Second Semester Examination
2018/2019 Academic Session

June 2019

ESA344 – Propulsion Systems
[Sistem Dorongan]

Duration : 2 hours
(Masa : 2 jam)

Please check that this examination paper consists of **ELEVEN (11)** pages of printed material before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **SEBELAS (11)** muka surat yang bercetak sebelum anda memulakan peperiksaan ini].*

Instructions : Answer **FOUR (4)** questions. **All questions are COMPULSORY**.

*[**Arahan** : Jawab **EMPAT (4)** soalan. **Semua soalan WAJIB dijawab.**]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].

1. The following are the design parameters of a turbojet engine

Compressor pressure ratio	16
Compressor and turbine efficiencies	0.86
Combustor pressure loss (% of CDP)	5
Mass flow entering compressor	100 kg/s
TET	1500 K
FCV	43 MJ/kg

Given:

T_a=288K, P_a=101kPa

Cold (compressors and heat exchangers) C_p and γ: 1000 J/kg/K and 1.4 respectively
Hot (combustors, turbines and reheat) C_p and γ: 1150 J/kg/K and 1.333 respectively
Turbomachinery efficiencies are isentropic.

(a). Calculate thrust and SFC of the turbojet fitted with a convergent nozzle.

(16 marks)

(b). In actual process, losses in engine components can happen due to a friction drag. Draw T-s diagram comparing ideal and actual process. Discuss how these losses may affect engine components particularly compressor, combustion chamber and turbine.

(9 marks)

2. (a). What is meant by “Thermal NOx and “Fuel Bond NOx” ? What are the factors that govern the production of thermal NOx?

(10 marks)

(b). In a gas turbine combustor, a large amount of Carbon Monoxide (CO) is formed due to lack of oxygen to complete the combustion. Discuss factors that may cause the above situation and suggest **TWO** approaches to reduce the production of CO.

(10 marks)

(c). Discuss how fuel properties will influence smoke formation.

(5 marks)

3. A propeller-piston engine propulsion system design for an aircraft has the following parameters:

Aircraft maximum takeoff mass	1200 kg (1 N = 0.2248 lb)
Required design for climbing at angle, θ	22 degrees
Maximum propeller RPM allowed, $PRpm_{max}$	3100
Propeller efficiency, η_{prop}	0.83

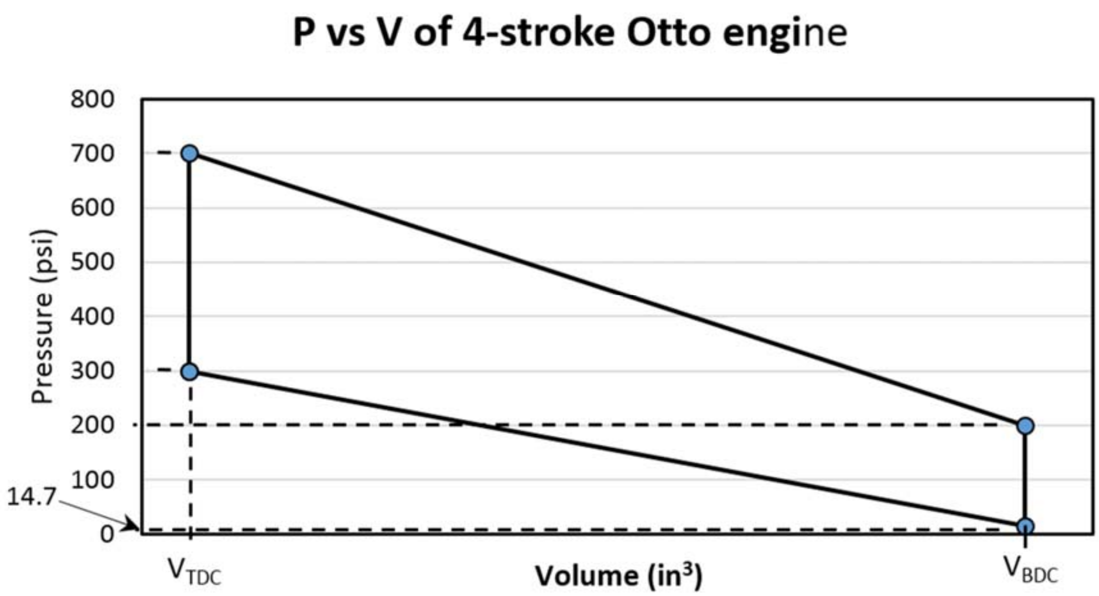
Assume:

- during takeoff, the aircraft climbs at constant velocity, v,
- the aircraft’s lift force, $L = 0.2\ v^2$
- the aircraft’s drag force, $D = 0.03\ v^2$,

where L & D are in lb and v in knots (1 knot = 1.688 ft/s)

The aircraft's engine is a 4-stroke, 4-cylinder reciprocating engine. Its parameters and P–V diagram are as follows:

Piston's bore diameter, b	5.5 in
Piston's stroke, s	4.95 in
V_{TDC}	7.127 in^3
V_{BDC}	124.7 in^3
Engine's Mechanical efficiency, η_{mech}	0.86



If the propeller's shaft is connected directly to the engine crankshaft (no gear reduction), does the propulsion system meet the requirements of the climbing maneuver? Show all calculations.

