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UNIVERSITI SAINS MALAYSIA

First Semester Examination  
2008/2009 Academic Session  
*Peperiksaan Semester Pertama  
Sidang Akademik 2008/2009*

November 2008  
*November 2008*

**ESA 342/3 – Propulsion Systems**  
*Sistem Dorongan*

Duration : 3 hours  
*[Masa : 3 jam]*

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**INSTRUCTION TO CANDIDATES**  
**ARAHAN KEPADA CALON**

Please ensure that this paper contains **FOURTEEN (14)** printed pages and **FIVE (5)** questions before you begin examination.

*Sila pastikan bahawa kertas soalan ini mengandungi **EMPAT BELAS (14)** mukasurat bercetak dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan.*

Answer **FOUR (4)** questions.  
*Jawab **EMPAT (4)** soalan.*

Student may answer the questions either in English or Bahasa Malaysia.  
*Pelajar boleh menjawab soalan dalam Bahasa Inggeris atau Bahasa Malaysia.*

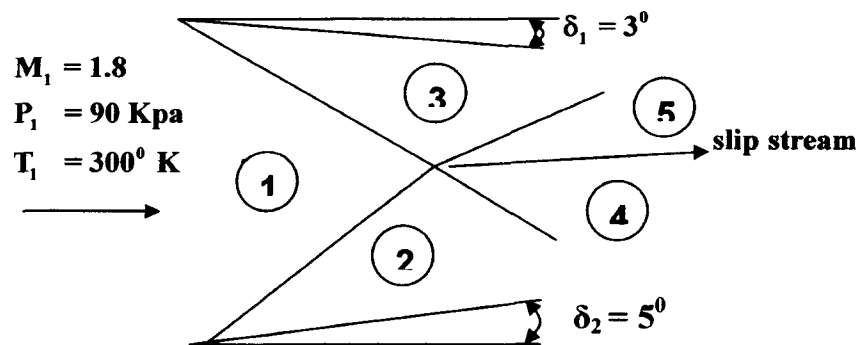
Each questions must begin from a new page.  
*Setiap soalan mestilah dimulakan pada mukasurat yang baru.*

1. (a) **Figure Q1(a)** shows a schematic diagram of supersonic flow pass through an inlet engine. The wedge angle at lower side  $\delta_1$  is equal to  $5^\circ$ , while the wedge upper side angle  $\delta_2$  is equal  $3^\circ$ . The oblique shock wave appear in the flow field as result the flow domain can be defined into 4 regions as shown in that figure. The incoming free stream condition is given as :

- Mach number  $M_1 = 1.8$
- Static Pressure  $P_1 = 90$  KPa
- Static temperature  $T_1 = 300^\circ$  K

*Rajah S1(a)* memperlihatkan skematik diagram dari aliran supersonik melalui bagian inlet. Sudut baji bahagian bawah  $\delta_1$  sama dengan  $5^\circ$  dan sudut baji bahagian atas  $\delta_2$  sama dengan  $3^\circ$ . Gelombang kejut serong terbentuk di dalam medan aliran sehingga aliran terbahagi menjadi 4 kawasan seperti yang ditunjukkan dalam rajah tersebut. Keadaan aliran bebas diberikan sebagai berikut :

- Nombor Mach  $M_1 = 1.8$
- Tekanan statik  $P_1 = 90$  Kpa
- Suhu statik  $T_1 = 300^\circ$  K



**Figure Q1(a) Flow pass through inlet/Rajah S1(a) Aliran melalui inlet**

Other air properties :

*Sifat sifat udara lainnya:*

Universal gas constant  $R = 287 \text{ J}/(\text{Kg } ^\circ\text{K})$

*Pemalar gas semesta  $R = 287 \text{ J}/(\text{Kg } ^\circ\text{K})$*

Heat coefficient at constant pressure  $c_p = 1004 \text{ J}/(\text{Kg } ^\circ\text{K})$

