Version NS/3

EGT3
ENGINEERING TRIPOS PART IIB

---

Monday 11 May 2026    9.30 to 11.10

---

**Module 4A13**

**COMBUSTION AND ENGINES**

*Answer not more than **three** questions.*

*All questions carry the same number of marks.*

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

**STATIONERY REQUIREMENTS**
Single-sided script paper

**SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM**
CUED approved calculator allowed
Engineering Data Book

**10 minutes reading time is allowed for this paper at the start of the exam.**

**You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.**

**You may not remove any stationery from the Examination Room.**

1 (a) Describe briefly flame *blow-off* using a carefully drawn graph for the physics of a well-stirred reactor. [25%]

(b) An approximate theory suggests that flame blow-off occurs in a combustor when

$$\tau_{\text{chem}} > B\,\tau_{\text{res}}$$

where $B$ is a constant. The chemical time scale of a flammable mixture at temperature $T_0$ is $\tau_{\text{chem}} = \lambda / \left(\rho_0 c_p S_L^2\right)$ and the residence time is $\tau_{\text{res}} = L/U$ with $U$ as the bulk-mean velocity of the mixture with density $\rho_0$ entering the combustor of length $L$. Assume that the isobaric specific heat capacity of the mixture $c_p$ is constant and the mixture thermal conductivity $\lambda$ increases with temperature as $\lambda/\lambda_{\text{ref}} = (T_0/T_{\text{ref}})^{1/2}$. The laminar burning velocity $S_L$ increases with mixture temperature as $S_L/S_{L,\text{ref}} = (T_0/T_{\text{ref}})^2$.

Find the percentage increase in mass flow rate at blow-off when $T_0$ is increased from 300 K to 600 K and the combustor length is doubled, with all other parameters kept constant. [30%]

(c) Briefly describe the various mechanisms of nitric oxide generation from combustion. Discuss strategies used to mitigate nitric oxide emission from common combustion environments. [35%]

(d) Would these strategies change if one uses zero-carbon fuels? Explain your answer. [10%]

2 A droplet of a sustainable aviation fuel with density $\rho_\ell$ and diameter $d$ is evaporating in a stagnant environment of air at 1 bar and temperature $T_a = 700$ K. The fuel vapour mass fraction at the droplet surface is $Y_{f,0}$ and its value in the far-field is $Y_{f,\infty}$. The droplet initial diameter is $d_0$.

(a) Taking the fuel mass flux due to evaporation to be $\dot{m}'' = \rho_\ell \beta/(4\,d)$, where $\beta$ is a constant, derive an expression for the variation of $d$ with time. [20%]

(b) Using your result for (a) and

$$\beta = \frac{8\rho\mathcal{D}}{\rho_\ell} \ln\left(\frac{1 - Y_{f,\infty}}{1 - Y_{f,0}}\right)$$

where $\rho$ is the gas mixture density and $\mathcal{D}$ is the mass diffusivity, deduce an expression for the time, $t_v$, taken to completely evaporate the droplet. [15%]

(c) Considering the energy balance at the evaporating surface and taking the surface heat flux to be $\dot{q}'' = 2\lambda\,(T_a - T_s)\,/d$, where $T_s$ is the saturation temperature for the fuel at 1 bar, show that the fuel vapour mass fraction at the surface is

$$Y_{f,0} = 1 - \exp\left[-c_p\,(T_a - T_s)\,/h_{fg}\right]$$

for the binary mixture of unity Lewis number. The mixture specific heat capacity at constant pressure is $c_p$ and the enthalpy of evaporation is $h_{fg}$. [35%]

(d) Calculate $t_v$ for $\rho_\ell = 750$ kg m$^{-3}$, $c_p = 1.075$ kJ kg$^{-1}$K$^{-1}$, $T_s = 490$ K, $\mathcal{D} = 1.78 \times 10^{-5}$ m$^2$ s$^{-1}$, $h_{fg} = 256$ kJ kg$^{-1}$ and $d_0 = 20$ $\mu$m. Using carefully drawn diagrams, explain how $t_v$ changes with $T_a$, $d_o$ and pressure. [20%]

(e) Briefly explain how you would modify the above analysis if the droplet is evaporating in a convective flow field? [10%]

3 (a) Discuss the combustion and emission characteristics of sustainable liquid aviation fuels in comparison with fossil kerosene. [30%]

(b) A designer is considering ammonia as an aviation fuel and proposes to recuperate heat from the exhaust in order to decompose some of the ammonia into its constituents. The fraction of ammonia that has been decomposed is $X$. Sketch qualitatively the flame speed and adiabatic flame temperature as a function of $X$ for fuel (i.e. ammonia and its decomposed products) – air mixtures at stoichiometric proportions. Explain the trends shown. [30%]

(c) Discuss the possible mechanisms of unburnt ammonia emissions from ammonia combustion in compression-ignition engines, spark-ignition engines, and gas turbines. [40%]

4 (a) Discuss with appropriate sketches the mechanisms of generation of mean flow and turbulence inside reciprocating engines. [30%]

(b) State an expression for the power generated by a reciprocating engine as a function of the fuel mass flow rate. Discuss the origins of the various inefficiencies and measures that can be taken to reduce these. [40%]

(c) Why do current liquid-fuelled marine engines produce much more smoke compared to automotive diesel engines? [30%]

**END OF PAPER**

THIS PAGE IS BLANK