(20 marks)

4. The following test data was found by launching a prototype sea-skimming missile that is propelled by a solid rocket. Assume that the nozzle is optimized at sea-level and that the atmospheric pressure 101.325 kPa.

Sea-level thrust (F_N): $8.0\ kN$	Characteristic velocity (C^*): $1200\ m/s$
Burning time (t_b): $15\ sec$	Ratio of specific heats of exhaust gas (γ): 1.3
Chamber pressure (P_C): $5.5\ MPa$	

(a). Determine:

(i). the ideal thrust coefficient $\left(C_F^{\circ}\right)$

(ii). the specific impulse $\left(I_{sp}\right)$

(iii). the mass flow rate of the exhaust gases $(\dot{m})$

(iv). the approximate total propellant weight

(22 marks)

(b). Determine:

(i). the total impulse (I_t)

(ii). the nozzle throat area (A^*)

(8 marks)

1. *Berikut merupakan parameter-parameter berkaitan untuk enjin turbojet:*

Nisbah tekanan pemampat	*16*
Kecekapan pemampat dan turbin	*0.86*
Kehilangan tekanan pembakar (% daripada CDP)	*5*
Aliran jisim	*100 kg/s*
TET	*1500 K*
FCV	*43 MJ/kg*

Diberi:

T_a=288K, P_a=101kPa

Sejuk (pemampat dan penukar haba) C_p *dan* γ*: masing-masing adalah: 1000 J/kg/K dan 1.4*
Panas (pembakar, turbin dan pemana.s semula) C_p *dan* γ*: masing-masing adalah: 1150 J/kg/K dan 1.333*
Kecekapan turbo mesin adalah seentropi

(a). *Kira daya tujahan dan SFC untuk turbojet yang dipasang dengan sebuah muncung tumpu.*

(16 markah)

(b). *Dalam proses yang sebenar, kehilangan dalam komponen enjin boleh berlaku disebabkan geseran daya seretan. Lukis gambarajah T-s yang membezakan proses ideal dan sebenar. Bincang bagaimana kehilangan ini boleh memberi kesan kepada komponen enjin terutamanya pemampat, kebuk pembakar dan turbin.*

(9 markah)

2. (a). *Apakah yang dimaksudkan dengan "Thermal NOx" dan "Fuel Bond NOx"? Apakah faktor-faktor yang terlibat dalam penghasilan "Thermal NOx"*

(10 markah)

(b). *Kekurangan oksigen dalam proses pembakaran menyebabkan peningkatan penghasilan Karbon Monoksida. Bincangkan faktor-faktor yang menyebabkan kejadian ini dan cadangkan* ***DUA*** *pendekatan yang boleh diaplikasikan dalam mengurangkan penghasilan Karbon Monoksida.*

(10 markah)

(c). *Bincangkan bagaimana sifat-sifat minyak boleh memberi kesan terhadap penghasilan asap.*

(5 markah)

3. *Berikut adalah maklumat rekabentuk sistem tujahan pesawat yang menggunakan enjin piston-kipas:*

Jisim pesawat semasa berlepas	1200 kg (1 N = 0.2248 lb)
Kebolehan mendaki pada sudut, θ	22 darjah
RPM maksimum kipas yang dibenarkan, $PRpm_{max}$	3100
Kecekapan kipas, η_{prop}	0.83

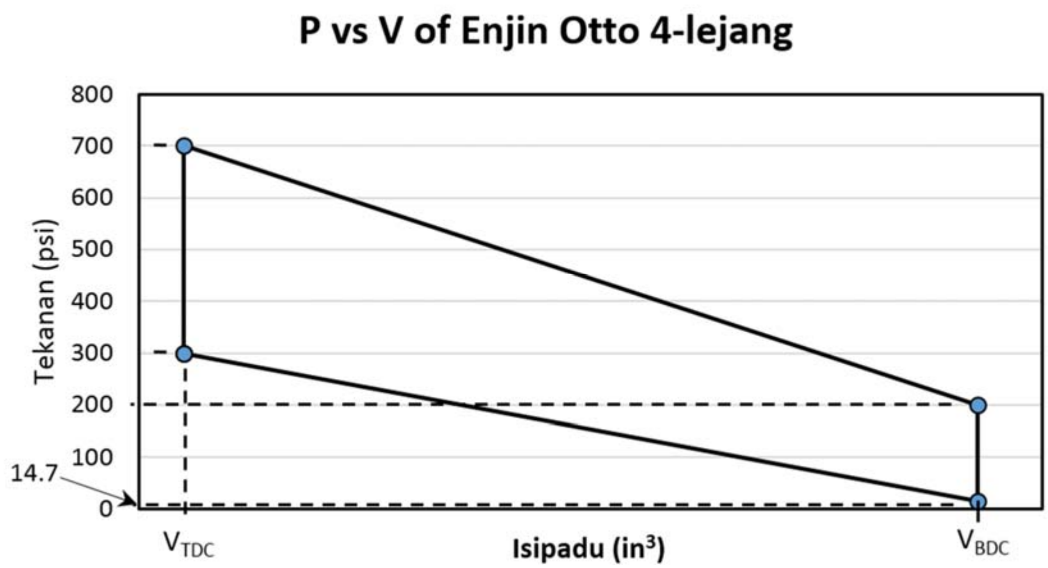
Anggapan:

