Second Semester Examination
2017/2018 Academic Session

May/June 2018

ESA344/2 – Propulsion Systems
[Sistem Dorongan]

Duration : 2 hours
Masa: 2 jam

Please check that this paper contains **FOURTEEN (14)** printed pages included **THREE (3)** pages appendix and **FOUR (4)** questions before you begin the examination.

*[Sila pastikan bahawa kertas soalan ini mengandungi **EMPATBELAS (14)** mukasurat bercetak termasuk **TIGA (3)** mukasurat lampiran dan **EMPAT (4)** soalan sebelum anda memulakan peperiksaan.]*

Instructions : Answer **ALL** questions.

[Arahan *: Jawab **SEMUA** soalan].*

Appendix/*Lampiran*:

1. Appendix A : List of Equations. [**3 pages**/*mukasurat*]
   [*Lampiran A : Senarai Persamaan].*

You may answer the questions either in **English** or **Bahasa Malaysia**.

*[Calon boleh menjawab soalan dalam **Bahasa Inggeris** atau **Bahasa Malaysia**.]*

Answer to each question must begin from a new page.

[Jawapan untuk setiap soalan mestilah dimulakan pada mukasurat yang baru].

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. 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.

The following are the design parameters of a single shaft gas turbine at ISASLS:

Table 1: Engine Parameters

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

[a] Calculate the thrust and SFC of a turbojet fitted with the above gas generator and a convergent nozzle.

(15 marks)

[b] Make a sketch of a turbojet engine fitted with the above gas generator if reheat chamber is incorporated into the system. Draw a T-s diagram of the engine indicating clearly each component and explain on the process and advantage of the system.

(8 marks)

[c] List down TWO (2) situations why we need thrust augmentation.

(2 marks)

2. [a] Smoke is the most obvious pollutant from gas turbine engines because it can be seen with the naked eye. Smoke is generated in any part of the combustion zone where mixing is inadequate. Fuel properties is one of the main controlling factors for soot and smoke formation. The properties of **Fuel A** and **Fuel B** are given to you. By comparing their properties, discuss how they can influence the soot formation. Based on your discussion, select which fuel forms less soot and justify your answer.

Fuel A
Viscosity: 8 mm^2/sec
Boiling point: 513.75 K
Aromatics content by volume: 20%

Fuel B
Viscosity: 4.37mm^2/sec
Boiling point: 623.00 K
Aromatics content by volume: 31.9%

(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 that yield to the reduction in CO.

(10 marks)

[c] Discuss the mechanisms involved with the production of nitrogen oxides, and how these provide an insight as to how future low emissions combustors should be designed

(5 marks)

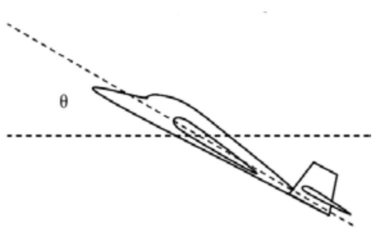
3. A propeller-piston engine propulsion system design for an aircraft has the following details:

Aircraft parameter	Value
Aircraft maximum takeoff weight	2536 lb
Required design for climbing at angle, θ	30 degree
Maximum propeller RPM allowed, $PRpm_{max}$	3000
Propeller efficiency, η_{prop}	0.86

Assume:

- during takeoff aircraft climb at constant velocity, v
- aircraft lift force, $L = 0.57\ v^2$
- aircraft drag force, $D = 0.086\ v^2$

where L & D in lb and v in ft/s

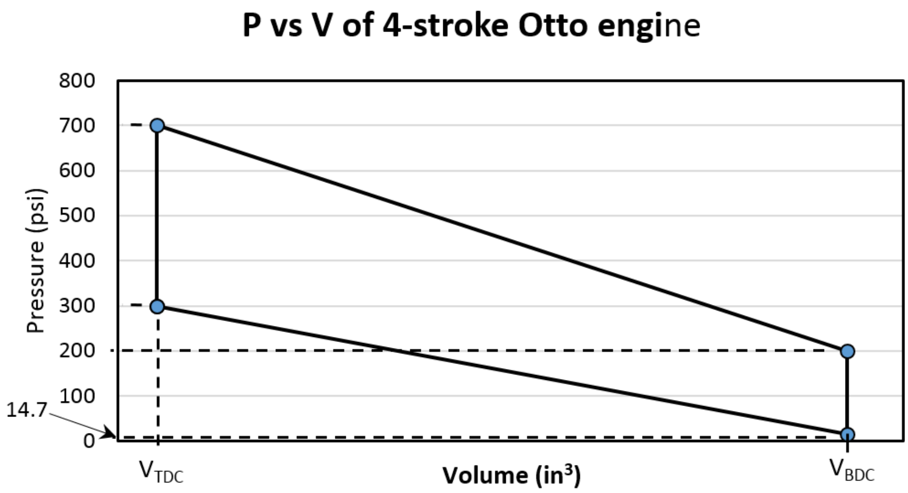


The aircraft's engine specifications:

