac{P^*}{P_0} = 0,528$

ou

$P^* = \frac{P^*}{P_0} \frac{P_0}{P} \cdot P \rightarrow$ tab A1 $\cdot \frac{P_0}{P(M=1)} = \frac{P_0}{P^*}$ $\frac{T_0}{T(M=1)} = \frac{T_0}{T^*}$ $T^* = \frac{T^*}{T_0} \frac{T_0}{T} \cdot T$

$0,1893 \times 10$ $0,12 \times 10$

$P^* = \frac{1}{1,893} \times 3,671 \times 1890 = 3665 \frac{lb}{ft^2}$

$T^* = \frac{1}{1,2} \times 1,450 \times 450$

$T^* = 543,8°R$

Ex. 06 Onda de Choque Normal

$M_1 = 3$

$P_1 = 0{,}5 ATM = 0{,}5 \times 1{,}01 \times 10^5 Pa$

$T_1 = 200 K$

$M_2 = ?$

$P_2 = ?$

$T_2 = ?$

$V_2 = ?$

$$M_2^2 = \frac{1 + [(k-1)/2] M_1^2}{k M_1^2 - (k-1)/2}$$

$$M_2^2 = \frac{1 + [(1{,}4-1)/2]\, 3^2}{1{,}4 \cdot 3^2 - \frac{(1{,}4-1)}{2}} \Rightarrow M_2^2 = 0{,}2258 \Rightarrow \underline{M_2 = 0{,}47}$$

$$\frac{P_2}{P_1} = 1 + \frac{2k}{k+1}(M_1^2 - 1)$$

$$\frac{P_2}{P_1} = 1 + \frac{2 \times 1{,}4}{1{,}4+1}(3^2 - 1) \Rightarrow \frac{P_2}{P_1} = 10{,}33 \Rightarrow \underline{P_2 = 5{,}17 \text{ ATM}}$$

$$\frac{T_2}{T_1} = \left[1 + \frac{2k}{k+1}(M_1^2 - 1)\right]\left[\frac{2 + (k-1) M_1^2}{(k+1) M_1^2}\right]$$

$$\frac{T_2}{T_1} = \left[1 + \frac{2 \times 1{,}4}{1{,}4+1}(3^2 - 1)\right]\left[\frac{2 + (1{,}4-1)3^2}{(1{,}4+1)\, 3^2}\right] \Rightarrow \frac{T_2}{T_1} = 2{,}619 \Rightarrow \underline{T_2 = 535{,}8 K}$$

$$C_2 = \sqrt{kRT_2} = \sqrt{1{,}4 \times 287 \times 535{,}8} \Rightarrow C_2 = 463{,}99$$

$$M = \frac{V}{C} \Rightarrow V_2 = M_2 C_2 = 0{,}475 \times 463{,}99 \Rightarrow V_2 = 220{,}4 \frac{m}{s}$$

ou

tab A2:

| M | $P_2/P_1$ | $T_2/T_1$ | $M_2$ |
|---|---|---|---|
| 3 | $0{,}1033 \times 10^2$ | $0{,}2619 \times 10$ | $0{,}4752$ |

Ex 07 $M = 2$

$T_0$

$P_0$

| tab A1 | M | $\frac{P_0}{P}$ | $\frac{T_0}{T}$ |
|---|---|---|---|
| | 2 | 0,7824x10 | 0,18x10 |

Condições ambientes ao nível do mar: $T_1 = 288{,}15K$

$P_1 = 101{,}325kPa$

escoamento adiabático: $T_{02} = T_{01} = T \times 1{,}8 = 288{,}15 \times 1{,}8 \Rightarrow T_0 = 518{,}67k$

| tab A2 | M | $\frac{P_{02}}{P_1}$ | $\frac{P_{02}}{P_{01}}$ |
|---|---|---|---|
| | 2 | | |
| | | 0,5640x10 | 0,7209 |

