

SOE3047

UNIVERSITY OF EXETER

SCHOOL OF ENGINEERING AND
COMPUTER SCIENCE

DEPARTMENT OF ENGINEERING

Advanced Fluid Mechanics

Time allowed: **THREE HOURS**

January 2000

The marks for this module are calculated from 80% of the percentage mark for this paper plus 20% of the percentage mark for associated coursework.

Full marks may be obtained from full answers to four questions.

This is a **closed book** examination. Candidates are permitted to use approved portable calculators. **Relevant data for questions 1-4 has been supplied on a separate data sheet : graphs 1-4.**

The allocation of marks to each part of a question is shown thus :

[n]

Question 1. Define the Reynolds number for a cylinder of diameter D whose axis is at right angles to air flowing with velocity V . [2]

If the diameter of the cylinder is 4cm what are the Reynolds numbers for the following flow velocities?

- a. 0.035 mm/s
- b. 1.4 cm/s
- c. 18 cm/s
- d. 5 m/s [2]

Describe the types of flow pattern that you would expect to see as the velocity is increased from case a. to case d. [6]

A cylinder 1.2 m in diameter and 5 m tall is subjected to a uniform crosswind of velocity 40 km/hr. If end effects and gusts can be neglected, estimate the bending moment exerted at the base due to wind forces. [5]

A novel design for a sailing yacht replaces the conventional sail with a vertical rotating cylinder. If the cylinder has the previous dimensions, and is rotating at 300 rpm, what is the lateral force in this wind? [5]

Question 2. How does an airfoil generate lift? What design considerations are important for a wing designed for

- a. a jet fighter
- b. a human-powered aircraft [8]

For the airfoil described in graph 2, of chord length 1.4 m and span 6.8 m determine the lift and drag at an angle of attack of 10° at a speed of 200 km/hr. [6]

Discuss methods of determining C_L , C_D in airfoil design. [6]

Question 3. Describe the structure of a turbulent boundary layer. [6]

A ship may be approximated as a flat plate 60 m long submerged to a depth of 6 m. Below the water line the hull is encrusted with barnacles which give a roughness height of 1.2 cm. Calculate the power consumption of the vessel when it is travelling at 9 m/s. [6]

Estimate the maximum speed of the ship for the same power consumption after it has been cleaned of barnacles. [8]

Question 4. Discuss briefly the importance of the following subjects in Computational Fluid Dynamics :

- a. The mesh, [3]
- b. Turbulence modelling, [3]
- c. Differencing schemes. [3]

Air at 20° C and atmospheric pressure flows through a smooth 10 cm diameter tube under fully developed conditions with a mean velocity (U) of 8 m/s. By equating the frictional losses in the tube to the wall effects, estimate

- a. the wall shear stress τ_0 ,
- b. the friction velocity u_* [7]

Using these results, comment on the design of the mesh near the wall in a CFD simulation of this case. [4]

Question 5. How is dimensional analysis used in a. analytical and b. experimental areas of fluid mechanics? Give examples. [8]

Show by dimensional analysis that the torque τ required to rotate a disk of diameter D at angular velocity ω in a fluid of density ρ and viscosity μ is given by

$$\tau = \rho D^5 \omega^2 F \left(\frac{\rho D^2 \omega}{\mu} \right)$$

[3]

A disk A of diameter 0.3 m requires a torque of 10 Nm when rotating in water at 300 rad/s. Another disk B of diameter 0.9 m is to be tested in air under dynamically similar conditions. Calculate :

- a. the corresponding speed of disk B [3]
- b. the torque required by disk B at that speed [3]
- c. the power required to drive disk B [3]

Question 6. Define the time average \bar{a} of a fluctuating quantity a . If a and b are fluctuating quantities, show that

a. $\overline{a + b} = \bar{a} + \bar{b}$

b. $\overline{ab} = \bar{a}\bar{b} + \overline{a'b'}$

where $'$ denotes the fluctuations around the time average. [4]

A mountain climber has put up an awning as protection in a storm with air speed U_0 . The flow separates from the edge and forms a wake whose velocity profile at BD of the control volume (see figure below) is

$$u_x(y) = \begin{cases} \frac{U_0}{2} \left[1 - \cos\left(\frac{\pi y}{\delta}\right) \right] & 0 \leq y \leq \delta \\ U_0 & y > \delta \end{cases}$$

Assuming that the flow may be considered to be 2 dimensional,

a. Evaluate the mass flux across CD, [6]

b. Find the force in the x -direction on the awning [10]

(the viscous stresses along AC, CD, DB may be neglected. You may assume that

$$\cos^2 \theta = \frac{1}{2} (1 + \cos 2\theta) \quad)$$

Data Sheet for module SOE 3047

Graph 1 : Drag force on a cylinder.

Graph 2 : Lift coefficient for aerofoil.

Graph 3 : Skin friction drag coefficient for rough surfaces.

Graph 4 : Darcy friction factor for flow in pipes

Physical Data

Substance	Kinematic Viscosity ν	Density ρ
Air	$1.4 \times 10^{-5} \text{ m}^2/\text{s}$	$1.2 \text{ kg}/\text{m}^3$
Water	$1.14 \times 10^{-6} \text{ m}^2/\text{s}$	$1.0 \times 10^3 \text{ kg}/\text{m}^3$