CONFIDENTIAL

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2022/2023

COURSE NAME	:	AIRCRAFT PROPULSION
COURSE CODE	:	BDU 20203
PROGRAMME	:	BDC
EXAMINATION DATE	:	FEBRUARY 2023
DURATION	:	**3** HOURS
INSTRUCTION	:	1. ANSWER **FOUR (4)** QUESTIONS ONLY 2. THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSED BOOK**. 3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL SOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK.

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

Q1 (a) Differentiate single and two-spool gas turbines. Sketch to the engine diagram to elaborate your explanation.

(4 marks)

(b) Explain the impact of altitude and ambient conditions on the performance of a gas turbine engine

(6 marks)

(c) An aircraft with a two-spooled turbojet engine is flying at an altitude with an ISA deviation of 21.1K. The arrangement of the engine is given in **Figure Q1(c)**. The recorded flight and engine data from the flight and engine management system are given as follows:

Ambient Temperature	:	36°C
Ambient Pressure	:	101.25 kPa
Mach number	:	0.85
Inlet mass flow	:	45 kg/s
Compressor pressure ratio	:	10
Turbine entry temperature	:	1240 K

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

(i) the fuel-to-air ratio;
(ii) the engine thrust;
(iii) the specific thrust;
(iv) the thrust SFC;
(v) the propulsive efficiency; and
(vi) the thermal efficiency.

Sketch the *T-S* diagram. Take for air, $\gamma = 1.4$, $C_P = 1.005$ kJ/kg and, $R = 0.287$ kJ/kg.K. Take for fuel, LHV = 43,000 kJ/kg.

(15 marks)

Q2 (a) Differentiate a turbofan with a mixed and unmixed nozzle in terms of its function and thrust equation used. Sketch to the engine diagram to elaborate your explanation.

(6 marks)

(b) A military aircraft is equipped with a single-spooled, mixed-nozzle jet engine. The engine configuration is given in **Figure Q2(b)**. The aircraft is flying at ISA sea level with Mach Number 0.5. The recorded engine data from the engine management system are given as follows:

Inlet mass flow	:	120 kg/s
Bypass ratio	:	2.381
Fan pressure ratio	:	2.5
Compressor pressure ratio	:	4.5
Turbine entry temperature	:	1450 K

Fan pressure ratio	:	2.5
Compressor pressure ratio	:	4.5

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

(i) nozzle exit velocity;
(ii) the engine thrust;
(iii) the engine specific thrust; and
(iv) the thrust SFC.

Sketch the *T-S* diagram. Take for air, $\gamma = 1.4$, $C_P = 1.005$ kJ/kg and, $R = 0.287$ kJ/kg.K. Take for fuel, LHV = 42,000 kJ/kg.

(19 marks)

Q3 (a) Define the engine's performance and design parameters.

(2 marks)

(b) **Table Q3(b)** lists the typical parameters of a gas turbine. Classify them based on the list given into performance, operating, and design parameters.

(5 marks)

(c) Define the purpose of an engine afterburner.

(2 marks)

(d) A new single-spooled engine with an afterburner was tested in the engine test bed to analyse the engine performance. The engine arrangement is given in **Figure Q3(d)**. During the test, the ambient conditions recorded are 37°C and 101.325 kPa. The test was set to have an incoming air of 0.5 Mach number. The engine data recorded by the laboratory data logger are as follows:

Inlet mass flow	:	63 kg/s
Compressor pressure ratio	:	17
Turbine entry temperature	:	1400 K
Afterburner entry temperature	:	1500 K

Based on the data recorded, using an ideal cycle approach, investigate the performance of the engine to obtain the following:

(i) the engine thrust;
(ii) the thrust SFC
(iii) the propulsive efficiency;
(iv) the thermal efficiency; and
(v) the overall efficiency

Sketch the *T-S* diagram. Take for air, $\gamma = 1.4$, $C_P = 1.005$ kJ/kg and, $R = 0.287$ kJ/kg.K. Take for fuel, LHV = 43,000 kJ/kg.

(16 marks)

Q4 (a) Off-design point performance analysis is crucial in defining the engine's overall performance. Define the off-design point and list the three types of compatibility that need to be achieved when performing the off-design point performance analysis. Sketch the typical compressor map that is used in the performance analysis.

