Question 1

a) Define:

   i) A Fluid [3 Marks]

   ii) Newton’s Law of Viscosity. [7 Marks]

b) A cylinder, with a shaft attached through its centre, spins at a constant angular velocity of 1200 rads/second inside a tube filled with oil (Fig. Q1). The shaft torque is measured at 40.7 Nm. Calculate the approximate viscosity of the oil.

Figure Q1 [15 Marks]
Question 2

A rectangular observation window in a dolphin aquarium, shown in Fig Q2 is aligned at 45° to the horizontal, with its centroidal axis 6m below the surface of the water. The window is 1.5m in width (W) and 5m in length (L, into the paper).

a) Sketch the hydrostatic pressure distribution on the window, also showing the location of the centroidal axis, C, the approximate position of the centre of pressure, CP, and the distances \( y \) and \( y_{CP} \), where the axis \( y \), runs parallel with the window.  

[5 Marks]

b)  

i) Calculate the net force on the window and the position at which it acts.  

[15 Marks]

ii) Calculate the moment on the bottom hinge point, which is locked tight. Note that the top of the window is unsupported.  

[5 Marks]

Figure Q2

Note that for a rectangular area the second moment of area: \( I_{xx} = LW^3/12 \)
Question 3

a) State Bernoulli’s equation, describing each of the four terms and stating the four assumptions in its derivation.  

[7 marks]

Water flows horizontally from a reservoir where the mean velocity is zero at Station A, into a nozzle, shown in Figure Q3, and exits into the atmosphere, at a velocity of 7.5m/s and a pressure of 1bar at Station D. The nozzle diameter varies between 0.7m at Station B, to 0.4m at Station C, to 0.5m at Station D.

b) Calculate the flow velocity at Stations B and C  

[6 marks]

c) Calculate the gauge pressure at Station A, B and C  

[6 marks]

d) Calculate the depth of the reservoir above level ABCD.  

[6 marks]

Figure Q3

Note:
1bar = 10^5 Pa and the density of water is \( \rho = 1000 \text{ kg/m}^3 \)
Question 4

Air is vented to atmosphere through a curving, contracting circular nozzle with a 0.25m diameter at the inlet (station 1) and a 0.1m diameter at the exit (station 2). The air enters the nozzle at station 1 with a mean velocity of 5m/s and exits at an angle of 45° to the inlet air vector.

a) Write the equation for the force, \( F \), in an arbitrary direction, \( i \), acting between the two stations 1 and 2, in terms of pressure, \( p \), nozzle cross-section area, \( A \), velocity, \( V \), and mass flow rate, \( \dot{m} \).

[5 marks]

b) Calculate the inlet pressure and the exit velocity.

[6 marks]

c) Evaluate the force acting on the nozzle, and its direction with reference to the inlet velocity vector (x-direction).

[14 marks]

Assume that for air, the variation in the hydrostatic pressure term is negligible.

Figure Q4

Note:
The density of air is \( \rho = 1.2 \ kg/m^3 \)
Question 5

The thrust of a rocket engine, $F$, is known to be highly dependent on the exhaust velocity, $V$, air density, $\rho$, nozzle diameter, $D$, engine chamber pressure, $p$, exhaust gas viscosity, $\mu$, and the speed of sound in air, $a$.

a) Use Buckingham’s $\pi$ analysis to identify the four non-dimensional groups governing this problem. For each group, state its recognised name and its physical meaning.

[22 marks]

b) State how complete dynamic similarity between scale model and prototype in a wind tunnel can be achieved.

[3 marks]