*Pemalar panas pada tekanan tetap  $c_p = 1004 \text{ J}/(\text{Kg } ^\circ\text{K})$*

Ratio of heat coefficient  $\gamma = 1.4$

*Nisbah pemalar panas  $\gamma = 1.4$*

Determine:

*Tentukan:*

- (i) Mach number  $M_2$ , static pressure  $P_2$ , and static temperature  $T_2$ .  
*Nombor Mach  $M_2$ , Tekanan Statik  $P_2$ , and suhu statik  $T_2$ .*
- (ii) Mach Number  $M_3$ , static pressure  $P_3$ .  
*Nombor Mach  $M_3$ , tekanan statik  $P_3$ .*
- (iii) Use an iteration process calculate the Mach number at flow domain 4 and 5. (Try up to two iterations process).  
*Gunakan iterasi untuk menentukan Nombor Mach pada domain aliran 4 and 5. (Cukup dicuba sampai 2 iterasi).*
- (iv) Explain why the slip stream appear in the flow region between flow domain 4 and 5.  
*Terangkan mengapa terjadi "slip stream" antara domain aliran 4 dan 5.*

**(15 marks/markah)**

- (b) A Duct with a circular cross section as depicted in **Figure Q1(b)** consist of three section. Flow pass through section  $1 \rightarrow 2$  can be considered as the flow with heat interaction only ( friction is ignored). The flow from station 2 to station 3 as isentropic flow pass through duct with variable area. While the last section ( station 3 to 4 ) represent as the flow dominated by friction effects only. At the entry station ( station 1 ) , the flow conditions are given as :

*Sebuah saluran dengan penampang berupa lingkaran seperti yang diperlihatkan pada **Rajah S1(b)**. Saluran terdiri dari tiga bagian. Aliran melalui bahagian  $1 \rightarrow 2$  dapat dianggap sebagai aliran dengan interaksi panas . Aliran dari stesen 2 ke 3 sebagai aliran isentropik melalui saluran dengan penampang berubah. Sedang bagian akhir (dari stesen 3 ke 4) sebagai aliran yang sangat dipengaruhi oleh geseran. Pada bagian masuk (stesen 1), kondisi aliran diberikan sebagai :*

Mach number  $M_1 = 0.2$   
 Nombor Mach  $M_1 = 0.2$

Static Pressure  $P_1 = 90$  KPa  
 Tekanan statik  $P_1 = 90$  Kpa

Static temperature  $T_1 = 400^0$  K  
 Suhu statik  $T_1 = 400^0$  K

Heat addition into station  $1 \rightarrow 2$  is 300 KJ/Kg  
 Penambahan panas kedalam stesen  $1 \rightarrow 2$  : 300 KJ/Kg

Duct cross section area :  
 Keluasan penampang saluran :

$$A_1 = A_2 = 0.4 \text{ m}^2$$

$$A_1 = A_2 = 0.4 \text{ m}^2$$

$$A_3 = A_4 = 0.3 \text{ m}^2$$

$$A_3 = A_4 = 0.3 \text{ m}^2$$

Duct length station  $3 \rightarrow 4$  :  $L_{34} = 2$  m  
 Panjang saluran stesen  $3 \rightarrow 4$  :  $L_{34} = 2$  m

Coefficient skin friction  $c_f = 0.001$ .  
 Pemalar " skin friction"  $c_f = 0.001$