$$P_{02} = P_1 \times 0{,}5640 \times 10 = 571{,}47\ kPa$$

ou

$$P_{02} = \frac{P_{02}}{P_{01}} \frac{P_{01}}{P} P = 0{,}7209 \times 7824 \times 101{,}325 \times 10^3 \Rightarrow P_{02} \cong 571{,}50kPa$$

ou

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2} \quad , \quad V = M \cdot \sqrt{KRT} = 2\sqrt{1{,}4 \times 287 \times 288{,}15} \Rightarrow V = 680\ m/s$$

$$C_pT_1 + \frac{V_1^2}{2} = C_pT_2 \Rightarrow T_2 = \left(1004 \times 288{,}15 + \frac{680{,}52^2}{2}\right) / 1004 \Rightarrow \boxed{T_2 = 518{,}78}$$

Ex. 08 $M > 1$

$P_1 = 0{,}4$ Atm
$P_0 = 3$ atm

$$\frac{P_0}{P_1} = \frac{3}{0{,}4} = 7{,}5$$

a) $M = ?$

b) $\Delta s = ?$

a) tubo de Pitot em escoamento supersônico ⇒ forma um choque normal

tab A2

| $\frac{P_{02}}{P_1}$ | $M$ |
|---|---|
| 7,592 | 2,35 |
| 7,5 | X |
| 7,294 | 2,3 |

$$\frac{X - 2{,}35}{7{,}5 - 7{,}592} = \frac{2{,}3 - 2{,}35}{7{,}294 - 7{,}592} \Rightarrow \boxed{M \cong 2{,}34}$$

b) $$S_2 - S_1 = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

$$\frac{T_2}{T_1} = \left[1 + \frac{2k}{k+1}(M_1^2 - 1)\right]\left[\frac{2 + (k-1)M_1^2}{(k+1)M_1^2}\right] = \left[1 + \frac{2 \times 1{,}4}{1{,}4+1}(2{,}34^2 - 1)\right]\left[\frac{2 + (1{,}4-1)\,2{,}34^2}{(1{,}4+1)\,2{,}34^2}\right] = \left[1 + \frac{2{,}8}{2{,}4}(2{,}34^2 - 1)\right]\left[\frac{2+0 \ldots}{2{,}4 \ldots}\right]$$

$$\frac{T_2}{T_1} = 1{,}984$$

$$\frac{P_2}{P_1} = 1 + \frac{2k}{k+1}(M_1^2 - 1) = 1 + \frac{2 \times 1{,}4}{(1{,}4+1)}(2{,}34^2 - 1) = 1 + \frac{2{,}8}{2{,}4}(2{,}34^2 - 1) = 6{,}22$$

$$S_2 - S_1 = 1004 \ln(1{,}984) - 287 \ln(6{,}22) \Rightarrow S_2 - S_1 = 163{,}21 \ \frac{J}{kg\,K}$$

ou

$$S_2 - S_1 = -R \ln \frac{P_{02}}{P_{01}}$$

tab A2 $M = 2{,}34 \rightarrow \frac{P_{02}}{P_{01}} \cong 0{,}5615$

$$S_2 - S_1 = -287 \ln(0{,}5615) \Rightarrow S_2 - S_1 \cong 165{,}64$$

Ex 09 Choque Normal $\quad s_2 - s_1 = -R \ln\left(\frac{P_{02}}{P_{01}}\right)$

tab A2:

| M | 1,04 | 1,08 | 1,12 | 1,16 | 1,2 |
|---|---|---|---|---|---|
| $\frac{P_{02}}{P_{01}}$ | 0,9999 | 0,9994 | 0,9982 | 0,99612 | 0,9928 |
| $s_2 - s_1 \left[\frac{J}{kg\,K}\right]$ | 0,0287 | 0,172 | 0,517 | 1,12 | 2,07 |
| R (0,0287) | – | 6x | 18 | 39 | 72 |

Choque muito fraco

Aproximação isentrópica para escoamento transônico $\Rightarrow M \leq 1{,}08$

Ex 10 Ar: $k = 1{,}4$ $\quad M = 5 \quad P_2/P_1$
hélio: $k = 1{,}67$

tab A2 $\quad M = 5 \quad P_2/P_1 = 29$

$$\frac{P_2}{P_1} = 1 + \frac{2k}{k+1}\left(M_1^2 - 1\right) \Rightarrow \text{Hélio: } \frac{P_2}{P_1} = 1 + \frac{2 \times 1{,}67}{1{,}67+1}\left(5^2 - 1\right) \Rightarrow \frac{P_2}{P_1} = 31$$

p/ $M_1 = 5$ Choque hélio mais forte que choque no ar.