(6 marks)

(b) List the losses or deficiencies in the gas turbine intake.

(2 marks)

(c) An aircraft flying with a two-spooled jet engine is flying at 30,000 ft with an ISA deviation of 0 K. The atmospheric conditions at that altitude are 229.15 K and 30 kPa. The aircraft's speed is 0.8 Mach number. The engine arrangement is given in **Figure Q4(c),** and the engine data for the flight are given in **Table Q4(c)**. Using a non-ideal cycle approach, analyse the engine performance to obtain the following:

(i) the engine thrust;
(ii) the engine specific thrust; and
(iii) the thrust SFC.

Sketch the *Ts* diagram. Take for air, $\gamma = 1.4$, CP =1.005 kJ/kg, R = 0.287 kJ/kg.K while for combusted gas air, $\gamma = 1.33$, CP =1.148 kJ/kg, R = 0.285 kJ/kg.K. Take also for fuel, LHV = 44,000 kJ/kg.

(17 marks)

Q5 (a) Differentiate the in-line and V-type engines used as aircraft propulsion in terms of their design and advantage.

(4 marks)

(b) A propeller-driven aircraft which uses an in-line engine has the following cylinder specification:

Bore	:	12 cm
Stroke	:	14 cm
Clearance distance	:	1.5 cm

Calculate:

(i) piston area;
(ii) clearance volume;
(iii) volumetric displacement or swept volume; and
(iv) compression ratio.

(6 marks)

(c) A propeller-driven aircraft uses a four-stroke, six-cylinder, spark-ignition boxer engine. The aircraft is flying at an altitude of 300ft and a speed of 150 knots (77.17 m/s). At this altitude, the intake manifold pressure, temperature and density are 100.23 kPa, 297.55 K, and 1.225 kg/m^3, respectively. The following data are recorded:

Swept volume	:	1.582×10^{-3} m^2
Compression ratio	:	10.33
Air to fuel ratio	:	10
Engine RPM	:	3,000
Mechanical efficiency	:	95%
Propulsive efficiency	:	96%

If the diameter of the engine's propeller is 2m, analyse the engine performance to obtain the following:

(i) indicated power;
(ii) shaft brake power;
(iii) available power;
(iv) thrust; and
(iv) maximum static thrust.

Take for air, $\gamma = 1.4$, CV =0.718 kJ/kg and, R = 0.287 kJ/kg.K. Take also for fuel, LHV = 43,500 kJ/kg.

(15 marks)

- END OF QUESTIONS -

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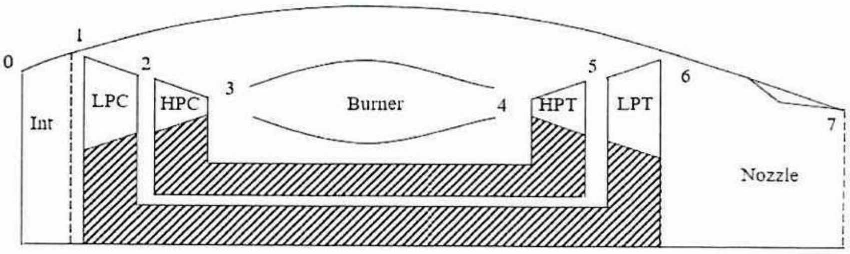

LPC : Low Pressure Compressor | HPC : High Pressure Compressor | LPT : Low Pressure Turbine | HPT : High Pressure Turbine

Figure Q1(c)

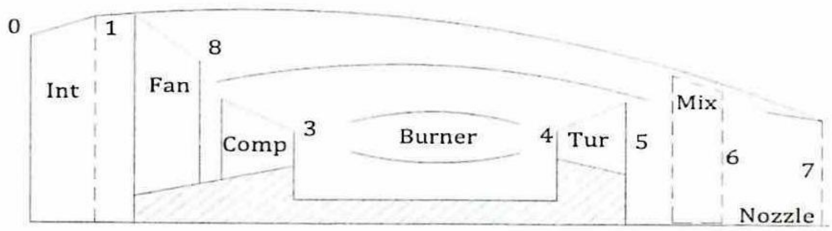

Figure Q2(b)

