

SOE3212 Referred/Deferred

UNIVERSITY OF EXETER

**SCHOOL OF ENGINEERING, COMPUTER
SCIENCE AND MATHEMATICS**

DEPARTMENT OF ENGINEERING

Thermofluids and Energy Conversion B

Time allowed : TWO HOURS

September 2006

For **DEFERRED** candidates, the marks for this module are calculated from the better of : 70% of the percentage mark for this paper plus 30% of the percentage mark for associated coursework, or 100% of the percentage mark for this paper.

For **REFERRED** candidates, the marks for this module are calculated from 100% of the mark for this paper. The maximum mark that can be achieved is 40%.

Full marks on the paper may be obtained from full answers to three questions. Candidates must answer **one question from each section**

This is a **closed book** examination. Candidates are permitted to use approved portable calculators. Separate formula and data sheets have been provided. Graph paper is available on request.

SECTION A

Question 1 (20 marks)

1(a) (10 marks) A cylinder is placed crosswise in a visualisation flow tank and the flow patterns observed for various free stream flow speeds. Describe the different flow patterns observed as the Reynolds number is increased from $Re \sim 1$ to $Re > 10,000$, and discuss how the flow affects the forces on the cylinder.

1(b) (10 marks) The roadway of a new suspension bridge consists of an enclosed circular tube of diameter D . A scale model of the bridge is placed in a wind tunnel and subjected to an air flow $u_\infty = 50$ m/s. At a distance $8D$ downstream, the wake profile is found to be linear with distance from the centreline, with a minimum speed of 10 m/s at the centreline, and regaining the full speed at a distance $2.5D$ from the centreline. If $D = 30$ cm for the model, what is the force per unit length on the model? If the actual bridge has $D = 5$ m, what is the equivalent wind speed?

Question 2 (20 marks)

2(a) (3 marks) What is the difference between an *impulse* turbine and a *reaction* turbine? Give an example of each.

2(b) (4 marks) Power losses in a turbine can be ascribed to *mechanical* and *hydraulic* losses : hydraulic losses including *casing*, *leakage* and *impeller* losses. Explain each of these terms.

2(c) (3 marks) Show that the type number for a turbine is independent of its size, and develop a formula for it in terms of rotational speed N , head H and power P .

2(d) (10 marks) A centrifugal water pump can deliver $0.35 \text{ m}^3/\text{s}$ with a head of 35 m. The radial outflow velocity is 4 m/s, the pump runs at 1200 RPM, and the hydraulic efficiency is 80%. If the blade angle $\beta_2 = 30^\circ$ at the outflow, there is zero whirl at the inlet and the turbine operates under no-shock conditions,

- i. Find the ideal head developed by the system.
- ii. Draw the exit velocity triangle. State any assumptions you make in the analysis
- iii. Find the outside diameter of the impeller and the exit blade height

SECTION B

Question 3 (20 marks)

3(a) (7 marks) Describe briefly a typical heat pump unit and discuss the economic and technical factors which you would take into account when considering the installation such a unit for the heating of a domestic house in the U.K.

3(b) (13 marks) A small domestic heat pump unit operates on an ideal vapour-compression cycle using refrigerant 717 (ammonia, NH_3) and is designed to produce 22 kW of heating. The pressure in the evaporator is 2.077 bar and the pressure in the condenser is 10.99 bar. There are negligible pressure losses in the heat exchangers and in the pipelines. The compressor, which operates adiabatically and reversibly, is fed by refrigerant at -15°C . The refrigerant enters the throttle valve at 24°C .

i. Sketch the cycle on $T - s$ and $P - h$ diagrams. **(2 marks)**

ii. Determine the following quantities: **(1 mark each)**

- the entropy at compressor inlet
- the enthalpy at compressor inlet
- the temperature at compressor outlet
- the enthalpy at compressor outlet
- the enthalpy at throttle entry
- the enthalpy at throttle outlet

iii. Calculate the following: **(1 mark each)**

- the dryness fraction (quality) at throttle outlet
- the heat transferred in the condenser per kg of NH_3
- the compressor work per kg of NH_3
- the coefficient of performance, COP_{hp}
- the NH_3 mass flow rate for the required heat output.

Question 4 (20 marks)

4(a) (2 marks) Explain briefly what you understand by the term ‘fuel cell’.

4(b) (2 marks) Explain why fuel cells exhibit increasing overpotential losses when the current produced is increased.

4(c) (6 marks) Explain briefly how two of the following types of fuel cell work. **(3 marks each)**

i. Hydrogen-oxygen fuel cell.

ii. Molten carbonate fuel cell.

iii. Solid oxide fuel cell.

4(d) (10 marks) A four-stroke, eight-cylinder spark-ignition engine of swept (or displaced) volume 3.8 litres is running on a test bed at 4250 rpm. It is connected to a hydraulic dynamometer via a torque arm of length 0.32 m, and the measured brake load is 1125 N. Fuel, of net calorific value 44500 kJkg^{-1} , is fed to the engine at the rate of 0.0135 kgs^{-1} . Calculate the following : **(2 marks each)**

i. the brake power (bp)

ii. the rate of energy input to the engine

iii. the brake thermal efficiency

iv. the brake mean effective pressure (bmep)

v. the brake specific fuel consumption (bsfc) in μgmJ^{-1} .

SECTION C

Question 5 (20 marks)

5(a) (10 marks) The flow between two parallel plates of infinite extent one of which is in motion is known as Couette flow. If the moving plate has a velocity in the x -direction of U , and the distance between the plates (y -direction, measured from the static plate) is h ,

- i. What are the boundary conditions at the two plates?
- ii. Show that the Navier-Stokes equations can be simplified to give

$$\frac{d^2 u_x}{dy^2} = 0$$

if there is no pressure gradient in the x -direction

- iii. From this, find a solution for $u_x(y)$

5(b) (10 marks) Repeat the problem in part (a) above if there is a constant, non-zero pressure gradient $\frac{dp}{dx}$. What will be the effect of large positive and large negative pressure gradients on the flow?

Question 6 (20 marks)

6(a) (10 marks) Give an account of the generation of electricity from tidal energy.

6(b) (10 marks) Each of the 216 turbines of a proposed tidal power scheme for the Severn Estuary will drive a 40 MW generator.

- i. Calculate the volume of water per second which must flow through each turbine in order to produce full output when the water level in the basin is 3.8 m above the level of the sea, assuming an overall system efficiency of 85%. **(4 marks)**
- ii. If the surface area of the water in the basin is 480 km² how far will the level fall in an hour, assuming that the volumetric flow rate in (a) is maintained? **(3 marks)**
- iii. If the predicted energy output from the scheme is 17000 GWhr per year what is the average energy output per tide? **(3 marks)**

DATA: acceleration due to gravity, $g = 9.81 \text{ m s}^{-2}$

density of water, $\rho = 1000 \text{ kg m}^{-3}$

tidal period = 12.42 hours

1 GW h = $3.6 \times 10^{12} \text{ J}$