Ex 11 $V = 1700$ m/s
$T = 288$ K

$$C_{ar} = \sqrt{kRT} = \sqrt{1{,}4 \times 287 \times 288} \Rightarrow C_{ar} = 340 \text{ m/s} \Rightarrow M_{ar} = 5$$

$$C_{Hélio} = \sqrt{kRT} = \sqrt{1{,}67 \times 2078{,}5 \times 288} \Rightarrow C_{Hélio} = 999{,}84 \text{ m/s} \Rightarrow M_{He} = 1{,}7$$

$$\left(M = 4 \Rightarrow R = \frac{8314}{4} = 2078{,}5 \frac{J}{kg\,K}\right)$$

ar: $\frac{P_2}{P_1} = 29$

Hélio: $\frac{P_2}{P_1} = 1 + \frac{2 \times 1{,}67}{1{,}67+1}\left(1{,}7^2 - 1\right) \Rightarrow \frac{P_2}{P_1} = 3{,}36$

Para velocidades, temperatura a montante iguais, Choque no Hélio muito mais fraco do que no ar.

Velocidade do som no hélio muito maior que no ar devido ao menor peso molecular

Ex 12. Área constante

$M_1 = 0,2 \rightarrow M_2\ ?$ $\quad \rho_2 = ?$

$p_1 = 1\,atm \rightarrow p_2\ ?$ $\quad T_{02} = ?$

$T_1 = 273K \rightarrow T_2\ ?$ $\quad p_{02} = ?$

$$q = 1,0 \times 10^6 \frac{J}{Kg}$$

Usando escoamento sônico como referência

$M_1 = 1 \Rightarrow p_1 = p^*,\ T_1 = T^*,\ \rho_1 = \rho^*,\ p_{01} = p_0^*,\ T_{01} = T_0^*$

Propriedades para qualquer outro valor de M:

$$\frac{p}{p^*} = \frac{1+k}{1+kM^2}, \quad \frac{T}{T^*} = M^2\left(\frac{1+k}{1+kM^2}\right)^2, \quad \frac{\rho}{\rho^*} = \frac{1}{M^2}\left(\frac{1+kM^2}{1+k}\right)$$

$$\frac{p_0}{p_0^*} = \frac{1+k}{1+kM^2}\left[\frac{2+(k-1)M^2}{k+1}\right]^{k/k-1}, \quad \frac{T_0}{T_0^*} = \frac{(k+1)M^2}{(1+kM^2)^2}\left[2+(k-1)M^2\right]$$

tab. A3

* Condições de referência sônica são constantes!

1) Obter $T_{01}$, $p_{01}$ $\Rightarrow$ tab A1

| $M_1$ | $T_{01}/T_1$ | $p_{01}/p_1$ |
|---|---|---|
| 0,2 | 1,008 | 1,028 |

$$\frac{p_{01}}{p_1} = 1,028 \Rightarrow p_{01} = 1,028 \times 1 = \boxed{1,028\ atm}$$

$$\frac{T_{01}}{T_1} = 1,008 \Rightarrow T_{01} = 1,008 \cdot T_1 = 1,008 \cdot 273 = \boxed{275,2K}$$

$$q = c_p(T_{02} - T_{01}) \Rightarrow T_{02} = \frac{q}{c_p} + T_{01} \Rightarrow T_{02} = \frac{1,0 \times 10^6}{1004} + 273 \Rightarrow \boxed{T_{02} \approx 1270K}$$

tab A3

| M | $T_1/T^*$ | $p_1/p^*$ | $p_{01}/p_0^*$ | $T_{01}/T_0^*$ |
|---|---|---|---|---|
| 0,2 | 0,2066 | 2,273 | 1,235 | 0,1736 |

$$\frac{T_{02}}{T_0^*} = \frac{T_{02}}{T_{01}}\,\frac{T_{01}}{T_0^*} \Rightarrow \frac{T_{02}}{T_0^*} = \frac{1210}{275,2}\,0,1736 \Rightarrow \boxed{\frac{T_{02}}{T_0^*} = 0,8013}$$