4-stroke, 4-cylinder and its P-V diagram is shown below

Aircraft engine parameter	Value
Piston bore diameter, b	5.5 in
Piston stroke, s	4.5 in
V_{TDC}	7.0 in^3
V_{BDC}	130.0 in^3
Engine Mechanical efficiency, η_{mech}	0.85

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



(20 marks)

4. The first stage of a two-stage medium lift launch rocket must accelerate Stage 2 and its payload to a velocity of 3400 m/s. Assume that the first stage follows a vertical trajectory where drag and variations in gravity can be neglected and that the initial mass of the second stage and payload is 370,000 kg. Also assume that the maximum allowable acceleration during this phase of the launch is 5 g's. In addition, use the following data regarding the first stage rocket:

Fuel = H_2 (specific gravity=0.08);
Oxidizer = O_2 (specific gravity=1.14);
Fuel-Oxidizer mixture = 3 kg of O_2 per kg of H_2;
I_{sp} = 400 s; $\Lambda = m_o/m_f = 4$;
Tanks mass = 3% of propellant mass;
Structure mass (excluding tanks) = 3 x 10^{-4} kg per Newton of takeoff thrust;
Guidance equipment mass = 300 kg;
Propellant tanks L-to-D ratio = 8-to-1;

Considering a constant thrust rocket :

[a] Find mass of :

(i) oxidizer of stage 1

(ii) fuel of stage 1

(iii) tanks of stage 1

(iv) structure mass (excluding tanks) of stage 1

(v) entire vehicle at liftoff

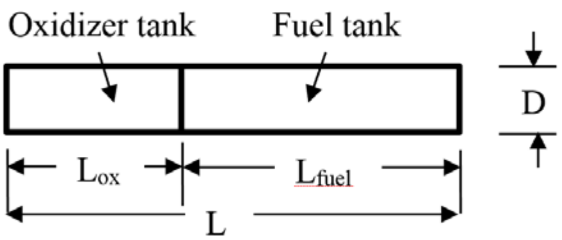
Find:

(vi) takeoff thrust of stage 1.

(18 marks)

[b] Find lengths (L_{fuel} and L_{ox}) and diameter, D of the fuel and oxidizer tanks of stage 1 (assume both tanks have the same diameters – see figure below).

(8 marks)



[c] Find:

(i) time to burnout of stage 1

(ii) altitude at burnout of stage 1.

(4 marks)

1. *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 pemanas semula) C_p dan γ masing-masing adalah: 1150 J/kg/K dan 1.333.
Kecekapan turbo mesin adalah seentropi.

Berikut merupakan parameter-parameter berkaitan untuk rekabentuk sebuah penjana gas dua kili ketika ISASLS:

Jadual 1: Parameter Janakuasa

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

[a] *Kira daya tujahan dan SFC untuk turbojet yang dipasang dengan jentera gas seperti di atas dan sebuah muncing tumpu.*

(15 markah)

[b] *Lukiskan lakaran enjin jet yang dipasang dengan gabungan jentera gas di atas dan pemanas semula. Lukiskan gambarajah T-s untuk enjin tersebut dan tunjukkan secara jelas setiap komponen dan bincangkan tentang proses dan kebaikan sistem tersebut*

(8 markah)

[c] *Senaraikan DUA (2) situasi "Thrust Augmentation" diperlukan*

(2 markah)

2. [a] *Asap merupakan bahan cemar yang sangat jelas kerana ia dapat dilihat dengan mata kasar. Asap terhasil di dalam kebuk pembakar yang mengalami pembakaran yang tidak mencukupi. Sifat-sifat minyak merupakan salah satu faktor penyebab penghasilan asap. Sifat-sifat **Minyak A** dan **Minyak B** adalah seperti di bawah. Berdasarkan maklumat yang diberi, bincangkan bagaimana sifat-sifat ini mempengaruhi penghasilan asap. Berdasarkan hasil perbincangan pilih minyak yang menghasilkan kurang asap dan pertahankan jawapan anda*

