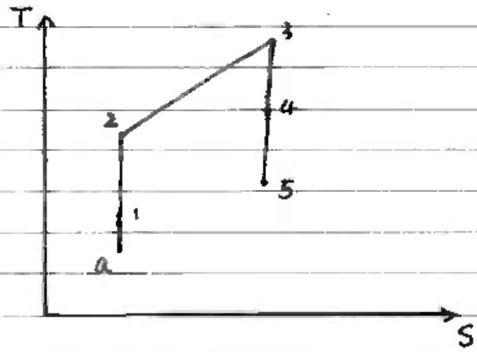
AE 3006. Aircraft Propulsion

No

Semester I. 2008 - 2009

1. (i)



$a-1$ intake

$1-2$ compressor

$2-3$ combustion

~~3-4 turbine~~

$4-5$ nozzle

(ii) From $a - 1$

$P_a = 84\ kPa \quad T_a = 5^\circ C = 283\ K$

$$T_1 = T_a + \frac{C_a^2}{2C_p} = 283 + \frac{125^2}{2 \times 1000} = 290.8\ (K)$$

$$\frac{P_1}{P_a} = \left(\frac{T_1}{T_a}\right)^{\frac{\gamma}{\gamma-1}} = \left(\frac{290.8}{283}\right)^{\frac{1.4}{0.4}} = 1.1$$

$\therefore P_1 = 92.4\ (kPa)$

From $1 - 2$

$$\frac{P_2}{P_1} = 8 \Rightarrow P_2 = 739.2\ (kPa)$$

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Since it's isentropic process.

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 8^{\frac{0.4}{1.4}} = 1.81$$

$\therefore\ T_2 = 526.3\ (K)$

From 2 - 3

$P_3 = P_2 = 739.2\ (kPa)$

$T_3 = 927°C = 1200\ (K)$

Energy balance

$$\left.\begin{aligned} &\dot{m}_f \cdot Q = C_p(\dot{m}_f + \dot{m}_a)\cdot T_3 - C_p(\dot{m}_a)\cdot T_2 \\ &Q = 42\times10^6\ J/kg \\ &C_p = 1000\ J/kg\cdot K. \\ &\dot{m}_a = 25\ kg/s \end{aligned}\right\} \Rightarrow$$

$\therefore\ \dot{m}_f = 0.413\ kg/s$

From 3 - 4

Work balance for compressor and turbine

$$C_p(\dot{m}_a + \dot{m}_f)(T_3 - T_4) = C_p\,\dot{m}_a\,(T_2 - T_1)$$

$\therefore\ T_4 = 968.3\ (K)$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow P_4 = 348.9\ (kPa)$$

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From 4 – 5

check whether the flow is choked or not.

$$\frac{P_c}{P_4} = \left[1 - \frac{1}{\eta_j}\left(\frac{\gamma-1}{\gamma+1}\right)\right]^{\frac{\gamma}{\gamma-1}}$$

$$\eta_j = 1$$

$$\therefore \frac{P_c}{P_4} = 0.53$$

$$\frac{P_a}{P_4} = \frac{84}{348.8} = 0.24$$

$$\frac{P_c}{P_4} > \frac{P_a}{P_4} \quad \therefore \text{ the flow is choked}$$

$$\therefore P_5 = P_c = 0.53 P_4 = 184.8 \ (kPa)$$

$$\frac{T_4}{T_5} = \left(\frac{P_4}{P_5}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_5 = 807.7 \ (K)$$

the gas density at stage 5 is

$$\rho_5 = \frac{P_5}{RT_5} = \frac{184.8 \times 10^3}{287 \times 807.7} = 0.798 \ kg/m^3$$

$$\cancel{A_5} = T_4 = T_5 + \frac{C_5^2}{2C_p} \Rightarrow C_5 = 566.7 \ (m/s)$$

$$\dot{m} = \dot{m}_a + \dot{m}_f = \rho_5 C_5 \cdot A_5 \Rightarrow A_5 = 0.056 \ (m^2)$$

$$\therefore T = (\dot{m}_a + \dot{m}_f) C_5 - \dot{m}_a C_a + (P_5 - P_a) A_5 = 16.826 \ (kN$$

$$SFC = \frac{\dot{m}_f}{T} = \frac{0.413}{16.926\times10^3} = 2.44\times10^{-5}\ (kg/s.N)$$

(iii)

① compressor efficiency

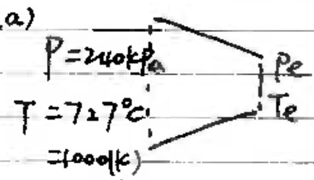
② combustion efficiency

③ turbine efficiency

④ bleeding air ratio

⑤ nozzle efficiency

2 (a)