Da tab A3 ; $\frac{T_{02}}{T_0^*} = 0,8013$

$$\begin{array}{ll} 0,7965 & -\ 0,58 \\ 0,8013 & -\ M_2 \\ 0,8189 & -\ 0,6 \end{array} \Rightarrow \frac{M_2 - 0,58}{0,6-0,58} = \frac{0,8013-0,7965}{0,8189-0,7965} \Rightarrow \boxed{M_2 \cong 0,584}$$

Da tab A3 : $M = 0,584 \approx 0,58$

| $\frac{p}{p^*}$ | $\frac{T}{T^*}$ | $\frac{\rho}{\rho^*}$ | $\frac{p_0}{p_0^*}$ | $\frac{T_0}{T_0^*}$ |
|---|---|---|---|---|
| 1,632 | 0,8955 | 1,822 | 1,083 | 0,7965 |

$$T_2 = \left(\frac{T_2}{T^*}\right)\left(\frac{T^*}{T_1}\right)(T_1) = 0,8955 \cdot \frac{1}{0,2066} \cdot 273 \Rightarrow \boxed{T_2 = 1183\,K}$$

$$p_2 = \frac{p_2}{p^*}\,\frac{p^*}{p_1}\,p_1 = 1,632 \cdot \frac{1}{2,273} \cdot 1 \Rightarrow \boxed{p_2 = 0,718\ atm}$$

$$p_{02} = \frac{p_{02}}{p_0^*}\,\frac{p_0^*}{p_{01}}\,p_{01} = 1,083 \cdot \frac{1}{1,235} \cdot 1,028 \Rightarrow \boxed{p_{02} = 0,902\ atm}$$

$$\rho_2 = \frac{p_2}{RT_2} = \frac{0,718 \times 1,01 \times 10^5}{287 \times 1183} \Rightarrow \boxed{\rho_2 \cong 0,214\ \frac{kg}{m^3}}$$

Ex 13

Dn : $k = 1,4 \quad R = 287 \quad c_p = 1004$

$M_1 = 3 \,, \quad p_1 = 1\ atm \,, \quad T_1 = 300K \quad , \; q = 3 \times 10^5\ J/kg$

a) $M_2 , p_2 , T_2 , \rho_2 , T_{02} , p_{02}$

tab A1 : $M = 3$

| | $p_{01}/p_1$ | $\rho_{01}/\rho_1$ | $T_{01}/T_1$ |
|---|---|---|---|
| | 36,73 | 13,12 | 2,80 |

$\frac{p_{01}}{p_1} = 36,73 \Rightarrow p_{01} = 36,73 \times 1\,atm \Rightarrow \boxed{p_{01} = 36,73\ atm}$

$T_{01} = T_1 \times 2,80 \rightarrow T_{01} = 300 \times 2,80 \Rightarrow \boxed{T_{01} = 840K}$

$q = c_p (T_{02} - T_{01}) \Rightarrow T_{02} = \frac{q}{c_p} + T_{01} = \frac{3 \times 10^5}{1004} + 840 \Rightarrow \boxed{T_{02} = 1138,8K}$

Da tab A3

| M | $p_1/p^*$ | $T_1/T^*$ | $T_{01}/T_0^*$ | $\frac{p_{01}}{p_0^*}$ |
|---|---|---|---|---|
| 3 | 0,1765 | 0,2803 | 0,6540 | 3,424 |