Minyak A

Kelikatan: 8 mm^2/sec

Takat didih: 513.75 K

Kandungan aromatik: 20%

Minyak B

Kelikatan: 4.37mm^2/sec

Takat didih: 623.00 K

Kandungan aromatik: 31.9

(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 daripada kebuk pembakaran gas turbin.*

(10 markah)

[c] *Bincangkan mekanisma yang terlibat dalam penghasilan nitrogen oksida, dan bagaimana ini boleh memberikan idea tentang penghasilan kebuk pembakar rendah bahan tercemar.*

(5 markah)

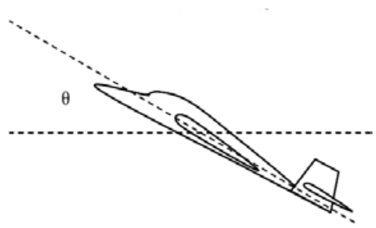
3. *Berikut adalah maklumat rekabentuk sistem tujahan pesawat yang menggunakan enjin piston-kipas:*

Parameter pesawat	*Nilai*
Berat pesawat semasa berlepas	*2536 lb*
Kebolehan mendaki pada sudut, θ	*30 degree*
RPM maksimum kipas yang dibenarkan, $PRpm_{max}$	*3000*
Kecekapan kipas, η_{prop}	*0.86*

Anggapan:

- *pesawat mendaki pada laju seragam*, *v*
- *daya angkat pesawat,* $L = 0.57\,v^2$
- *daya seret pesawat,* $D = 0.086\,v^2$

di mana L & D dalam lb dan v dalam ft/s

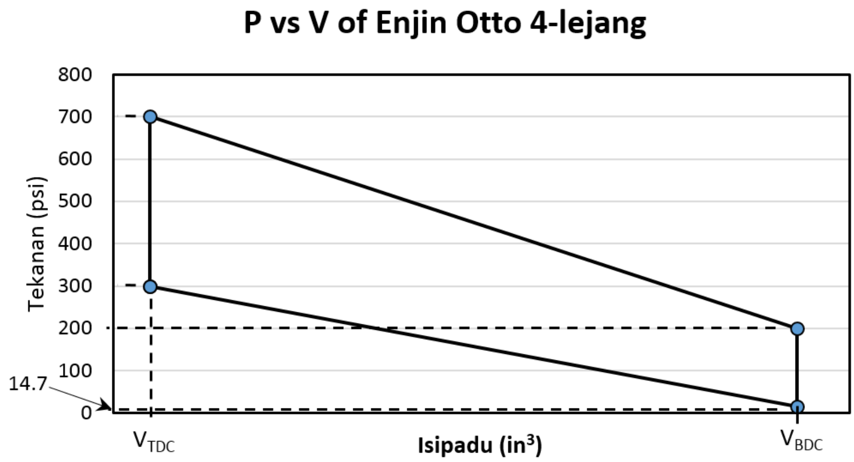


Spesifikasi enjin pesawat:

4-lejang, 4-silinder dan rajah P-V *nya adalah di bawah*

Parameter engin pesawat	*Nilai*
Garispusat lubang omboh,, b	*5.5 in*
Strok piston, s	*4.5 in*
V_{TDC}	$7.0\ in^3$
V_{BDC}	$130.0\ in^3$
Kecekapan mekanikal enjin, η_{mech}	*0.85*

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



(20 markah)

4. *Fasa pertama daripada dua fasa sebuah roket daya tujah sederhana harus memecut fasa 2 dan muatan kepada halaju 3400 m/s. Anggap fasa pertama mempunyai pergerakan menegak dan abaikan daya rintangan dan graviti serta anggap jisim asal fasa kedua dan muatannya adalah 370,000 kg. Juga anggap kadar pecutan maksima yang dibenarkan semasa fasa pelancaran adalah 5 g serta menggunakan data-data berikut berkaitan roket fasa pertama:*

Bahan api = H_2 (graviti tentu=0.08);
Pengoksida = O_2 (graviti tentu =1.14);
Campuran Bahan api-Pengoksida = 3 kg O_2 per kg H_2;
I_{sp} = 400 s; $\Lambda = {}^{m_o}/_{m_f} = 4$;
Jisim tangki = 3% dari jisim bahan-dorongan;
Jisim struktur (selain tangki) = 3 x 10^{-4} kg per Newton tujahan berlepas;
Jisim alatan panduan = 300.0 kg;
Nisbah tangki bahan-dorongan L-*kepada*-D = *8-kepada-1;*

