Boundary Layer Thickness

Q.1 Magnus effect may be used advantageously in games such as cricket, tennis, table tennis and golf. In order to obtain a lift, i.e. a rising curve for the trajectory of the ball, from left to right, the nature of the spin to be given is
(a) anticlockwise in the vertical plane
(b) anticlockwise in the horizontal plane
(c) clockwise in the vertical plane
(d) clockwise in the horizontal plane

Q.2 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. $\left(\frac{\partial u}{\partial y}\right)_{y=0}$ is zero

B. $\left(\frac{\partial u}{\partial y}\right)_{y=0}$ is +ve

C. Displacement thickness

D. Momentum thickness

List-II

1. The flow is attached flow
2. The flow is on the verge of separation
3. $\int_0^\delta \frac{u}{U}\left(1-\frac{u}{U}\right)dy$
4. $\int_0^\delta \left(1-\frac{u}{U}\right)dy$

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	1	3	4
(c)	1	2	4	3
(d)	2	1	4	3

Q.3 A thin smooth plate 1 m wide and 2 m long is towed through water at a velocity of 2 m/s. Assuming that boundary remains laminar, then drag on both sides of the plate is (kinematic viscosity = 10^{-6} m²/s)
(a) 5.3 N (b) 26.6 N
(c) 53 N (d) 72.5 N

Q.4 The velocity distribution for flow over a plate is given by $u = 0.5y - y^2$ where 'u' is the velocity in m/s at a distance 'y' meter above the plate. If the dynamic viscosity of the fluid is 0.9 N-s/m², then what is the shear stress at 0.20 m from the boundary?
(a) 0.9 N/m² (b) 1.8 N/m²
(c) 2.25 N/m² (d) 0.09 N/m²

Q.5 In the case of a sphere placed in a fluid stream
(a) friction drag is very large and pressure drag is zero
(b) pressure drag is very large and friction drag is practically zero
(c) pressure and friction drags both contribute almost equally
(d) friction drag is predominant and pressure drag is considerably less

Q.6 A very tiny sphere is settling down in a viscous liquid at Reynold's number of 0.2. Its drag coefficient will be
(a) 320 (b) 120
(c) 80 (d) 5

Q.7 In which of the following the friction drag is generally larger than pressure drag?
(a) a circular disc or plate held normal to flow
(b) a sphere
(c) a cylinder
(d) an airfoil

Q.8 The drag force experienced by an object in a fluid stream is
(a) the resultant fluid dynamic force acting on the object
(b) the horizontal component of the resultant fluid dynamic force acting on the object
(c) the horizontal force due to pressure variation over the surface of object
(d) the component of the resultant fluid dynamic force in the flow direction

Q.9 The correct relationship among displacement thickness 'd', momentum thickness 'm' and energy thickness 'e' is
(a) $d > m > e$ (b) $d > e > m$
(c) $e > m > d$ (d) $e > d > m$

Q.10 The existence of boundary layer is on account of
(a) fluid density
(b) gravitational effect
(c) fluid viscosity
(d) flow turbulence

Q.11 The boundary layer exists in
(a) flow of ideal fluid
(b) flow of real fluid
(c) only in pipe flow
(d) only flow over flat plate

Q.12 The concept of boundary layer decides the flow fluid into two zones these zones are
(a) the region in which eddies formation takes place
(b) the region in which viscous effect are negligible and flow is analysed by potential flow theory
(c) the region in which turbulence and viscous effect both takes place
(d) the region in which viscous effect are predominant

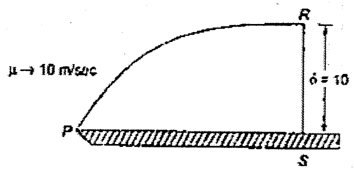
Q.13 For air flow over a flat plate, velocity (U) and boundary layer thickness (δ) can be expressed respectively, as

$$\frac{U}{U_\infty} = \frac{3}{2}\frac{y}{\delta} - \frac{1}{2}\left(\frac{y}{\delta}\right)^3; \quad \delta = \frac{4.64x}{\sqrt{Re_x}}$$