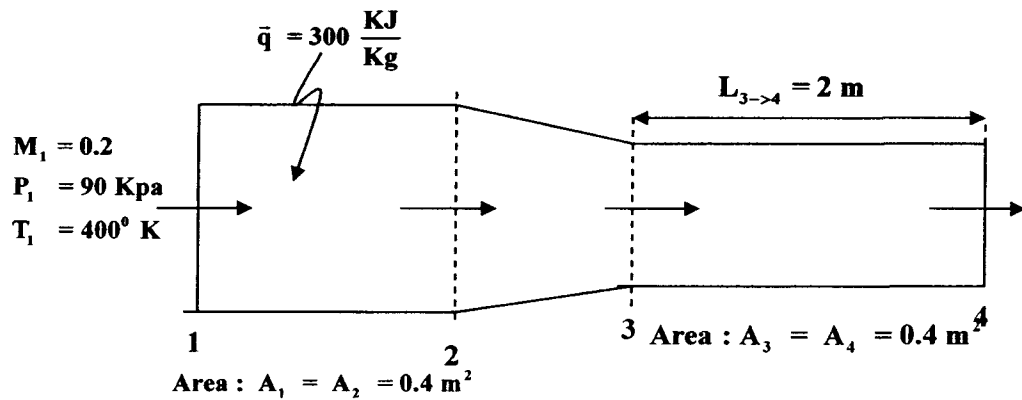


Figure Q1(b) Flow pass through a duct/Rajah S1(b) Aliran melalui saluran

Determine:

Tentukan:

- (i) Mach number  $M_2$ , static Pressure  $P_2$ , and static temperature  $T_2$ .  
Nombor Mach  $M_2$ , tekanan statik  $P_2$ , dan suhu statik  $T_2$ .
- (ii) Mach Number  $M_3$ , static Pressure  $P_3$ .  
Nombor Mach  $M_3$ , tekanan statik  $P_3$ .
- (iii) Mach Number  $M_4$ , static Pressure  $P_4$  and density  $\rho_4$ .  
Nombor Mach  $M_4$ , tekanan statik  $P_4$  dan ketumpatan  $\rho_4$ .
- (iv) Thrust generated by the flow system.  
Daya dorong yang dihasilkan oleh sistem aliran.

(10 marks/markah)

2. (a) Proof that the fuel air ratio  $f$  for an ideal ram jet is given by:

*Buktikan bahawa nisbah bahan bakar – udara untuk ram jet ideal diberikan dengan:*

$$f = \frac{C_p T_0}{h_{pr}} [\tau_\lambda - \tau_r]$$

where:

*di mana:*

$C_p$  : Heat coefficient at constant pressure

$C_p$  : *Pemalar panas pada tekanan tetap*

$T_0$  : Free stream temperature

$T_0$  : *Suhu udara aliran bebas*

$h_{pr}$  : Fuel heating value

$h_{pr}$  : *Nilai panas bahan bakar*

$\tau_\lambda$  : The ratio of the burner exit to the ambient enthalpy

$\tau_\lambda$  : *Nisbah entalpi "burner exit" terhadap entalpi persekitaran*

$\tau_r$  : The temperature ratio of the free stream

$\tau_r$  : *Nisbah suhu aliran bebas*

**(5 marks/markah)**

- (b) Proof that the specific thrust maximum for an for an ideal ram jet is occurred if the value of Mach number  $M_\infty$  is equal to :

*Buktikan bahawa daya dorong maksimum untuk ram jet ideal terjadi apabila nombor Mach  $M_\infty$  adalah sama dengan :*

$$M_\infty^2 = \frac{2}{\gamma-1} [\sqrt[3]{\tau_\lambda} - 1]$$

where:

*di mana :*

$M_\infty$  : Free flow Mach number

$M_\infty$  : *Nombor Mach aliran bebas*

$\tau_\lambda$  : The ratio of the burner exit to the ambient enthalpy

$\tau_\lambda$  : *Nisbah entalpi "burner exit" terhadap entalpi persekitaran*

$\gamma$  : Coefficient heat ratio

$\gamma$  : *Nisbah pemalar panas*

**(10 marks/markah)**

- (c) A Cruise missile powered by ram jet engine flight at the mach number  $M_\infty = 2.4$ . Assume that the ram jet engine works as an ideal engine. The turbine temperature limitation  $T_{T4} = 1600^{\circ}\text{K}$ . If the cruise missile has a lift to drag ratio is equal to 8 and weight of 10000 N.