$P_a = 101$ kPa

$T_a = 15°C = 288\,(K)$

check the flow is choked or not.

$$\frac{P_c}{P} = \left[1 - \frac{1}{\eta_j}\left(\frac{\gamma-1}{\gamma+1}\right)\right]^{\frac{\gamma}{\gamma-1}}$$

$\eta_j = 1$

$$\frac{P_c}{P} = 0.53.$$

$$\frac{P_a}{P} = 0.42$$

$$\therefore \frac{P_c}{P} > \frac{P_a}{P}$$

the flow is choked.

$$P_e = P_c = 0.53\,P = 127.2\ (kPa)$$

$$\frac{T}{T_e} = \left(\frac{P}{P_e}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_e = 834.1\ (K)$$

$$T = T_e + \frac{c_e^2}{2C_p} \Rightarrow C_e = 617.2\ (m/s)$$

$$\rho_e = \frac{P_e}{KT_e} = \frac{127.2\times 10^3}{287\times 834.1} = 0.532\ kg/m^3$$

$$\dot m = \rho_e A_e C_e \Rightarrow A_e = \frac{\dot m}{\rho_e C_e} = \frac{23}{0.532\times 617.2} = 0.07\ (m^2$$

$$T = \dot m C_e + (P_e - P_a)A_e$$

$$= 23\times 617.2 + (127.2\times 10^3 - 101\times 10^3)\times 0.07$$

$$= 16.029\ (kN)$$

(b) $J = \dfrac{N C_a}{n D}$ N is the number of blade

$$= \frac{5\times 80}{\frac{2000\times 2\times 3.14}{60}\times 3} = 0.64$$

From Figure 2

$k_T = 0.34$

$\eta = 0.55$

$$\therefore T = k_T\cdot \rho n^2 D^4 = 1.18\times 10^6\ (N)$$

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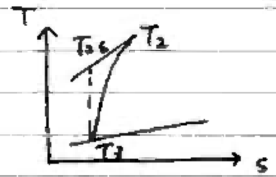
$$P_s = \frac{T \cdot C_a}{\eta} = 172 \times 10^6 \ (W)$$

3 (a)



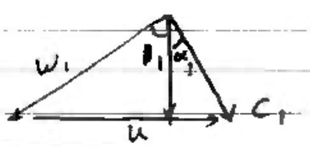
$$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 1.3^{\frac{0.4}{1.4}}$$

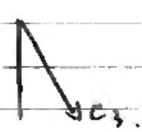
$$\therefore T_{2s} = 310.4 \ (K)$$

$$\eta = \frac{T_{2s} - T_1}{T_2 - T_1} = 0.9$$

$$\therefore T_2 = 312.89 \ (K)$$

$$W = C_p \cdot (T_2 - T_1) = \frac{\gamma}{\gamma - 1} R \cdot (T_2 - T_1) = 2500.2 \ (J)$$





$$\left.\begin{array}{l} C_z = 100 \text{ m/s} \\ \alpha_1 = 30^\circ \end{array}\right\} \Rightarrow \tan\beta_1 = \frac{U - C_z \cdot \tan\alpha_1}{C_z} = 1.42$$

$$\Rightarrow \beta_1 = 54.8^\circ$$

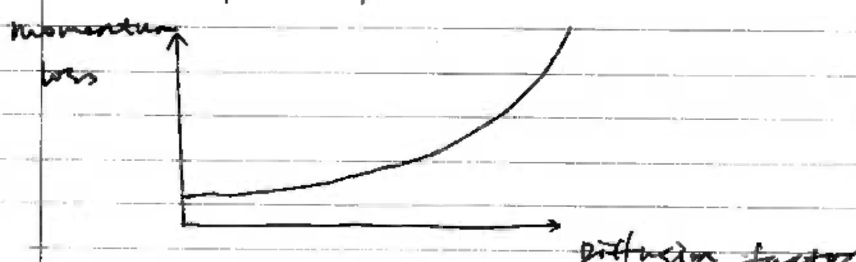
$$W = C_p(T_2 - T_1) = U(C_{\theta 2} - C_{\theta 1})$$

$$\therefore C_{\theta 2} = 182.7 \text{ (m/s)}$$

$$\therefore \tan\alpha_2 = \frac{C_{\theta 2}}{C_z} = \frac{182.7}{100} \Rightarrow \alpha_2 = 61.31^\circ$$

$$\tan\beta_2 = \frac{U - C_{\theta 2}}{C_z} = \frac{200 - 182.7}{100} \Rightarrow \beta_2 = 9.82^\circ$$

(b) Diffusion factor is defined as a measure of pressure loss for compressor blade.