If the free stream velocity is 2 m/s, and air has kinematic viscosity of 1.5×10^{-5} m²/s and density of 1.23 kg/m³, the wall shear stress at x = 1 m, is
(a) 2.36×10^2 N/m²
(b) 43.6×10^{-3} N/m²
(c) 4.36×10^{-3} N/m²
(d) 2.18×10^{-3} N/m²

Q.14 The velocity profile in fully developed laminar flow in a pipe of diameter D is given by $u = u_0(1 - 4r^2/D^2)$, where r is the radial distance from the center. If the viscosity of the fluid is m, the pressure drop across a length L of the pipe is
(a) $\frac{\mu u_0 L}{D^2}$ (b) $\frac{4\mu u_0 L}{D^2}$
(c) $\frac{8\mu u_0 L}{D^2}$ (d) $\frac{16\mu u_0 L}{D^2}$

Q.15 The mass flow rate (in kg/s) across the section s-r is



(a) zero (b) 0.05
(c) 0.10 (d) 0.15

Q.16 The integrated drag force (in N) on the plate, between p-s, is
(a) 0.67 (b) 0.33
(c) 0.17 (d) zero

Q.17 Consider an incompressible laminar boundary layer flow over a flat plate of length L, aligned with the direction of an incoming uniform free stream. If F is the ratio of the drag force on the front half of the plate to the drag force on the rear half, then
(a) $F < 1/2$ (b) $F = 1/2$
(c) $F = 1$ (d) $F > 1$

Q.18 The power consumed per unit length in laminar flow for the same discharge, varies directly as D^n where D is the diameter of the pipe. What is the value of 'n'?
(a) 1/2 (b) −1/2
(c) −2 (d) −4

Q.19 What is the commonly used boundary layer control method to prevent separation?
(a) Use of smooth boundaries
(b) Using large divergence angle in the boundary
(c) Suction of accelerating fluid within the boundary layer
(d) Suction of retarded fluid within the boundary layer

Q.20 **Assertion (A) :** Flow in the boundary layer is always laminar.
Reason (R) : In turbulent flow on a smooth boundary, a laminar sub-layer still exists within the boundary layer.
Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Q.21 The mean drag coefficient C_{Df} for a laminar boundary layer over a flat plate was found to be 0.015. If all other flow factors remain the same and the length of the plate is decreased to 1/4 of its original value, the drag coefficient C_{Df} would be equal to
(a) 0.015 (b) 0.060
(c) 0.030 (d) 0.0075

Q.22 The separation of boundary layer is a phenomenon in which the boundary-layer gets detached (or separated) from the wall due to progressive deceleration of flow.
The boundary-layer separation occurs when
(a) $\left(\frac{\partial u}{\partial y}\right)_{y=0} = 0$ (b) $\frac{dp}{dx} < 0$
(c) $\left(\frac{\partial u}{\partial y}\right)_{y=0} < 0$ (d) $\left(\frac{\partial u}{\partial y}\right)_{y=0} > 0$

Q.23 Separation of flow occurs when
(a) the pressure intensity reaches a minimum
(b) the cross-section of a channel is reduced
(c) the boundary layer comes to rest
(d) All of the above

Q.24 The ratio of the coefficient of friction drag in laminar boundary layer compared to that in turbulent boundary layer is proportional to
(a) $R_L^{1/2}$ (b) $R_L^{1/5}$
(c) $R_L^{3/10}$ (d) $R_L^{-3/10}$

Q.25 The displacement thickness of a boundary layer is
(a) the distance to the point where (V/V_∞)= 0.99
(b) the distance where the velocity 'V' is equal to the shear velocity V_*, that is, where $v = V_*$
(c) the distance by which the main flow is to be shifted from the boundary to maintain the continuity equation
(d) one-half the actual thickness of the boundary layer