$\frac{T_{02}}{T_0^*} = \frac{T_{02}}{T_{01}} \frac{T_{01}}{T_0^*} = \frac{1138,8}{840} \cdot 0,6540 \Rightarrow \boxed{\frac{T_{02}}{T_0^*} = 0,8868}$

Da tab A3 $\frac{T_0}{T_0^*} = 0,8868 \Rightarrow \boxed{M_2 \approx 1,58} \Rightarrow$

| $\frac{p_2}{p^*}$ | $\frac{T_2}{T^*}$ | $\frac{p_{02}}{p_0^*}$ |
|---|---|---|
| 0,5339 | 0,7117 | 1,164 |

$p_2 = \frac{p_2}{p^*} \frac{p^*}{p_1} p_1 = (0,5339)\left(\frac{1}{0,1765}\right) \cdot 1 \Rightarrow \boxed{p_2 = 3,025\ atm}$

$T_2 = \frac{T_2}{T^*} \frac{T^*}{T_1} T_1 = 0,7117 \cdot \left(\frac{1}{0,2803}\right) 300 \Rightarrow \boxed{T_2 = 761,7K}$

$\rho_2 = \frac{p_2}{RT_2} = \frac{3,025 \times 1,01 \times 10^5}{287 \times 761,7} \Rightarrow \boxed{\rho_2 = 1,398\ kg/m^3}$

$\frac{p_{02}}{p_{01}} = \frac{p_{02}/p_0^*}{p_{01}/p_0^*} = \frac{1,164}{3,424} =$

$\frac{p_{01}}{p_1} = 36,73$

$p_{02} = \frac{p_{02}}{p_{01}} \frac{p_{01}}{p_1} p_1 = 12,49\,a$

b) $q = ? \Rightarrow M_2 = 1 \qquad q = c_p(T_{02} - T_{01})$

$T_{01} = 840K$

$M_1 = 3$

$\frac{T_{01}}{T_0^*} = 0{,}6540 \Rightarrow T_0^* = \frac{T_{01}}{0{,}6540} = \frac{840}{0{,}6540} \Rightarrow \boxed{T_0^* = 1284K}$

$M_2 = 1 \Rightarrow T_{02} = T_0^* = 1284K$

$q = c_p(T_{02} - T_{01}) = 1004(1284 - 840) \Rightarrow \boxed{q = 4{,}46 \times 10^5\ J/kg}$

c) $q = 6 \times 10^5 \frac{J}{kg} \rightarrow$ maior que valor obtido p/ estrangular o escoamento

Propriedades na entrada, a $M_1 = 3$, irão mudar devido à onda de pressão forte

↳ nova condição de entrada surgirá para acomodar a quantidade de calor adicion

↳ mecanismo não altera a temperatura total : $T_{01} = 840K$

$T_{02} = T_0^* \Rightarrow q = c_p(T_{02} - T_{01}) \Rightarrow T_{02} = \frac{q}{c_p} + T_{01} = \frac{6 \times 10^5}{1004} + 840 = \underline{1437K}$

$\frac{T_{01}}{T_0^*} = \frac{840}{1437} = 0{,}5846 \rightarrow$ tab A3

| $\frac{T_{01}}{T_0^*}$ | M |
|---|---|
| 0,5846 | 0,43 |

Escoamento supersônico a $M_1 = 3$ irá se tornar escoamento subsônico a $M_1 = 0{,}43$

Ex 15  Ar: $k = 1{,}4$  $c_p = 1004$  * corrigir: $M_1 = 0{,}3$ !!!