Andainya roket menghasilkan daya tujah yang seragam:

[a] *Kira jisim:*

(i) *pengoksida fasa 1*

(ii) *bahan api fasa 1*

(iii) *tangki fasa 1*

(iv) *struktur (selain tangki) fasa 1*

(v) *keseluruhan kenderaan semasa pelancaran*

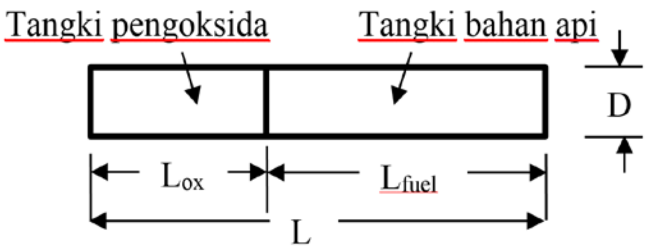
Kira:

(vi) *daya tujah fasa 1 semasa pelancaran.*

(18 markah)

[b] *Kira panjang (L_{fuel} dan L_{ox}) dan diameter, D tangki bahan api dan pengoksida fasa 1 (anggap semua tangki berdiameter sama - lihat gambar di bawah).*

(8 markah)



[c] *Kira:*

(i) *masa untuk melengkapkan pembakaran fasa 1*

(ii) *ketinggian ketika pembakaran fasa 1 lengkap.*

(4 markah)

APPENDIX/*LAMPIRAN*

Appendix A: List of Equations.

Gas Turbine Engine Propulsion

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

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

$$combustor\ losses = \frac{\Delta P_{34}}{P_3}$$

$\dot{m}_0 C_p(T_3) + \dot{m}_f FCV = (\dot{m}_0 + \dot{m}_f)C_p T_4$, where $\dot{m}_f$ is fuel mass flow

$$\frac{P_5}{P_4} = \left[1 - \frac{1 - \frac{T_5}{T_4}}{\eta_T}\right]^{\frac{\gamma}{\gamma-1}}$$

$$\frac{P_6}{p_6} = \left(1 + \frac{\gamma - 1}{2}M^2\right)^{\frac{\gamma}{\gamma-1}}$$

$$\frac{T_6}{t_6} = \left(1 + \frac{\gamma - 1}{2}M^2\right)$$

$$V_j = \sqrt{\gamma R t_6}$$

$$p = \rho RT$$

$$\dot{m} = \rho AV$$

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

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

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

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

$$c \ = \ I_{sp}\ g_o$$

$$\Lambda \ = \frac{m_o}{m_f}$$

$$n_{max} = \frac{a_{max}}{g_o}$$

$$Constant\ thrust\ trajaectory: \frac{\Delta v}{c} \ = \ln \Lambda - \frac{(\Lambda - 1)}{n_{max}}$$

$$Final\ mass\ of\ stage\ 1, m_f$$
$$= \ stage\ 2\ \&\ payload\ mass\ + stage\ 1\ guidance\ equip\ mass$$
$$+ stage\ 1\ tanks\ mass + stage\ 1\ structure\ mass\ (excluding\ tanks)$$

$$m_p \ = \ m_o - m_f \ = \ m_o\left(1 - \frac{m_f}{m_o}\right) = \ m_o\ (1 - \frac{1}{\Lambda})$$

$$\frac{F_o}{w_o} \ = \frac{(n_{max} + 1)}{\left(\frac{m_o}{m_f}\right)} = \frac{(n_{max} + 1)}{\Lambda}$$

$$where\ F_o\ =\ takeoff\ thrust\ \&\ w_o\ =\ m_o g_o$$

$$time\ to\ burnout,\ t_{bo}\ = \frac{I_{sp}}{\phi}\left(1 - \frac{1}{\Lambda}\right)$$

$$where\ \phi\ = \frac{n_{max} + 1}{\Lambda}$$

$$altitude\ of\ rocket\ at\ burnout, h_{bo}\ = g_o\left(-I_{sp} t_{bo}\frac{ln\ \Lambda}{\Lambda - 1} + I_{sp}\ t_{bo}\ - \frac{t_{bo}^2}{2}\right)$$

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