Q.26 If f is friction factor, then Chezy's coefficient is proportional to
(a) f (b) $\sqrt{f}$
(c) $\frac{1}{f}$ (d) $\frac{1}{\sqrt{f}}$

Q.27 The shear velocity V_0 is expressed as
(a) $\rho + \tau_0$ (b) $\sqrt{\rho \times \tau_0}$
(c) $\sqrt{\frac{\rho}{\tau_0}}$ (d) $\sqrt{\frac{\tau_0}{\rho}}$

Q.28 Along a surface with adverse pressure gradient, the point of boundary layer separation is characterized by
(a) $\left.\frac{\partial u}{\partial y}\right|_{y=0} = 0$
(b) shear stress at surface is maximum
(c) air and other dissolved gases in water start appearing as tiny cavities
(d) fluid layer adjacent to surface has velocity equal to free stream velocity

Q.29 For turbulent boundary layer, having velocity distribution

$$\frac{u}{v_0} = \left(\frac{y}{\delta}\right)^{1/m}$$

Which of the following matches are correct?

	Column-A		Column-B
A.	$\frac{\delta^*}{\delta}$	1.	$\frac{m}{(m+1)(m+2)}$
B.	$\frac{\theta}{\delta}$	2.	$\frac{1}{(m+1)}$
C.	$\frac{\delta^*}{\theta}$	3.	$\left(\frac{m+2}{m}\right)$

Codes:

	A	B	C
(a)	1	2	3
(b)	3	2	1
(c)	2	1	3
(d)	1	3	2

Q.30 The ratio of drag on 1st half of the plate to the drag on 2nd half of the plate in case of laminar boundary layer throughout the plate is
(a) $\sqrt{2}-1$ (b) $\sqrt{2}+2$
(c) $\sqrt{2}+1$ (d) $1+\frac{1}{\sqrt{2}}$

Q.31 A laminar flow wind tunnel, has a test section i.e., 40 cm in dia. and 60 cm in length. The air flowing through the wind tunnel has $\nu = 1.516 \times 10^{-5}$ m²/s and at the inlet of wind tunnel, air velocity = 2 m/s. By how much percentage the air velocity change by the end of the section
(a) 4%↑ (b) 4%↓
(c) 2%↑ (d) 2%↓

Q.32 The boundary flow separates from the surface if
(a) $\frac{du}{dy} = 0$ and $\frac{dp}{dy} = 0$
(b) $\frac{du}{dy} = 0$ and $\frac{dp}{dx} > 0$
(c) $\frac{du}{dy} = 0$ and $\frac{dp}{dx} < 0$
(d) The boundary layer thickness is zero

Q.33 **Assertion (A):** Boundary layer theory is applicable only in the vicinity of the leading edge of a flat plate.
Reason (R): Boundary layer theory is based on the assumption that its thickness is small when compared to other linear dimensions in the flow.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

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Answers **Boundary Layer Thickness**

1. (d) 2. (d) 3. (a) 4. (d) 5. (d) 6. (b) 7. (d) 8. (d) 9. (b) 10. (c)
11. (b) 12. (d) 13. (c) 14. (d) 15. (b) 16. (d) 17. (d) 18. (d) 19. (d) 20. (d)
21. (c) 22. (a) 23. (c) 24. (d) 25. (c) 26. (d) 27. (d) 28. (d) 29. (c) 30. (c)
31. (a) 32. (b) 33. (d)

Explanations **Boundary Layer Thickness**

1. (d)
For rising curve, lift force in the vertical plane is needed. So for lift to right trajectory clockwise rotation should be given in horizontal plane.

2. (d)
The point of separation is defined as the limit between forward and reverse flow in the layer very close to the wall, $\left(\frac{\partial u}{\partial y}\right)_{y=0} = 0$.
The minimum pressure occur little upstream of stagnation point.