- *pesawat mendaki pada laju seragam*, *v,*
- *daya angkat pesawat,* $L = 0.2\ v^2$,
- *daya seret pesawat,* $D = 0.03\ v^2$,

di mana L & D dalam lb dan v dalam knots (1 knot = 1.688 ft/s)

Enjin pesawat adalah enjin salingan 4-lejang, 4-silinder. Parameter dan rajah P-V adalah seperti berikut:

Garispusat lubang omboh, b	*5.5 in*
Strok piston, s	*4.95 in*
V_{TDC}	*7.127 in*^{3}
V_{BDC}	*124.7 in*^{3}
Kecekapan mekanikal enjin, η_{mech}	*0.86*



Jika aci kipas disambung terus ke aci-engkol enjin (tiada pengurangan gear), adakah sistem tujahan memenuhi keperluan misi pesawat untuk mendaki? Tunjukkan semua pengiraan.

(20 markah)

4. *Data uji berikut diperolehi setelah melancarkan prototaip peluru berpandu laut yang digerakkan oleh roket pepejal. Anggapkan bahawa muncung dioptimumkan di paras laut dan tekanan atmosfera 101.325 kPa.:*

Teras paras laut $(F_N): 8.0\ kN$	*Halaju ciri* $(C^*): 1200\ m/s$
Masa pembakaran $(t_b): 15\ sec$	*Nisbah haba spesifik gas ekzos* $(\gamma): 1.3$
Tekanan kebuk $(P_C): 5.5\ MPa$	

(a). *Tentukan:*

(i). *pekali teras ideal* $\left(C_F^{\circ}\right)$

(ii.) *impuls tertentu* $\left(I_{sp}\right)$

(iii). *kadar alir jisim gas ekzos* $(\dot{m})$

(iv). *anggaran berat keseluruhan bahan dorongan*

(*22 markah*)

(b). *Tentukan:*

(i). *jumlah impuls* (I_t)

(ii.) *kawasan leher muncung* (A^*)

(*8 markah*)

APPENDIX 1/ *LAMPIRAN 1*

List of Equations

Gas Turbine Engine Propulsion

$$\frac{T_y}{T_x} = \left[1 + \frac{\left(\frac{P_y}{P_x}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\eta_c} \right]$$

$$work = \dot{m} C_p \Delta T$$

$$combustor\ losses = \frac{\Delta P_{xy}}{P_x}$$

$$\dot{m}_0 C_{pc}(T_x) + \dot{m}_f FCV = (\dot{m}_0 + \dot{m}_f) C_{ph} T_y\ ,$$

where $\dot{m}_f$ is fuel mass flow, $\dot{m}_0$ is mass flow entering compressor, and FCV is fuel caloric value

$$\frac{P_y}{P_x} = \left[1 - \frac{1 - \frac{T_y}{T_x}}{\eta_T} \right]^{\frac{\gamma}{\gamma-1}}$$

$$\frac{P_x}{p_x} = \left(1 + \frac{\gamma - 1}{2} M^2 \right)^{\frac{\gamma}{\gamma-1}}$$

$$\frac{T_x}{t_x} = \left(1 + \frac{\gamma - 1}{2} M^2 \right)$$

$$V_j = \sqrt{\gamma R t_x}$$

$$p = \rho R t$$

$$\dot{m} = \rho A V$$

$$F_N = \dot{m}(V_j - V_0) + A_N(p_N - p_0)$$

$$Specific\ fuel\ consumption, SFC = \frac{Fuel\ flow\ rate}{thrust} = \frac{\dot{m}_f}{F_N}$$

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

Propeller-Piston Engine Propulsion

$$Power = Thrust\ \times velocity = Tv$$

$$Indicated\ mean\ effective\ Pressure\ (IMEP), P = \frac{net\ work}{volume\ change} = \frac{W_{net}}{V_{BDC} - V_{TDC}}$$

$$Indicated\ power, IP = PLANK$$

where

P = Indicated mean effective pressure

L = Length of the stroke

A = Area of the piston head or cross-sectional area of the cylinder

N = Number of power strokes per minute

$$\left(rpm\ if\ 2\ stroke\ \& \frac{rpm}{2}\ if\ 4\ stroke\right)$$

K = Number of cylinders

Rocket Engine Propulsion

$$C_F^{\circ} = \sqrt{\frac{2\gamma^2}{(\gamma-1)}\left[\frac{2}{\gamma+1}\right]^{\frac{\gamma+1}{\gamma-1}}\left[1 - \left(\frac{P_e}{P_c}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

$$C^* C_F = \frac{P_C A^*}{\dot{m}} \frac{F_N}{P_C A^*}$$

$$\frac{F_N}{\dot{m}} = V_{eff} = I_{sp} g$$

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