2506/305
AIRCRAFT MECHANICAL
TECHNOLOGY II
Oct. / Nov. 2022
Time: 3 hours

THE KENYA NATIONAL EXAMINATIONS COUNCIL

DIPLOMA IN AERONAUTICAL ENGINEERING (AIRFRAME AND ENGINES OPTION)

MODULE III

AIRCRAFT MECHANICAL TECHNOLOGY II

3 hours

INSTRUCTIONS TO CANDIDATES

You should have the following for this examination:

Answer booklet;
Mathematical tables/Non-programmable scientific calculator;
Thermodynamic and transport properties of fluids tables, by G.F.C. Rogers and Y.R. Mayhew;
Drawing instruments.

*This paper consists of **EIGHT** questions in **TWO** sections; **A** and **B**.*
*Answer **THREE** questions from section **A** and **TWO** questions from section **B**.*
All questions carry equal marks.
Maximum marks for each part of a question are as indicated.
Candidates should answer the questions in English.

This paper consists of 5 printed pages.

Candidates should check the question paper to ascertain that all the pages are printed as indicated and that no questions are missing.

SECTION A: THERMODYNAMICS

*Answer any **THREE** questions from this section.*

1. (a) (i) With the aid of a diagram, describe the operation of an axial flow compressor.

(ii) Show that the volumetric efficiency η_{vol} of a reciprocating air compressor is

given by: $\eta_{vol} = 1 - \frac{V_c}{V_s}\left\{\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right\}$.

Where: Vc = clearance volume;
Vs = swept volume;
P_1 = suction pressure;
P_2 = delivery pressure;
n = index of compression and expansion.

(8 marks)

(b) A two-stage single-acting reciprocating compressor compresses 1 kg/s of air from 1 bar and 18 °C to 15. 5 bar. Compression is polytropic and n = 1. 3 for both compression and expansion. The clearance volume is 4% of the swept volume in both stages and intercooling is perfect. If the intermediate pressure is ideal, determine the:

(i) indicated power;
(ii) heat transferred through the low pressure cylinder walls;
(iii) cylinder total volumes required in the two stages.

(12 marks)

2. (a) (i) State the following gas laws:

(I) Boyle's law;
(II) Charles' law.

(ii) In a thermodynamic process, 0.2 kg of a gas at 140 kN/m^2 and 17 °C is compressed to a final pressure of 1. 5 MN/m^2 according to the law $PV^{1.3}$ = constant. The characteristic constant for the gas is 278 J/kgK and its adiabatic index is 1.4. Determine the:

(I) initial and final volumes of the gas;
(II) final temperature;
(III) work transfer;
(IV) heat transfer.

(12 marks)

(b) (i) Define the following terms:

(I) wet vapour;
(II) dryness fraction;
(III) superheated steam.

(ii) Steam with a dryness fraction of 0.95 and a pressure of 7 bar is supplied through a pipe of 25 mm diameter with a velocity of 12 m/s. Determine the mass flow rate of the steam. (8 marks)

3. (a) (i) Using a Temperature-Entropy (T-S) diagram, describe the Carnot cycle as applied to a heat engine.

(ii) Show that the thermal efficiency of the Carnot cycle η_{carnot} is given by the equation:

$$\eta_{\text{carnot}} = 1 - \frac{T_3}{T_1} \; .$$

Where T_3 is the minimum temperature and T_1 is the maximum temperature. (5 marks)

(b) In an ideal diesel cycle, the compression ratio is 15. The pressure and temperature at the beginning of the compression are 1 bar and 17 °C respectively. The heat transfer to the air is 1470 kJ/kg. Sketch the cycle on a Pressure -Volume (P-V) diagram and determine the:

(i) pressure and temperature at the end of each process;
(ii) cycle efficiency;
(iii) mean effective pressure.

Take for air: $C_p = 1.005$ kJ/kgK, $C_V = 0.718$ kJ/kgK and $\gamma = 1.4$. (15 marks)

4. (a) With the aid of sketches, distinguish between open and closed gas turbine plants. (4 marks)

(b) A gas turbine unit takes in air at 17 °C and 1.01 bar and the pressure ratio is 8/1. The compressor is driven by the High Pressure (HP) turbine and the Low Pressure (LP) turbine drives a separate power shaft. The isentropic efficiencies of the compressor, HP and LP turbines are 0.8, 0.85 and 0.83 respectively. The maximum cycle temperature is 650 °C. For the compression process, take Cp = 1.005 kJ/kgK and $\gamma = 1.4$;
For the combustion process and for expansion take Cp = 1.15 kJ/kgK and $\gamma = 1.333$ respectively. Neglect the mass of fuel.

