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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2018/2019

COURSE NAME	:	AIRCRAFT PROPULSION
COURSE CODE	:	BDU 20203
PROGRAMME	:	BDC/ BDM
EXAMINATION DATE	:	DECEMBER 2018/ JANUARY 2019
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **FOUR (4) QUESTIONS** FROM **SIX (6) QUESTIONS** AVAILABLE

THIS QUESTION PAPER CONSISTS OF **NINE (9)** PAGES

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Q1 (a) A typical theoretical PV diagram of a spark-ignition piston aerodynamics engine as shown in **Figure Q1(a)** will consist of four cycles which are the induction cycle, the compression-combustion cycle, the power cycle and the exhaust cycle. Based on the figure, identify processes involved in the compression-combustion cycle and power cycle. For each cycle, determine how the pressure, volume and temperature are determined.

(5 marks)

(b) A general aviation aircraft, equipped with a flat 4-piston, four-stroke engine is flying at 2,500 m with a speed of 26 m/s. At this altitude, the ambient temperature, pressure and density are 290 K, 74.7 kPa and 0.897 kg/m^3 respectively. The engine has a propeller with a diameter of 1.6 m. The recorder engine data are as follows:

Engine rotational speed	4,200 rpm
Swept and clearance volumes	3.534 x 10^{-3} m^3 and 4.712 x 10^{-4} m^3
The fuel heat transfer per unit kg, q	2,639.75 kJ/kg
Mechanical and propulsive efficiencies	85 % and 39 %

Analyse the engine performance to obtain:

(i) indicated power
(ii) shaft brake power
(iii) available power
(iv) thrust
(v) maximum static thrust

Take for air, $\gamma = 1.4$, C_V=0.718 kJ/kg and, R = 0.287 kJ/kg.K,

(20 marks)

Q2 (a) Gas turbine uses Brayton Cycle as their ideal cycle, which consists of four important sub-processes. Sketch the *P-V* and *T-S* diagrams and provide explanation of the sub-processes.

(5 marks)

(b) A gas turbine operates with a simple Brayton cycle consist of a compressor, burner and turbine as shown in **Figure Q2(b)**. The compressor inlet temperature is 250 K and the turbine entry temperature is 1,750 K. The compressor pressure ratio is 40 and the inlet mass flow is 90 kg/s. Analyse the engine performance to obtain:

(i) the compressor and turbine powers
(ii) thermal efficiency

Sketch the *T-S* diagram. Take for air, γ = 1.4, C_P =1.005 kJ/kg and, R = 0.287 kJ/kg.K.

(10 marks)

(c) A turbojet is powering a business jet flying at 6,300 m with a speed of 700 km/h. The ambient conditions at that altitude are 247 K and 45 kPa respectively. The inlet and outlet area of the engine are 0.4 m^2 and 0.45 m^2 respectively. The fuel to air ratio is 0.023 while the nozzle exit pressure and velocity are 270 kPa and 670 m/s respectively. Analyse the engine performance to obtain:

(i) pressure thrust
(ii) momentum drag
(iii) momentum thrust
(iv) gross thrust
(v) net thrust

Sketch the *T-S* diagram. Take for air, γ = 1.4, C_P =1.005 kJ/kg and, R = 0.287 kJ/kg.K.

(10 marks)

Q3 (a) **Figure Q3(a)** provides the variation of pressures and temperatures as the air travels across the gas turbine. Relate the variation of pressures and temperatures with working principle of the gas turbine major components.

(5 marks)

(b) A single spool turbojet engine is used to power a military jet. The arrangement of the engine is given in **Figure Q3(b)**. The military jet is cruising at 7,000 m with speed reaching Mach 0.75. The ambient temperature and pressure at the cruising altitude are 243 K and 41 kPa respectively. The recorded engine data are as follows:

Inlet mass flow	110 kg/s
Compressor pressure ratio	11
Turbine entry temperature	1,450 K
Afterburner exit temperature	1,650 K
Fuel low heating value	45,000 kJ/kg

Using an ideal cycle approach, analyse the engine performance to obtain:

(i) engine thrust
(ii) thrust specific fuel consumption
(iii) propulsive efficiency

Sketch the *T-S* diagram. Take for air, γ = 1.4, C_P =1.005 kJ/kg and, R = 0.287 kJ/kg.K.

(20 marks)

Q4 (a) Provide the difference between a single-spool and a two-spool jet engine arrangement.

(2 marks)

(b) **Figure Q4(b)** presents three gas turbine arrangements. Explain how the gas turbine arrangement affect the relation between the compressor and turbine system.

