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]

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 δ_1 is equal to 5^0, while the wedge upper side angle δ_2 is equal 3^0 . 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 $T_1 = 300^0$ K

Rajah S1(a) *memperlihatkan skematik diagram dari aliran supersonik melalui bagian inlet. Sudut baji bahagian bawah δ_1 sama dengan 5^0 dan sudut baji bahagian atas δ_2 sama dengan 3^0. 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 $T_1 = 300^0$ K*

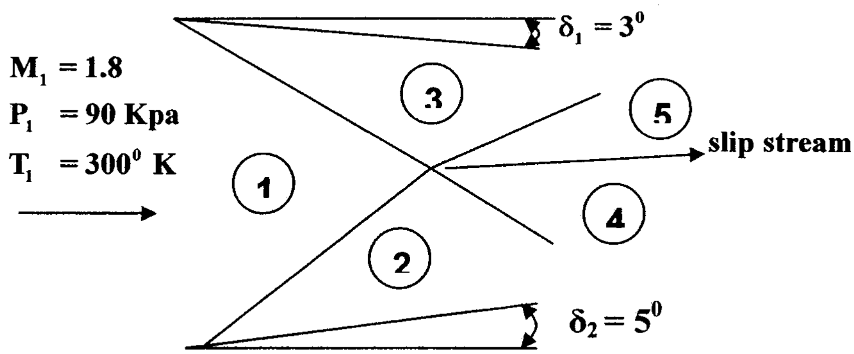

Figure Q1(a) Flow pass through inlet/*Rajah S1(a) Aliran melalui inlet*

Other air properties :
Sifat sifat udara lainnya:

Universal gas constant $R = 287$ J/(Kg ^{0}K)
Pemalar gas semesta $R = 287$ *J/(Kg* ^{0}*K)*

Heat coefficient at constant pressure $c_p = 1004$ J/(Kg ^{0}K)
Pemalar panas pada tekanan tetap $c_p = 1004$ *J/(Kg* ^{0}*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→ 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→ 2 dapat dianggap sebagai aliran dengan interaksi panas . Aliran dari stesen 2 ke 3 sebagai aliran isentropik melalui saluran dengan penambang 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→ 2 is 300 KJ/Kg
Penambahan panas kedalam stesen 1→ 2 : 300 KJ/Kg

Duct cross section area :
Keluasan penampang saluran :

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

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

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

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

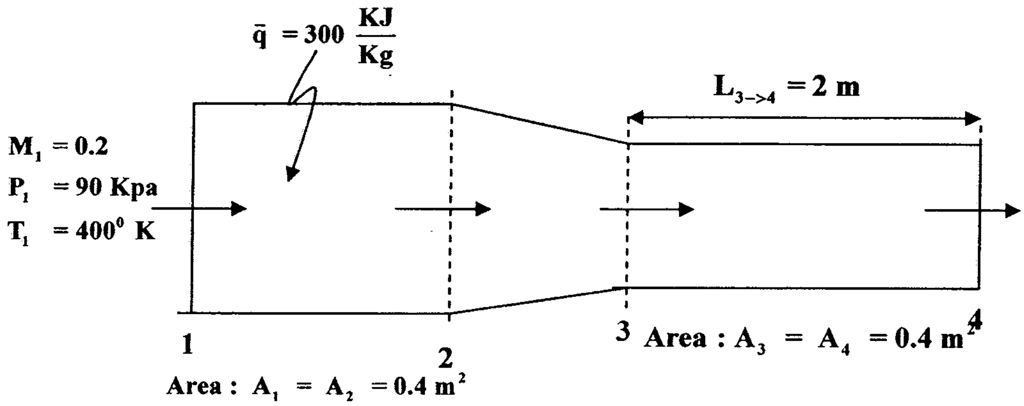

Figure Q1(b) Flow pass through a duct/*Rajah S1(b) Aliran melalui saluran*

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 ρ_4.
Nombor Machr M_4 , tekanan statik P_4 dan ketumpatan ρ_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:

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

where:
di mana:

Cp : Heat coefficient at constant pressure
Cp : Pemalar panas pada tekanan tetap

To : Free stream temperature
To : Suhu udara aliran bebas

h_{pr} : Fuel heating value
h_{pr} : *Nilai panas bahan bakar*

τ_λ : The ratio of the burner exit to the ambient enthalpy
τ_λ : *Nisbah entalpi "burner exit" terhadap entalpi persekitaran*

τ_r : The temperature ratio of the free stream
τ_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_∞ is equal to :