*Sebuah pelancar peluru berpandu menggunakan ram jet terbang pada halaju nombor Mach  $M_\infty = 2.4$ . Anggap sebagai ram jet ideal. Batasan Suhu turbin  $T_{T4} = 1600^{\circ}\text{K}$ . Jika pelancar peluru berpandu ini mempunyai nisbah daya angkat – daya seret (Lift / Drag) sama dengan 8 dan berat sebesar 10000 N*

Other required data:

*Data lainnya yang diperlukan:*

Heat coefficient at constant pressure  $C_p = 1004 \text{ (J/(kg } ^{\circ}\text{K))}$   
*Pemalar panas pada tekanan tetap  $C_p = 1004 \text{ (J/(kg } ^{\circ}\text{K))}$*

Coefficient heat ratio  $\gamma = 1.4$   
*Nisbah pemalar panas  $\gamma = 1.4$*

Fuel Heating value  $h_{pr} = 42798.4 \text{ kJ/kg}$   
*Nisbah panas bahan bakar  $h_{pr} = 42798.4 \text{ kJ/kg}$*

Determine:

*Tentukan:*

- (i) The jet velocity from the ramjet nozzle  $V_9$   
*Halaju aliran jet dari muncung ramjet  $V_9$*
- (ii) The specific thrust  
*Daya tujah spesifik*
- (iii) The fuel air ratio  
*Nisbah bahan bakar – udara*
- (iv) The rate of mass flow through the rame jet engine  
*Halaju jisim melalui ram jet*

**(10 marks/markah)**

3. (a) Proof that the fuel air ratio  $f$  for an ideal turbo jet is given by :

*Buktikan bahwa nisbah bahan bakar – udara untuk turbo jet ideal diberikan dengan :*

$$f = \frac{C_p T_0}{h_{pr}} [\tau_\lambda - \tau_r \tau_c]$$

where:

*di mana :*

$C_p$  : Heat coefficient at constant pressure

$C_p$  : *Pemalar panas pada tekanan tetap*

$T_0$  : Free stream temperature

$T_0$  : *Suhu udara aliran bebas*

$h_{pr}$  : Fuel heating value

$h_{pr}$  : *Nilai panas bahan bakar*

$\tau_\lambda$  : The ratio of the burner exit to the ambient enthalpy

$\tau_\lambda$  : *Nisbah entalpi "burner exit" terhadap entalpi persekitaran*

$\tau_r$  : The ratio of free stream temperature.

$\tau_r$  : *Nisbah suhu aliran bebas*

$\tau_c$  : The ratio of compressor temperature

$\tau_c$  : *Nisbah suhu kompresor*

**(5 marks/markah)**

- (b) The turbo jet engine consist of five main components : diffuser, compressor, combustion chamber, turbine and nozzle. Explain the function of those components.

*Mesin turbo jet terdiri 5 komponen utama : difusor, compressor, ruang bakar, turbin dan nozzle. Terangkan fungsi dari kelima komponen tersebut.*

**(10 marks/markah)**



- (c) An airplane with aircraft weight of 60000 Newton, has lift to drag ratio of 10. This airplane equipped with two turbo jet engines placed on the wing. Assume that those two engines work as an ideal engine. The aircraft flight at the speed of Mach number  $M_\infty = 0.6$  above sea level.