(3 marks)

(c) A two-spool, mixed nozzle turbofan is used to fly a military jet at a Mach number of 0.85. The ambient conditions are 230K and 22 kPa respectively. The half-diagram engine arrangement follows Engine Arrangement 3 of **Figure Q4(b)**. As shown in the figure, the fan is driven by the low-pressure turbine while the compressor is driven by high pressure turbine. The engine data are as follows:

Inlet mass flow	120 kg/s
Bypass ratio	5.706
Fan pressure ratio	2.5
Overall pressure ratio	20
Turbine entry temperature	1,750 K
Fuel low heating value	42,500 kJ/kg

Using an ideal cycle approach, analyse the engine performance to obtain:

(i) compressor pressure ratio
(ii) thrust
(iii) thrust specific fuel consumption

Sketch the *T-S* diagram. Take for air, $\gamma = 1.4$, $C_P = 1.005$ kJ/kg and, $R = 0.287$ kJ/kg.K

(20 marks)

Q5 (a) During an intake analysis, the combinations of component deficiency and pressure loss will determine the real intake exit total pressure and temperature. Using *T-S* diagram, provide a graphical explanation for the case of:

Case 1 : Pressure loss does not exist but intake is not isentropic
Case 2 : Pressure loss exist but intake is isentropic

(5 marks)

(b) A corporate jet equipped with two-spool turbojet engine is cruising at 7,500 m. At this altitude, the ambient temperature and pressure are 239 K and 38 kPa, respectively. The speed Mach number of the jet is 0.6. The engine configuration is given in **Figure Q5(b)** while the recorded engine data are as follows:

Intake mass flow	70 kg/s
Intake isentropic efficiency	90%
Low pressure compressor pressure ratio	4
High pressure compressor pressure ratio	6
Turbine entry temperature	1,450K
High pressure turbine isentropic efficiency	89%
Low pressure turbine isentropic efficiency	80%
Fuel Low heating value	42,500 kJ/kg

Using a non-ideal cycle approach, analyse the engine performance to obtain:

(i) overall engine pressure ratio
(ii) thrust
(iii) thrust specific fuel consumption
(iv) specific thrust

Sketch the *T-S* diagram. Take for air, $\gamma = 1.4$, C_P=1.005 kJ/kg, R = 0.287 kJ/kg.K while for combusted gas air, $\gamma = 1.33$, C_P=1.148 kJ/kg, R = 0.285 kJ/kg.K

(20 marks)

Q6 (a) Explain the difference between Design Point and Off Design Point.

(2 marks)

(b) Sketch the component characteristic of a turbine.

(3 marks)

(c) A two-spool turbofan with unmixed nozzle is flying at Mach number 0.65. The atmospheric conditions are 250 K and 35 kPa respectively. The engine configuration is given in **Figure Q6(c)**. The recorded engine data and the gas path values for the cold section are as follows:

<u>Engine data:</u>

Inlet mass flow	250 kg/s
Bypass ratio	6
Intake pressure recovery	90%
Fan pressure ratio	2
Fan isentropic efficiency	87%
Compressor pressure ratio	13
Compressor isentropic efficiency	85%
Burner efficiency	98%
Turbine entry temperature	1,800 K
High pressure turbine isentropic efficiency	95%
Low pressure turbine isentropic efficiency	95%
Fuel Low Heating Value	43,200 kJ/kg

<u>Gas path values at gas turbine cold section:</u>

$P_{01}' = 41.84$ kPa $\quad T_{01}' = 263.08$ K $\quad P_{08} = 83.68$ kPa

$T_{08}' = 329.31$ K $\quad P_{03} = 1{,}087.84$ kPa $\quad T_{03}' = 748.12$ K

Analyse the engine performance to obtain:

(i) remaining gas path values
(ii) fuel to air ratio of the burner
(iii) thrust
(iv) thrust specific fuel consumption

Sketch the Ts diagram. Take for air, $\gamma = 1.4$, C_P=1.005 kJ/kg, $R = 0.287$ kJ/kg.K while for combusted gas air, $\gamma = 1.33$, C_P=1.148 kJ/kg, $R = 0.285$ kJ/kg.K

(20 marks)

- **END OF QUESTIONS** -

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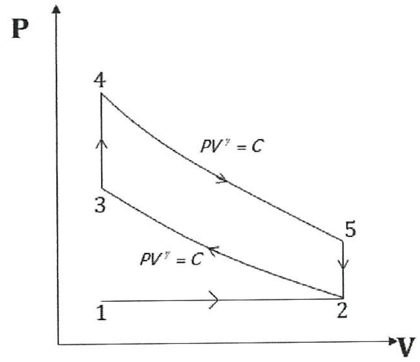

Figure Q1(a)