As diffusion factor increases, momentum loss of flow increases. As a result diffusion factor sets a limit for pressure rise across compressor blade.

(c)

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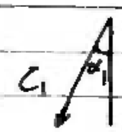

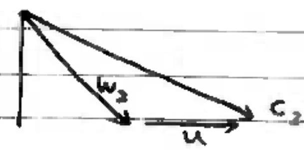

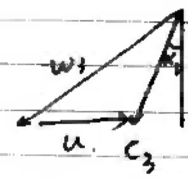

$$\left.\begin{aligned} R &= \frac{h_2 - h_3}{h_1 - h_3} \\ \alpha_1 &= \alpha_3 = 0 \\ c_1 &= c_3 \end{aligned}\right\}$$

$$R = \frac{\frac{1}{2}(w_3^2 - w_2^2)}{u(c_{\theta 2} + c_{\theta 3})} = \frac{w_{\theta 3} - w_{\theta 2}}{2u}$$

For $\alpha_3 = 0$

$w_{\theta 3} = u$

$$R = 0 = \frac{u - w_{\theta 2}}{2u} \Rightarrow w_{\theta 2} = u$$

Stage loading coefficient $\psi = \frac{\Delta h_0}{u^2} = \frac{u(c_{\theta 2} + c_{\theta 3})}{u^2}$

$$= \frac{u \cdot (2u + 0)}{u^2}$$

$$= 2$$

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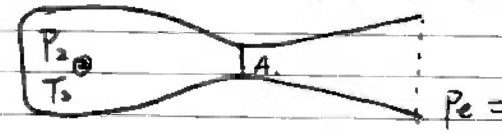
4 (a)



$P_e = P_a = 0.1\ mPa$

From ② to exit, the process is assumed to be isentropic.

$$\frac{T_2}{T_e} = \left(\frac{P_2}{P_e}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{5.19}{0.1}\right)^{\frac{0.4}{1.4}}$$

$$\therefore T_e = 1067.7\ (K)$$

$$T_2 = T_e + \frac{C_e^2}{2C_p}$$

$$C_p = \frac{\gamma}{\gamma-1} R = \frac{\gamma}{\gamma-1}\frac{\bar{R}}{M} = \frac{1.4}{0.4} \times \frac{8314}{15} = 1939.9$$

$$\therefore C_e = 2942.96\ (m/s)$$

$$I_{sp} = \frac{F}{\dot{m} g_e} = \frac{\dot{m} V_e + (P_e - P_a) A_e}{\dot{m} g_e} = \frac{V_e}{g_e} = 300$$

$$T = I_{sp} \cdot \dot{m} g_e = 300 \times \dot{m}\, g_e = 500 \times 10^3$$

$$\dot{m} = 169.9\ (kg/s)$$

$$\left.\begin{aligned} \dot{m} &= \frac{A^* P_{02}}{\sqrt{R T_{02}}} \sqrt{\gamma \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} \\ R &= \frac{\bar{R}}{M} = \frac{8314}{15} = 554.27 \end{aligned}\right\} \Rightarrow A^* = 0.065\ (m^2)$$

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(b)

(i) ① reduced gravitational loss.

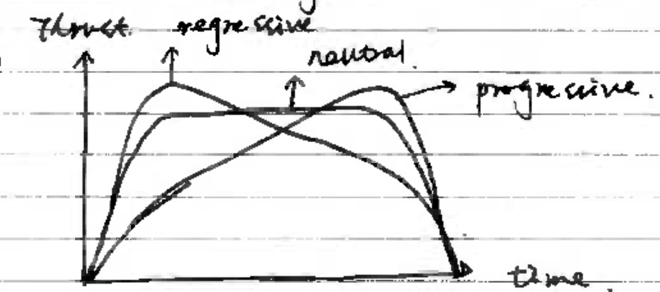
② each stage can use different type of rocket motor.

③ each stage engine is then suited to its operating condition.

(ii) ① high thrust at the launch stage.

② reduced gravitatitional loss

(c)



As pressure increases, burning rate also increase.

(d) In the gas feed system, helium or nitrogen is stored in a high pressure tank at pressure as high as 35 mPa. Through regulator valves, this gas is transferred to the fuel and oxidizer tanks to push the propellants into combustion chamber.

It's used for launch vehicles but not for missions involving large velocity increments.