*Suatu pesawat terbang dengan berat 60000 Newton, mempunyai nisbah daya angkat dan drag sebesar 10. Pesawat terbang ini memiliki dua mesin turbo jet yang terpasang pada bagian sayap pesawat. Anggapkan kedua mesin turbo jet ini bekerja secara ideal. Pesawat terbang pada halaju nombor Mach  $M_\infty = 0.6$  di atas paras laut.*

The data turbo jet engine:

*Data enjin turbo jet:*

Fuel Heating value  $h_{pr} = 42798.4$  kJ/kg

*Nisbah panas bahan bakar  $h_{pr} = 42798.4$  kJ/kg*

Temperature Turbine limitation  $T_{t4} = 1800^0$  K

*Batasan suhu turbin  $T_{t4} = 1800^0$  K*

High pressure compressor ratio  $\pi_c = 16$

*Nisbah kompresor tekanan  $\pi_c = 16$*

Flight ambient temperature  $T_\infty = 262^0$  K

*Suhu terbang sekitar  $T_\infty = 262^0$  K*

Flight ambient pressure  $P_\infty = 61.6$  Kpa

*Tekanan terbang sekitar  $P_\infty = 61.6$  Kpa*

Coefficient heat ratio  $\gamma = 1.4$

*Nisbah pemalar panas  $\gamma = 1.4$*

Heat coefficient at constant pressure  $C_p = 1004$  (J/(kg<sup>0</sup>K))

*Pemalar panas pada tekanan tetap  $C_p = 1004$  (J/(kg<sup>0</sup>K))*

Using an ideal cycle analysis determined :

*Dengan menggunakan analisis putaran ideal tentukan :*

- (i) Specific thrust  
*Daya tujah spesifik*
- (ii) The fuel air ratio,  $f$   
*Nisbah bahan bakar – udara,  $f$*
- (iii) The rate of mass flow for each engine  
*Halaju jisim untuk setiap engine*

**(10 marks/markah)**

4. An airplane flights at altitude of 4000 m above sea level. This airplane used a turbo Jet engine with the engine component data as follows :

*Suatu pesawat terbang terbang pada ketinggian 4000 m di atas permukaan laut. Pesawat tersebut menggunakan mesin turbo jet dengan data-data komponen mesin sebagai berikut :*

Temperature Turbine limitation  $T_{t4} = 1800^0 \text{ K}$   
*Batasan suhu turbin  $T_{t4} = 1800^0 \text{ K}$*

Fuel Heating value  $h_{pr} = 42798.4 \text{ kJ/kg}$   
*Nisbah panas bahan bakar  $h_{pr} = 42798.4 \text{ kJ/kg}$*

Coefficient heat ratio of cold air  $\gamma_c = 1.4$   
*Nisbah haba untuk udara sejuk  $\gamma_c = 1.4$*

Coefficient heat ratio of hot air  $\gamma_t = 1.30$   
*Nisbah haba untuk udara panas  $\gamma_t = 1.096$*

Heat coefficient at constant pressure of cold air  $C_{pc} = 1004 \text{ (J/(kg } ^0\text{K))}$   
*Pemalar haba pada tekanan tetap udara sejuk  $C_{pc} = 1004 \text{ (J/(kg } ^0\text{K))}$*

Heat coefficient at constant pressure of cold air  $C_{pt} = 1239 \text{ (J/(kg } ^0\text{K))}$   
*Pemalar haba pada tekanan tetap udara panas  $C_{pt} = 1239 \text{ (J/(kg } ^0\text{K))}$*

Ram diffuser efficiency  $\pi_{d \max} = 0.95$   
*Kecekapan ram diffuser  $\pi_{d \max} = 0.95$*

Burner pressure ratio  $\pi_b = 0.98$   
*Nisbah tekanan kebuk pembakaran  $\pi_b = 0.98$*

Nozzle pressure ratio  $\pi_N = 0.98$   
*Nisbah tekanan muncung  $\pi_N = 0.98$*

Polytrophic efficiency compressor  $e_c = 0.9$   
*Kecekapan politropik kompresor  $e_c = 0.9$*

Polytrophic efficiency turbine  $e_t = 0.9$   
*Kecekapan politropik turbin  $e_t = 0.9$*

