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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2022/2023

COURSE NAME	:	AIRCRAFT PROPULSION
COURSE CODE	:	BDU 20203
PROGRAMME	:	BDM/BDC
EXAMINATION DATE	:	JULY/AUGUST 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 **TEN (10)** PAGES

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Q1 (a) Explain the meaning of a four-stroke engine regarding the piston movement and its relationship with the power it produces.

(2 marks)

(b) Differentiate an aero-piston engine and a jet engine in terms of the engine's output and how the thrust is principally generated.

(3 marks)

(c) Define the following terms on a piston engine.

(i) Stroke
(ii) Clearance volume
(iii) Swept volume
(iv) Top dead centre
(v) Capacity

(5 marks)

(d) A propeller-driven aircraft uses a four-stroke, six-cylinder, spark-ignition, V-type engine. The aircraft is flying at 180 m and a 198 km/hour speed. The ambient temperature, pressure and density are 286.98 K, 99.18 kPa and 1.204 kg/m^3, respectively. The summary of the primary data is as follows:

Swept volume, V_S	:	1.0996 x 10^{-3} m^3
Clearance volume, V_C	:	1.2217 x 10^{-4} m^3
Engine speed	:	4,000 RPM
The heat generated during combustion, q	:	2,773,29 kJ/kg
Mechanical efficiency, η_m	:	90 %
Propulsive efficiency, η_P	:	85 %

If the diameter of the engine's propeller is 1.7 m, analyse the engine performance to obtain the following:

(i) Compression ratio
(ii) Indicated, brake and available powers
(iii) Thrust
(iv) Maximum static thrust.

Take for air, $\gamma = 1.4$, $C_V = 0.718\ \text{kJ/kg}$ and, $R = 0.287\ \text{kJ/kg.K}$. Take also for fuel, $LHV = 44{,}650\ \text{kJ/kg}$.

(15 marks)

Q2 (a) A typical gas turbine performance analysis will adopt two approaches: the component analysis approach and the total property approach. Briefly explain the two approaches.

(4 marks)

(b) Explain the law of conservation of mass and how the law is used in the gas turbine performance analysis.

(3 marks)

(c) A gas turbine engine has the following performance parameters:

TSFC	:	2.475×10^{-5} kg/Ns
η_{th}	:	58 %
η_P	:	42 %

Synthesise the data to provide the meaning of the performance parameters.

(3 marks)

(d) An aircraft with a single-spooled turbojet engine is flying at 5,800 m. The arrangement of the engine is given in **Figure Q2(d)**. The recorded flight and engine data from the flight and engine management system are given as follows:

Ambient Temperature	:	271.55 K
Ambient Pressure	:	48.49 kPa
Mach number	:	0.8
Inlet mass flow	:	70 kg/s
Compressor pressure ratio	:	12
Turbine entry temperature	:	1350 K

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

(i) The thrust
(ii) The specific thrust
(iii) The TSFC;
(iv) 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, $LHV = 42{,}800$ kJ/kg.

(15 marks)

Q3 (a) Sketch the engine diagram of a single-spool mixed and unmixed nozzle turbofan. Also, provide the thrust equation.

(6 marks)

(b) Describe the effect of Ram Pressure on Engine Thrust.

(4 marks)

(c) A military aircraft is equipped with a single-spooled, mixed-nozzle turbofan engine. The engine configuration is given in **Figure Q3(c)**. The aircraft is flying at Mach 0.65 at an altitude of 10,000 m. The ambient conditions are 244.25 K and 26.43 kPa, respectively. The recorded engine data from the engine management system are given as follows:

Inlet mass flow	:	100 kg/s
Bypass ratio	:	2.3825

Fan pressure ratio	:	3.2
Compressor pressure ratio	:	5.5
Turbine entry temperature	:	1600 K

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

(i) Nozzle exit velocity
(ii) The engine's thrust
(iii) The engine's specific thrust
(iv) The TSFC

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, $LHV = 42{,}800$ kJ/kg.

(15 marks)

Q4 (a) List the four assumptions for an ideal gas turbine cycle analysis.

(4 marks)

(b) **Figure Q4(b)** provides three arrangements of a mixed nozzle turbofan. For each arrangement, relate the work relationship between the turbine and the compressor system.