(i) Draw the plant and T-S diagrams.

(ii) Determine the:

(I) pressure and temperature of the gases entering the power turbine;
(II) net power developed;
(III) work ratio;
(IV) thermal efficiency.

(16 marks)

5. (a) A flat composite plate is made of two layers of aluminium and steel of 50 mm and 20 mm thickness respectively. The thermal conductivities of aluminium and steel are 205 W/mK and 45 W/mK respectively. The hot surface of aluminium side is in contact with hot liquid at 200 °C, the heat transfer coefficient of liquid film being 14 W/m^2K. The cold surface of steel is in contact with liquid at 25 °C, the heat transfer coefficient of liquid film being 29 W/m^2K. Determine the:

(i) overall thermal resistance of the composite;

(ii) heat transfer rate from hot liquid to cold liquid through a surface area of 10 m^2.

(4 marks)

(b) The dry exhaust gas from an engine had the following composition by volume:

$CO_2 = 8.85\%;\ CO = 1.2\%;\ O_2 = 6.8\%;\ N_2 = 83.15\%.$

The fuel had a percentage composition by mass of:

$C = 84\%;\ H_2 = 14\%;\ O_2 = 2\%.$

Determine the mass of air supplied per kg of fuel burnt.

Take: air contains 23% O_2 by mass.

(16 marks)

SECTION B: FLUID MECHANICS

*Answer any **TWO** questions from this section.*

6. (a) Experiments have shown that the resistance force F to the motion of a body moving through a fluid is proportional to the mass density ρ, dynamic viscosity μ of the fluid, velocity of the fluid V past a body of characteristic length l and acceleration due to gravity g. By use of dimensional analysis, show that the force $F = \rho v^2 l^2 \phi\left\{\frac{v l \rho}{\mu}, \frac{lg}{v^2}\right\}$;
where Ø = "function of"

(14 marks)

(b) An aircraft whose wing measures 12 m is required to fly at an average speed of 800 km/hr. Its drag force is to be estimated from tests in water on a third scale model. Determine the drag force on the full size aircraft, if the drag force on the model is 1500 N.
Take the:

- densities of air and water as 1.225 kg/m^3 and 1000 kg/m^3;
- dynamic viscosities of air and water as 1.8×10^{-5} and 1.31×10^{-3} respectively.

(6 marks)

7. (a) Define the following types of efficiencies in centrifugal pumps:

(i) manometric;
(ii) mechanical;
(iii) overall.

(3 marks)

(b) Show that the specific speed N_S of a centrifugal pump is given by: $N_S = \frac{NQ^{\frac{1}{2}}}{H^{\frac{3}{4}}}$.

Where: Q = flow rate in the pump;
H = head;
N = rotational speed of the impeller.

(7 marks)

(c) A centrifugal pump running at 100 rev/min is working against a total head of 20 m. The external diameter of the impeller is 500 mm and outlet width 60 mm. If the blade angle at outlet is 40° and manometric efficiency is 75%, determine the:

(i) velocity of flow at outlet;
(ii) absolute velocity of water leaving the blade;
(iii) angle made by the absolute velocity at outlet with the direction of motion;
(iv) flow rate through the pump.

(10 marks)

8. (a) From first principles, show that the loss of pressure P due to laminar flow in a horizontal pipe is given by: $P = \frac{32\eta VL}{d^2}$.

Where: η = coefficient of viscosity of the fluid;
V = mean velocity of flow of the fluid;
d = diameter of the pipe;
L = length of the pipe.

(14 marks)

(b) Oil of dynamic viscosity 0.097 kg/ms and relative density 0.93 flows through a horizontal circular pipe of diameter 150 mm and length 12 m. If the oil flow rate of 3.4 kg/s is collected in the tank, calculate the differences in pressure at the two ends of the pipe. (6 marks)

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