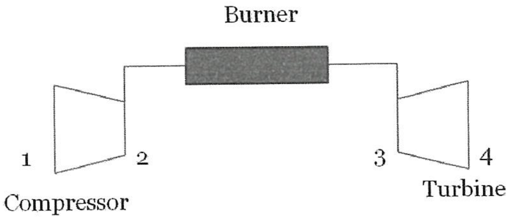

Figure Q2(b)

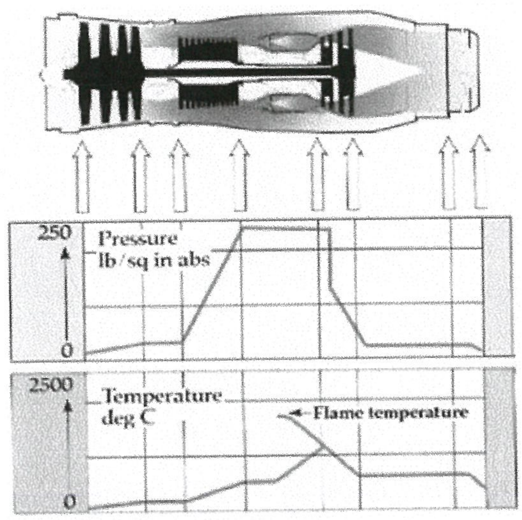

Figure Q3(a)

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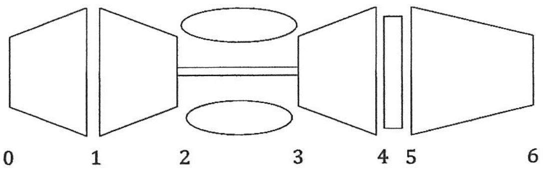
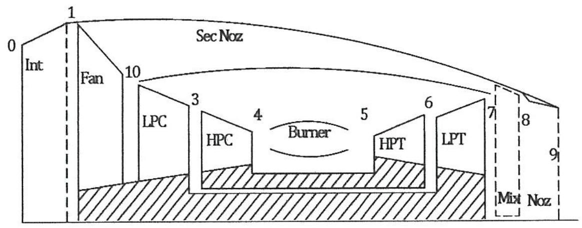
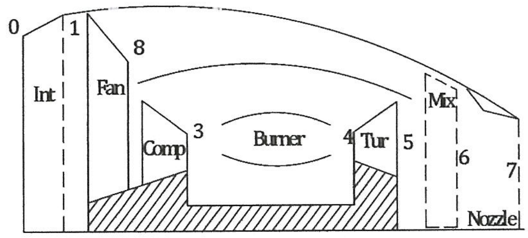


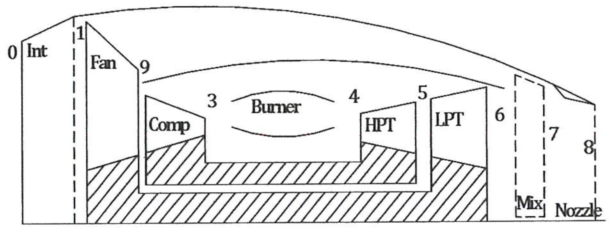
Figure Q3(b)



Engine Arrangement 1



Engine Arrangement 2



Engine Arrangement 3

Figure Q4(b)

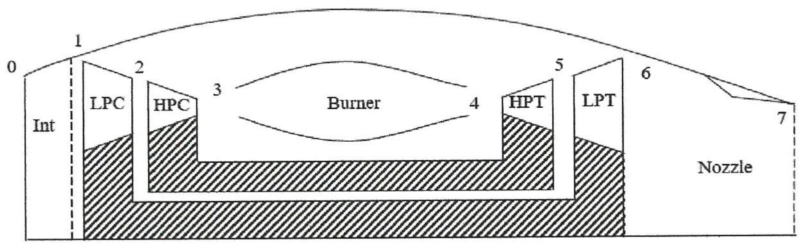


Figure Q5(b)

Note:
LPC : Low Pressure Compressor | HPC : High Pressure Compressor | LPT : Low Pressure Turbine | HPT : High Pressure Turbine

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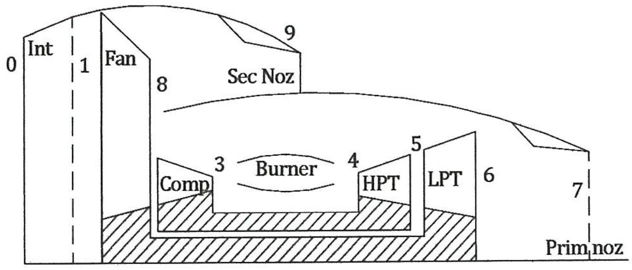

Figure Q6(c)

Note:
LPC : Low Pressure Compressor | HPC : High Pressure Compressor | LPT : Low Pressure Turbine | HPT : High Pressure Turbine