Buktikan bahawa daya dorong maksimum untuk ram jet ideal terjadi apabila nombor Mach M_∞ adalah sama dengan :

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

where:
di mana :

M_∞ : Free flow Mach number
M_∞ : *Nombor Mach aliran bebas*

τ_λ : The ratio of the burner exit to the ambient enthalpy
τ_λ : *Nisbah entalpi "burner exit" terhadap entalpi persekitaran*

γ : Coefficient heat ratio
γ : *Nisbah pemalar panas*

(10 marks/*markah*)

(c) A Cruise missile powered by ram jet engine flight at the mach number M_∞ =2.4. Assume that the ram jet engine works as an ideal engine. The turbine temperature limitation $T_{T4} = 1600^0K$. 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_∞ = 2.4. Anggap sebagai ram jet ideal. Batasan Suhu turbin T_{T4} = 1600 ^0K. 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 (J/(kg ^0K))
Pemalar panas pada tekanan tetap C_p = 1004 (J/(kg ^0K))

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

Fuel Heating value h_{pr} = 42798.4 kJ/kg
Nisbah panas bahan bakar h_{pr} = 42798.4 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 :

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

where:
di mana :

Cp : Heat coefficient at constant pressure
Cp : Pemalar panas pada tekanan tetap

To : Free stream temperature
To : Suhu udara aliran bebas

h_{pr} : Fuel heating value
h_{pr} : Nilai panas bahan bakar

τ_λ : The ratio of the burner exit to the ambient enthalpy
τ_λ : Nisbah entalpi "burner exit" terhadap entalpi persekitaran

τ_r : The ratio of free stream temperature.
τ_r : Nisbah suhu aliran bebas

τ_c ; The ratio of compressor temperature
τ_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 airpane 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 haluju nombor Mach M_∞ = 0.6 di atas paras laut.

The data turbo jet engine:
Data engin 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 π_c = **16**
Nisbah kompresor tekanan π_c = **16**

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

Flight ambient pressure P_∞ = 61.6 Kpa
Tekanan terbang sekitar P_∞ = 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 ^{0}K))
Pemalar panas pada tekanan tetap C_p = 1004 (J/(kg ^{0}K))

Using an ideal cycle analysis determined :
Dengan menggunakan analisis putaran ideal tentukan :

(i) Specific thrust
Daya tujah specifik

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

Fuel Heating value $h_{pr} = 42798.4$ kJ/kg
Nisbah panas bahan bakar $h_{pr} = 42798.4$ *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 $C_{pc} = 1004$ (J/(kg ^{0}K))
Pemalar haba pada tekanan tetap udara sejuk $C_{pc} = 1004$ *(J/(kg* ^{0}*K))*

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

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

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 r $e_t = 0.9$
Kecekapan politropik turbin r $e_t = 0.9$

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

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

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

Rate of mass flow $\overline{m}$ = **50 kg/saat**
Laju aliran jisim $\overline{m}$ = **50 kg/saat**

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

Flight ambient pressure P_∞ = 61.6 Kpa
Tekanan terbang sekitar P_∞ = *61.6 Kpa*

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

Nozzle mesin turbo jet menghasilkan eskpansi 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 $T_{T7} = 2400^0$ K , after burner pressure ratio $\pi_{AB} = 0.98$ and after burner efficiency $\eta_{AB} = 0.97$. Determine the increase of specifc thrust and fuel air ratio if the after burner was operated.

Jika ditambahkan "after burner" dengan batasan suhu "after burner " $T_{T7} = 2400^0$ *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 – f jika selepas pembakar beroperasi.*

(25 marks/*markah*)

5. An airplane fligt 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} = 1800^0 K
Batasan suhu turbin T_{t4} = 1800^0 *K*

Fuel Heating value h_{pr} = 42798.4 kJ/kg
Nisbah panas bahan bakar h_{pr} = *42798.4 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 (J/(kg ^{0}K))
Pemalar haba pada tekanan tetap udara sejuk C_{pc} = *1004 (J/(kg* ^{0}*K))*

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

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

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 $\pi_{FN} = 0.98$

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

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

Polytrophic 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 $\pi_C = \pi_{Lpc} \text{ x } \pi_{Hpc} = 20$
Nisbah tekanan kompresor $\pi_C = \pi_{Lpc} \text{ x } \pi_{Hpc} = 20$

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

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*

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

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

$$\frac{P_9}{P_\infty} = 1 \quad \text{and} \quad \frac{P_{19}}{P_\infty} = 1$$