$D = 0{,}15\,m$

$L = 30\,m$

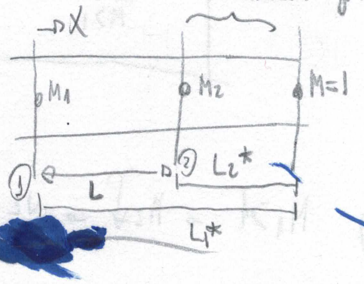
$M_1 = 3$  $P_1 = 1\,atm$  $T_1 = 273\,K$

$f = 0{,}005$

a) $M_2, P_2, T_2, P_{02}$

O comprimento do duto, L, necessário para que o Número de Mach mude de $M_1$ para $M_2$ é

$$\frac{fL}{D} = \left(\frac{fL}{D}\right)_{M_1} - \left(\frac{fL}{D}\right)_{M_2}$$




tab A1: 

| M | $P_{01}/P_1$ |
|---|---|
| 0,3 | 1,064 |

$\Rightarrow P_{01} = 1{,}064\,P_1 \Rightarrow P_{01} = 1{,}064\,atm$

tab A4:

| M | $\frac{4fL_1^*}{D}$ | $p_1/p^*$ | $T_1/T^*$ | $P_{01}/p^*$ |
|---|---|---|---|---|
| 0,3 | 5,299 | 3,619 | 1,179 | 2,035 |

$L = 30\,m = L_1^* - L_2^* \Rightarrow L_2^* = L_1^* - L$

$$\frac{4fL_2^*}{D} = \frac{4fL_1^*}{D} - \frac{4fL}{D} = 5{,}2993 - \frac{4 \cdot 0{,}005 \cdot 30}{0{,}15} = 1{,}2993$$

Da tab A4:

| $\frac{4fL^*}{D}$ | $M_2$ | $T_2/T^*$ | $P_2/p^*$ | $P_{02}/P_0^*$ |
|---|---|---|---|---|
| 1,2993 | 0,475 | 1,148 | 2,258 | 1,392 |

$$P_2 = \frac{P_2}{p^*}\frac{p^*}{P_1}P_1 = 2{,}258\,\frac{1}{3{,}169} \times 1 \Rightarrow P_2 = 0{,}713\,atm$$

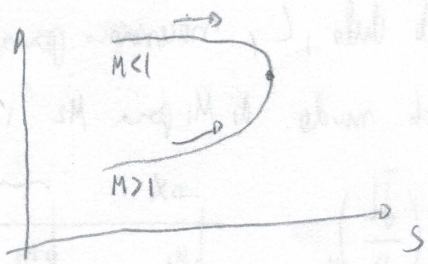
$$T_2 = \frac{T_2}{T^*}\frac{T^*}{T_1}T_1 = 1{,}148\,\frac{1}{1{,}173}\,273 \Rightarrow T_2 = 265{,}84\,K$$

$$P_{02} = \frac{P_{02}}{P_0^*}\frac{P_0^*}{P_1}P_1 = 1{,}392\,\frac{1}{2{,}035}\,1{,}064 \Rightarrow P_{02} = 0{,}728\,atm$$

b) tab A4: M 3, $\frac{4fL^*}{D}$ 5,299

$$L_1^* = 0{,}5222\,\frac{D}{4f} = 5{,}299\,\frac{0{,}15}{4 \cdot 0{,}005} \Rightarrow L_1^* = 39\,m$$

Ex 16 $M_1 > 1$




a) $M_1 > 1 \rightarrow M_2 \downarrow \rightarrow v_2 \downarrow$

| $M$ | $\frac{T}{T^*}$ | $\frac{P}{P^*}$ | $\frac{P_0}{P_0^*}$ | $\frac{4f L^*}{D}$ |
|---|---|---|---|---|
| $\downarrow$ | $\uparrow$ | $\uparrow$ | $\downarrow$ | $\downarrow$ |

a) $M_2 < M_1$

b) $P_2 > P_1$

c) $T_2 > T_1$

d) $P_{02} < P_{01}$

b) $M_1 < 1$

$M_2 > M_1$

| $M$ | $\frac{T}{T^*}$ | $\frac{P}{P^*}$ | $\frac{P_0}{P_0^*}$ | $\frac{4f L^*}{D}$ |
|---|---|---|---|---|
| $\uparrow$ | $\downarrow$ | $\downarrow$ | $\downarrow$ | |

a) $M_2 > M_1$

b) $P_2 < P_1$

c) $T_2 < T_1$

d) $P_{02} < P_{01}$

e) $v_2 > v_1$