EGT3
ENGINEERING TRIPOS PART IIB

Monday 20 April 2015 2 to 3.30

Module 4A13

COMBUSTION AND IC 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
Attachment: None

10 minutes reading time is allowed for this paper.

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

1 (a) Describe what is meant by the terms *laminar burning velocity, flammability limits* and *quenching distance* for a fuel-air mixture. What are the physical and/or chemical origins of the flammability limits? [30%]

(b) A premixed flame with laminar burning velocity S_L is stabilised on the rim of a vertical circular tube with radius R. Write down an expression for the angle $\theta(r)$ between the flame and the axis of the tube when the exit velocity $V(r)$

(i) is uniform; [5%]

(ii) varies as a parabola given by

$$V(r) = V_0 \left(1 - \frac{r^2}{R^2}\right)$$

where V_0 is the centreline velocity. Sketch the flame shape by assuming that $V_0 > S_L$ and ignoring the region close to the tube wall where $V < S_L$. [15%]

(c) The products of methane-air combustion at an equivalence ratio of 2.0 are in chemical equilibrium at 10 bar and 1600 K. Calculate their volumetric composition, assuming that the only species present are CO_2, CO, H_2O, H_2 and N_2. [50%]

2 (a) Describe briefly flame *blow-off*, using a carefully drawn graph for the physics of a well-stirred reactor. [20%]

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

$$\tau_{\text{chem}} > C\tau_{\text{res}}$$

where C is a constant. The chemical time scale of a flammable mixture at an initial temperature T_0 is defined as $\tau_{\text{chem}} = \lambda/(\rho_0 c_p S_L^2)$ and the residence time is $\tau_{\text{res}} = L/U$ with U as the bulk-mean velocity of the mixture entering the combustor of length L. The isobaric specific heat capacity of the mixture is c_p and is taken to be constant. The thermal conductivity λ increases with temperature as $\lambda/\lambda_{\text{ref}} = (T_0/T_{\text{ref}})^{1/2}$ and ρ_0 is the density of the mixture entering the combustor. The laminar burning velocity S_L increases with reactant 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 to 600 K and the combustor length is doubled, with all other parameters kept constant. [45%]

(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%]

(TURN OVER

3 For a naturally aspirated gasoline engine

(a) Draw a typical maximum torque characteristic on a *bmep* versus *engine speed* plot and justify what you have drawn. [30%]

(b) What limits the maximum torque? [10%]

(c) Add to this plot a typical top-gear road load characteristic with justifications. [10%]

(d) Describe how and why the *sfc* varies within the operating envelope. [20%]

(e) In the context of this plot, describe five approaches to reduce *sfc* which are being implemented. [10%]

(f) For all of the above, describe briefly how your commentary would vary in the case of a naturally aspirated *diesel* engine. [20%]

4 (a) Prove that the expression

$$W_{12} = \frac{p_1 V_1}{\gamma - 1}\left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{\gamma - 1}{\gamma}}\right]$$

is the work done during a reversible adiabatic (isentropic) compression of a perfect gas between states 1 and 2. The ratio of specific heat capacities is γ and the symbols p and V denote pressure and volume respectively. [10%]

(b) Figure 1 below shows an idealised, throttled, four-stroke engine cycle. Assuming the working fluid is a perfect gas, find expressions for the work done during the compression and expansion strokes in terms of p_e, p_i, p_3, V_m and V_c. [10%]

(c) If the compression ratio is 10, the manifold inlet temperature is 288 K, $\gamma = 1.4$, the temperature rise on combustion is 1300 K, and the exhaust and inlet manifold pressures are 1.05 bar and 0.5 bar respectively, determine p_3, and hence the gross *imep*. [40%]

(d) Determine the pumping work, and hence the *pmep* and the net *imep*. [30%]

(e) Sketch the *p-V* diagram of Fig. 1 in your script, and add to this a sketch of a cycle operating between the same minimum and maximum volumes, which would produce the same net work, based on late inlet valve closing. You may assume that the unthrottled inlet pressure is equal to p_e. No calculations are required, but justify your sketch with comments. [10%]

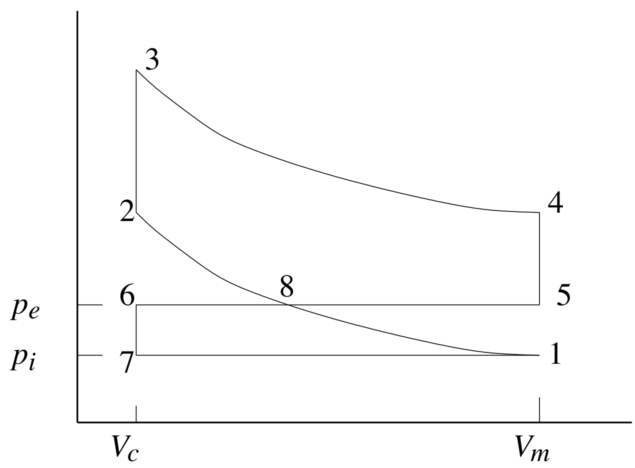

Fig. 1

END OF PAPER

THIS PAGE IS BLANK

Numerical Answers - 2015

1. (c) $x_{CO2} = 0.0277$, $x_{CO} = 0.1202$, $x_{H2O} = 0.1202$
$x_{H2} = 0.1755$, $x_{N2} = 0.5564$

2. (b) 466% increase in mass flow rate

4. (c) $p_3 = 35.13$ bar gross imep = 3.78 bar

(d) pumping work = $-0.358V_m$, *pmep* = 0.398 bar, net *imep* = 3.382 bar