SOE3047

UNIVERSITY OF EXETER

SCHOOL OF ENGINEERING AND COMPUTER SCIENCE

DEPARTMENT OF ENGINEERING

Advanced Fluid Mechanics

Time allowed: THREE HOURS

January 2001

The marks for this module are calculated from 70% of the percentage mark for this paper plus 30% of the percentage mark for associated coursework.

Full marks may be obtained from full answers to four questions. Candidates are required to answer at least two questions from section B.

This is a **closed book** examination. Candidates are permitted to use approved portable calculators. A separate formula and data sheet has been provided.

The allocation of marks to each part of a question is shown thus : **[n]**

Section A.

Question A1. a. The Mk 3 Aerosonde is a small robotic aircraft designed for mid-altitude atmospheric observations. The quoted characteristics of the craft are as follows :

Mass	15 kg	Speed :	Takeoff	18 m/s
Payload	5 kg + 2 kg fuel		Cruise	$20 - 32$ m/s
Altitude	< 6000 m		Climb	4 m/s
Range	4000 km			
Wingspan	2.9 m			
Mean chord	15 cm			

Calculate the lift coefficients for the following regimes :

i. Level flight at 32 m/s at ground level.

ii. Takeoff

iii. Level flight at 5000 m altitude, assuming a speed of 24 m/s. **[8]**

b. How would the design of the wing for the Aerosonde affect its performance? If the lift to drag ratio for the craft aerofoil is 80, how much energy does it expend for a full-range mission? (Assume it spends all its time in regime iii above). **[8]**

c. High altitude atmospheric measurements are often made using helium balloons, which provide a lift force per unit volume $(\rho_{air} - \rho_{He})g$. It is proposed to use a spherical balloon 4 m in diameter to lift a 20 kg instrument package. On release, the balloon quickly settles to a constant rise speed. Calculate this speed. (Take $\rho_{He} = 0.1626$ kg/m^3). **[9]**

Question A2. a. Sketch the energy spectrum for a turbulent fluid. **[6]**

b.Write brief notes on two of the following topics :

i. Turbulence in Engineering

ii. Computational Fluid Dynamics

iii. Drag reduction **[12]**

c. Water flows through a conical section of pipe which narrows from an internal diameter of 40 cm to an internal diameter of 20cm over a length of 4 m. Determine the frictional head loss for a flow of 0.1 m^3/s if the friction factor $f = 0.05$. (You may ignore entrance and exit losses). **[7]**

Question A3. a. Sketch the different flow patterns you would expect to see behind a cylinder at $\mathcal{R}e$ between 0.1 and 50,000. **[6]**

b. A car roofrack consists of 5 cylindrical bars 1.8 m in length and 1.4 cm in diameter. The roof is 2 m in length. If the car is driven at 80 km/hr, what is the drag force exerted on each bar? **[4]**

c. What is the ratio of the the drag on the roofrack to the drag on the roof? **[6]**

d. At what frequency do the bars vibrate? **[3]**

e. Discuss the structure of laminar and turbulent boundary layers. **[6]**

Section B.

Question B1. a. An aerofoil *NACA3047* has a lift coefficient that varies as

$$C_L(\alpha) = 0.6\,(1 + 0.233\,\alpha) \qquad (\alpha \text{ in degrees})$$

for $\alpha < 7.5°$. Plot this curve, and sketch how you would expect it to continue for $\alpha > 7.5°$. Explain your reasoning. **[5]**

b. A helicopter has 4 blades each of length R, width c, and with a lift coefficient $C_L(r)$. Show that the vertical force developed by the rotor is given by

$$F = \frac{1}{2} q \int_0^1 C_L y^2 dy, \qquad \text{where} \quad y = \frac{r}{R}$$

and deduce an expression for the coefficient q in terms of the angular speed of rotation Ω. **[12]**

c. A light helicopter has a rotor with blades 6 m in length and 12 cm in width. Its blades use the *NACA3047* aerofoil, and are twisted so that the angle of attack varies according to

$$\alpha(r) = \alpha_0 \left(1 - \frac{r}{2R}\right), \qquad \alpha_0 = 5°$$

If the loaded mass of the helicopter is 780 kg, at what speed must the blades rotate when the helicopter is hovering? **[8]**

Question B2. a. What is the difference between an axial flow impeller and a centrifugal flow impeller? Define the following terms for a pump :

i. Overall efficiency

ii. Hydraulic losses

iii. 'No shock' condition **[7]**

Show that the type number for a pump is independent of the size of the machine. **[6]**

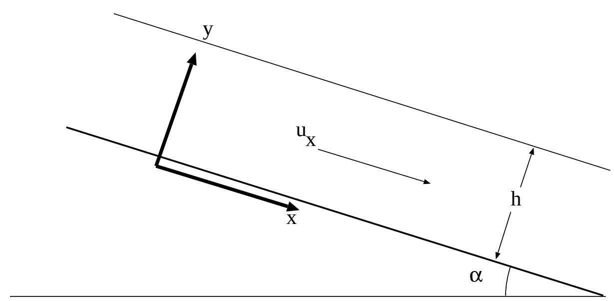
b. A centrifugal pump running at 800 RPM is supplying 10 m^3 water per minute against a head of 20 m. The blade angle at exit is 130° from the direction of motion of the blade tip. The velocity of flow is constant at 2 m/s and the relative velocity of the water at the exit is along the blade with the absolute velocity at inlet being radial. Calculate the necessary impeller diameter

i. if none of the energy corresponding to the velocity at the exit from the impeller is recovered and

ii. if 40% of this energy is recovered. **[12]**

Question B3. a. A viscous fluid of density ρ, viscosity μ is forced from a pipe of diameter D through a nozzle of diameter D_0 due to a pressure drop Δp. Use dimensional analysis to deduce an expression for the rate of flow Q through the nozzle. **[8]**

b.



A viscous liquid is draining from a plate held at an angle α to the horizontal. If the flow is fully developed, write the Navier-Stokes equations for the flow component u_x.**[3]**

c. Show that the velocity profile through the film is given by

$$u_x = \frac{g \sin \alpha}{\nu} \left(hy - \frac{y^2}{2} \right)$$

[8]

d. Cooking oil (viscosity $\nu = 9.15 \times 10^{-5}$ $m^2 s^{-1}$) is being poured onto a baking tray inclined at an angle $\alpha = 20°$. At what volumetric rate must it be poured to maintain a film of height $h = 2$ mm? **[6]**