Mechanical efficiency transmission  $\eta_m = 0.97$   
*Kecekapan tranmisi mekanik  $\eta_m = 0.97$*

Low pressure compressor ratio  $\pi_{Lpc} = 5.0$   
*Nisbah kompresor tekanan rendah  $\pi_{Lpc} = 5.0$*

Flight Mach number  $M_\infty = 0.85$   
*Nombor Mach terbang  $M_\infty = 0.85$*

Rate of mass flow  $\bar{m} = 50 \text{ kg/saat}$

*Laju aliran jisim  $\bar{m} = 50 \text{ kg/saat}$*

Flight ambient temperature  $T_\infty = 262^\circ \text{ K}$

*Suhu terbang sekitar  $T_\infty = 262^\circ \text{ K}$*

Flight ambient pressure  $P_\infty = 61.6 \text{ Kpa}$

*Tekanan terbang sekitar  $P_\infty = 61.6 \text{ Kpa}$*

The nozzle of turbo jet engine expanded the jet flow to the pressure ambient.

*Nozzle mesin turbo jet menghasilkan ekspansi gas dengan tekanan menuju ke ke tekanan ambient.*

$$\frac{P_9}{P_\infty} = 1$$

Find:

*Tentukan:*

- (i) Fuel air ratio  $f$   
*Nisbah bahan bakar – udara  $f$*
- (ii) The Mach number at the exit of primary nozzle  $M_9$   
*Nombor Mach saat keluar dari nozzle utama  $M_9$*
- (iii) The thrust of aircraft engine  $F$   
*Daya dorong mesin pesawat  $F$*
- (iv) If the after burner is added with the after burner temperature limitation  $T_{T7} = 2400^\circ \text{ K}$ , after burner pressure ratio  $\pi_{AB} = 0.98$  and after burner efficiency  $\eta_{AB} = 0.97$ . Determine the increase of specific thrust and fuel air ratio if the after burner was operated.

*Jika ditambahkan “after burner” dengan batasan suhu “after burner”  $T_{T7} = 2400^\circ \text{ K}$ , nisbah tekanan kebuk pembakaran  $\pi_{AB} = 0.98$  dan kecakapan after burner  $\eta_{AB} = 0.97$ . Tentukan kenaikan daya tujah spesifik dan nisbah bahan bakar – jika selepas pembakar beroperasi.*

**(25 marks/markah)**

5. An airplane flight at altitude of 4000 m above sea level. This airplane used a turbo fan engine with the engine component data as follows :

*Suatu pesawat terbang pada ketinggian 4000 m di atas permukaan laut. Pesawat tersebut menggunakan kipas turbin dengan data-data komponen mesin sebagai berikut :*

Temperature Turbine limitation  $T_{t4} = 1800^{\circ} \text{K}$   
*Batasan suhu turbin  $T_{t4} = 1800^{\circ} \text{K}$*

Fuel Heating value  $h_{pr} = 42798.4 \text{ kJ/kg}$   
*Nisbah panas bahan bakar  $h_{pr} = 42798.4 \text{ kJ/kg}$*

Coefficient heat ratio of cold air  $\gamma_c = 1.4$   
*Nisbah haba untuk udara sejuk  $\gamma_c = 1.4$*

Coefficient heat ratio of hot air  $\gamma_t = 1.30$   
*Nisbah haba untuk udara panas  $\gamma_t = 1.096$*

Heat coefficient at constant pressure of cold air  $C_{pc} = 1004 \text{ (J/(kg } ^{\circ}\text{K))}$   
*Pemalar haba pada tekanan tetap udara sejuk  $C_{pc} = 1004 \text{ (J/(kg } ^{\circ}\text{K))}$*

Heat coefficient at constant pressure of hot air  $C_{pt} = 1239 \text{ (J/(kg } ^{\circ}\text{K))}$   
*Pemalar haba pada tekanan tetap udara panas  $C_{pt} = 1239 \text{ (J/(kg } ^{\circ}\text{K))}$*