Table Q3(b)

No	Parameter
1	Turbine blade height
2	Thrust
3	Specific thrust
4	Altitude
5	Nozzle inlet area
6	Number of the compressor stage
7	Compressor pressure ratio
8	Mach No
9	Thrust specific fuel consumption
10	Thermal efficiency

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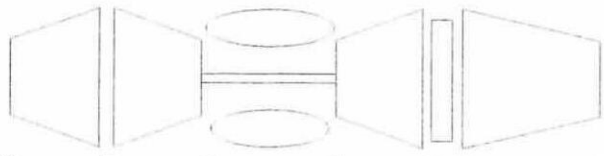
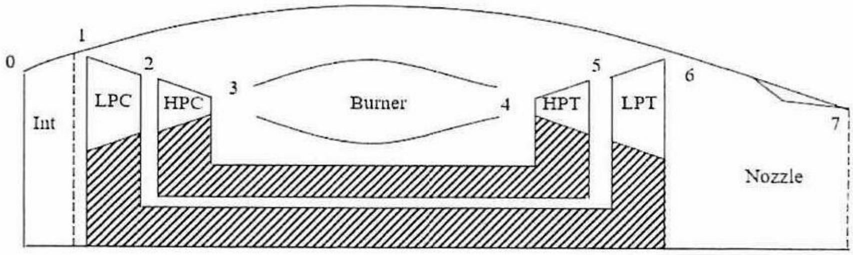


Figure Q3(d)



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

Figure Q4(c)

Table Q4(c)

No	Component	Value	No	Component	Value
1	**Intake** Mass flow Pressure recovery Isentropic efficiency	 85 kg/s 90% 100%	2	**Low Pressure Compressor** Pressure ratio Isentropic efficiency	 3 95%
3	**High Pressure Compressor** Pressure ratio Isentropic efficiency	 5.5 95%	4	**Burner** Burning efficiency Pressure loss	 98% No pressure loss
5	**High Pressure Turbine** Turbine entry temperature Isentropic efficiency Mechanical efficiency	 1400K 100% 100%	6	**Low Pressure Turbine** Isentropic efficiency Mechanical efficiency	 100% 100%
7	**Nozzle** Isentropic efficiency	 100%			

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LIST OF EQUATIONS

Eq. 1	$P_a V_a{}^{\gamma} = P_b V_b{}^{\gamma}$
Eq. 2	$\frac{T_a}{T_b} = \left(\frac{P_a}{P_b}\right)^{\frac{\gamma-1}{\gamma}}$
Eq. 3	$\frac{T_a}{T_b} = \left(\frac{V_b}{V_a}\right)^{\gamma-1}$
Eq. 4	$\frac{P_a V_a}{T_a} = \frac{P_b V_b}{T_b}$
Eq. 5	$\Gamma_V = \frac{V_{max}}{V_{min}}$
Eq. 6	$q = C_V (T_b - T_a)$
Eq. 7	$W_{ab} = \frac{P_b V_b - P_a V_a}{1-\gamma}$
Eq. 8	$\dot{W}_i = \frac{n_{shaft}}{2 \times 60} N \left(W_{expansion} - W_{compression}\right)$
Eq. 9	$\dot{W}_B = \eta_m \dot{W}_i$
Eq. 10	$\dot{W}_A = \eta_P \dot{W}_B$
Eq. 11	$F_N = \frac{\dot{W}_A}{\overline{V_o}}$
Eq. 12	$A_p = \frac{\pi d^2}{4}$

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LIST OF EQUATIONS (CONTINUES)

Eq. 13	$F_o = \left(\dot{W}_B\sqrt{2\rho A_p}\right)^{\frac{2}{3}}$
Eq. 14	$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{23}}$
Eq. 15	$M = \frac{\bar{V}}{\sqrt{\gamma R t}}$
Eq. 16	$T_{00} = T_0\left[1 + \frac{\gamma - 1}{2}{M_i}^2\right]$
Eq. 17	$PR = \frac{P_{max}}{P_{min}}$
Eq. 18	$\sum E_{in} = \sum E_{out}$
Eq. 19	$FAR = \frac{\dot{m}_f}{\dot{m}_i}$