(6 marks)

(c) A single-spooled, unmixed-nozzle turbofan engine powers a transport aircraft. The engine configuration is given in **Figure Q4(c)**. The aircraft is flying at ISA sea level at Mach 0.6. The recorded engine data from the engine management system are given as follows:

Inlet mass flow	:	200 kg/s
Bypass ratio	:	2.3
Fan pressure ratio	:	3
Compressor pressure ratio	:	15
Turbine entry temperature	:	1500 K

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

(i) Overall pressure ratio
(ii) The engine thrust
(iii) The TSFC
(iv) The engine's specific thrust

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, $LHV = 42{,}800$ kJ/kg

(15 marks)

Q5 (a) Off-design point performance analysis is crucial in defining the engine's overall performance:

(i) 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.

(2 marks)

(ii) Sketch the typical compressor map that is used in the performance analysis.

(4 marks)

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

(2 marks)

(c) An aircraft flying with a two-spooled jet engine is flying at 30,000 ft. The atmospheric conditions at that altitude are 229.15 K and 30 kPa. The aircraft's speed is Mach 0.8. The engine arrangement is given in **Figure Q5(c),** and the engine data for the flight are given in **Table Q5(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 TSFC.

Sketch the Ts diagram. Take for air, $\gamma = 1.4$, $C_P = 1.005\ \text{kJ/kg}$, $R = 0.287\ \text{kJ/kg.K}$ while for combusted gas air, $\gamma = 1.33$, $C_P = 1.148\ \text{kJ/kg}$, $R = 0.285\ \text{kJ/kg.K}$. Take also for fuel, $LHV = 42{,}800\ \text{kJ/kg}$.

(17 marks)

- END OF QUESTIONS -

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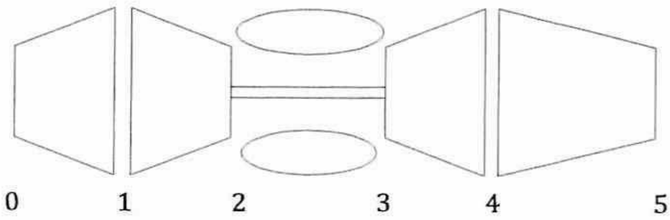


Figure Q2(d)

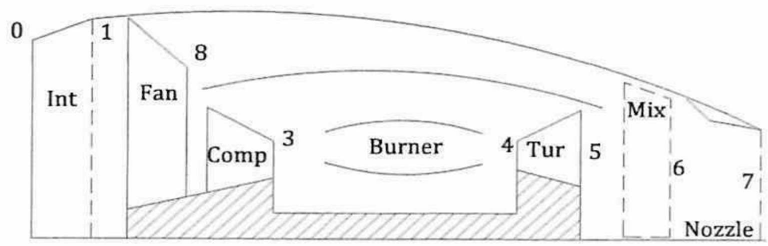
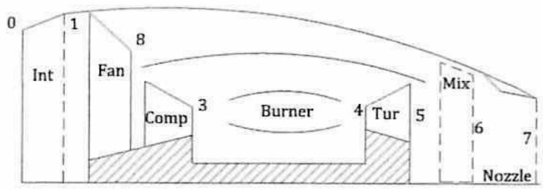
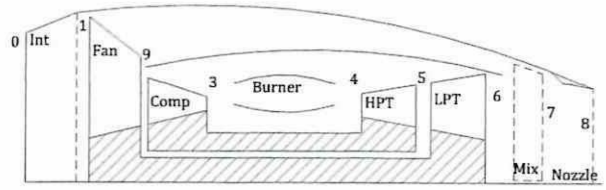


Figure Q3(c)



Arrangement 1



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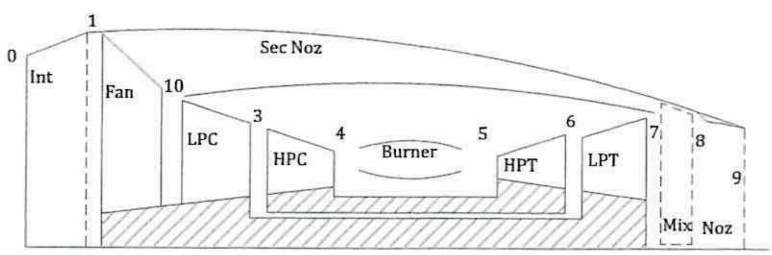

Arrangement 3

Figure Q4(b)