Ram diffuser efficiency  $\pi_{d_{max}} = 0.95$   
*Kecekapan ram diffuser  $\pi_{d_{max}} = 0.95$*

Burner pressure ratio  $\pi_b = 0.96$   
*Nisbah tekanan kebuk pembakaran  $\pi_b = 0.96$*

Nozzle pressure ratio  $\pi_N = 0.98$   
*Nisbah tekanan muncung  $\pi_N = 0.98$*

Nozzle's Fan pressure ratio  $\pi_{FN} = 0.98$   
*Nisbah tekanan muncung kipas  $\pi_{FN} = 0.98$*

Polytropic efficiency compressor  $e_c = 0.9$   
*Kecekapan politropik kompresor  $e_c = 0.9$*

Polytropic efficiency turbine  $e_t = 0.9$   
*Kecekapan politropik turbin  $e_t = 0.9$*

Polytropic efficiency fan  $e_f = 0.9$   
*Kecekapan politropik kipas  $e_f = 0.9$*

Mechanical efficiency transmission  $\eta_m = 0.99$   
*Kecekapan tranmisi mekanik  $\eta_m = 0.99$*

Low pressure compressor ratio  $\pi_{Lpc} = 5.0$

*Nisbah kompresor tekanan rendah  $\pi_{Lpc} = 5.0$*

High pressure compressor ratio  $\pi_{Hpc} = 4.0$

*Nisbah kompresor tekanan tinggi  $\pi_{Hpc} = 4.0$*

Pressure fan ratio  $\pi_f = 2.0$

*Nisbah tekanan kipas  $\pi_f = 2.0$*

Pressure compressor ratio  $\pi_c = \pi_{Lpc} \times \pi_{Hpc} = 20$

*Nisbah tekanan kompresor  $\pi_c = \pi_{Lpc} \times \pi_{Hpc} = 20$*

By pass ratio "  $\alpha = 4.0$

*Nisbah "by pass"  $\alpha = 4.0$*

Flight Mach number  $M_\infty = 0.85$

*Nombor Mach terbang  $M_\infty = 0.85$*

Rate of mass flow  $\bar{m} = 40 \text{ kg/saat}$

*Laju aliran jisim  $\bar{m} = 40 \text{ kg/saat}$*

Flight ambient temperature  $T_\infty = 262^0 \text{ K}$

*Suhu terbang sekitar  $T_\infty = 262^0 \text{ K}$*

Flight ambient pressure  $P_\infty = 61.6 \text{ Kpa}$

*Tekanan terbang sekitar  $P_\infty = 61.6 \text{ Kpa}$*

Both primary and secondary nozzle expanded the jet flow to the pressure ambient.

*Kedua-dua nozzle baik untuk yang pertama maupun yang kedua menghasilkan ekspansi gas dengan tekanan menuju ke tekanan ambient.*

$$\frac{P_2}{P_\infty} = 1 \quad \text{and} \quad \frac{P_{19}}{P_\infty} = 1$$

Find:

*Tentukan:*

- (i) Temperature turbine ratio  $\tau_t$   
*Nisbah suhu turbin  $\tau_t$*
- (ii) The Mach number at the exit of primary nozzle  $M_9$   
*Nombor Mach saat keluar dari nozzle utama  $M_9$*
- (iii) The Mach number at the exit of primary nozzle  $M_{19}$   
*Nombor Mach saat keluar dari nozzle kedua  $M_{19}$*
- (iv) Fuel air ratio  $f$   
*Bahan bakar – udara  $f$*
- (v) The thrust of aircraft engine  $F$   
*Daya dorong mesin pesawat  $F$*
- (vi) Explain what it does it mean with the by pass ratio  $\alpha$   
*Terangkan apa yang dimaksudkan dengan nisbat pirau  $\alpha$*

**(25 marks/markah)**

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