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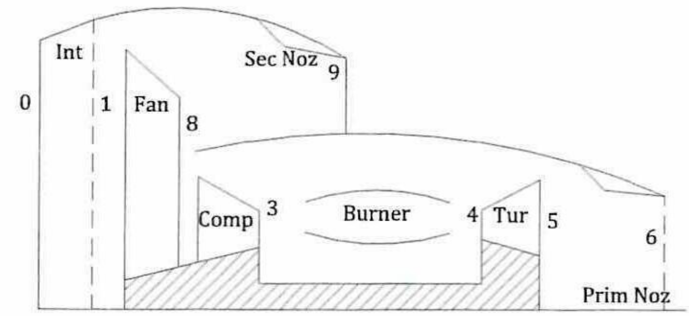
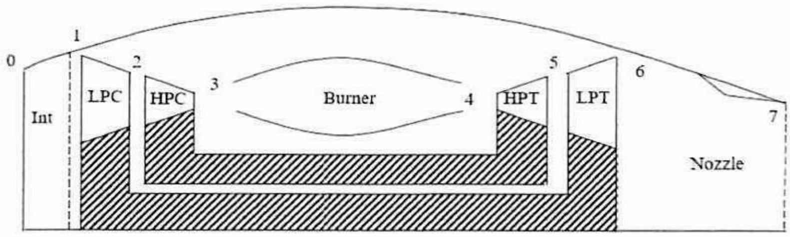


Figure Q4(c)



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

Figure Q5(c)

Table Q5(c)

No	Component	Value	No	Component	Value
1	**Intake** Mass flow Pressure recovery Isentropic efficiency	230 kg/s 85% 100%	2	**Low-Pressure Compressor** Pressure ratio Isentropic efficiency	3.5 95%
3	**High-Pressure Compressor** Pressure ratio Isentropic efficiency	5 95%	4	**Burner** Burning efficiency Pressure loss	98% No pressure loss
5	**High-Pressure Turbine** Turbine entry temperature Isentropic efficiency Mechanical efficiency	1530K 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	$q = C_V(T_b - T_a)$ - close system
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	$M = \frac{\bar{V}}{\sqrt{\gamma Rt}}$
Eq. 16	$T_{0A} = T_A\left[1 + \frac{\gamma - 1}{2}{M_i}^2\right]$
Eq. 17	$PR = \frac{P_{max}}{P_{min}}$
Eq. 18	$\sum E_{in} = \sum E_{out}$
Eq. 19	$FAR = \frac{\dot{m}_f}{\dot{m}_i}$
Eq. 20	$\dot{Q}_{AB} = \dot{m}C_P(T_B - T_A)$
Eq. 21	$T_{0A} = T_A + \frac{\bar{V}_A^2}{2Cp}$
Eq. 22	$F_S = \frac{F_N}{\dot{m}_i}$
Eq. 23	$\eta_P = \frac{2}{1 + \frac{V_e}{V_i}}$
Eq. 24	$TSFC = \frac{\dot{m}_f}{F_N}$
Eq. 25	$\eta_{th} = \frac{F_n\bar{V}_i + \frac{1}{2}\dot{m}_e(\bar{V}_e - \bar{V}_i)^2}{\dot{m}_f \times LHV}$
Eq. 26	$\dot{m}_{core} = \frac{\dot{m}_i}{1 + \beta}$

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Eq. 27	$\dot{m}_{BP} = \frac{\beta \dot{m}_i}{1+\beta}$
Eq. 28	$\sum \dot{H}_{in} = \sum \dot{H}_{in}$ for mixer
Eq. 29	$P_{\mathrm{Re}\,c} = \frac{P_{0A}'}{P_{0A}}$
Eq. 30	$\eta_m = \frac{\dot{W}_{comp}}{\dot{W}_{turbine}}$
Eq. 31	$t_C = \left(\frac{2}{\gamma+1}\right) T_{04}'$
Eq. 32	$P_C = P_{04}\left[1 - \frac{1}{\eta_N}\left(1 - \frac{T_C}{T_{04}'}\right)\right]^{\frac{\gamma}{\gamma-1}}$
Eq. 33	$\bar{V}_A = \sqrt{\gamma R T_A}$
Eq. 34	$\gamma = \frac{C_P}{C_V} = \frac{C_P}{C_P - R}$