3. (a)
Friction coefficient,

$$\bar{C}_f = \frac{1328}{\sqrt{Re_L}}$$

$$R_{eL} = \frac{VL}{\nu} = \frac{2\times 2}{10^{-6}} = 4\times 10^6$$

$$\therefore \quad \bar{C}_f = \frac{1328}{\sqrt{4\times 10^6}} = 6.64\times 10^{-4}$$

The drag force on both sides of the plate,

$$F_D = 2\bar{C}_f\left(\frac{1}{2}\rho V^2\right)(B.L)$$

$$= 2\times 6.64\times 10^{-4}\times 1000(2)^2\times 1\times 2$$
$$= 5.31 \text{ N}$$

4. (d)
Shear stress, $\tau = \mu\frac{du}{dy} = \mu\,(0.5 - 2y)$

at $y = 0.2$ m
$\tau = 0.9 \times (0.5 - 2\times 0.2)$
$= 0.09$ N/m²

5. (d)
For a well streamlined body the separation occurs only at the downstream end. As such the wake in this case is extremely small. Hence the pressure drag of such objects is very small fraction of that of the disc. However, the frictional drag of streamlined bodies is considerably large than that of the sphere, since there being more surface area in contact with the flow. Furthermore, for well streamlined objects friction drag is usually larger than pressure drag, but both are so small that their total drag is only about one-fortieth (1/40) of that of the disc.

6. (b)

$$C_D = \frac{24}{R_e} = \frac{24}{0.2} = 120$$

9. (b)
Displacement thickness,

$$\delta = \int_0^{\delta}\left(1-\frac{u}{U}\right)dy$$

Momentum thickness,

$$\delta_\theta = \int_0^{\delta}\frac{u}{U}\left(1-\frac{u}{U}\right)dy$$

Energy thickness,

$$\delta_E = \int_0^{\delta}\frac{u}{U}\left(1-\frac{u^2}{U^2}\right)dy$$

$$\delta^* > \delta_E > \delta_\theta$$

13. (c)
Reynold number,

$$Re_x = \frac{ux}{\nu} = \frac{2\times 1}{15\times 10^{-6}} = 1.33\times 10^5$$

$$\delta = \frac{4.64x}{\sqrt{Re_x}} = \frac{4.64\times 1}{\sqrt{1.33\times 10^5}} = 0.0127$$

Now, $\frac{du}{dy} = U\left[\frac{3}{2}\cdot\frac{1}{\delta} - \frac{3}{2}\left(\frac{y^2}{\delta^3}\right)\right]$

$$\left.\frac{du}{dy}\right|_{y=0} = \frac{3U}{2\delta}$$

Now, shear stress,

$$\tau_0 = \mu\left(\frac{du}{dy}\right)_{y=0}$$

$$= \mu\times\frac{3U}{2\delta} = \frac{3U\times\nu\times\rho}{2\delta}$$

$$= \frac{3\times 2\times 1.5\times 10^{-5}\times 1.23}{2\times 0.0127}$$

$$= 4.36\times 10^{-3} \text{ N/m}^2$$

14. (d)
We know that
Pressure drop across a length L of pipe is

$$\Delta p = \frac{32\mu\, u_{av}L}{D^2} \quad \text{... (i)}$$

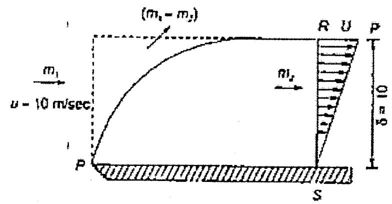
and

$$u_{av} = \frac{u_0}{2} \quad \text{... (ii)}$$

From equation (i) and (ii)

$$\Delta p = \frac{16\mu u_0 L}{D^2}$$

15. (b)



Mass flow rate entering

$(PQ) = \rho\times$ volume
$m_1 = \rho\times A\times U$
$= 1\times(1\times\delta)\times 10$
$= 1\times 10\times 10^{-3}\times 10$
$= 0.1$ kg/sec

Mass flow rate entering (SR)

$$m_2 = \rho\times 1\times\frac{1}{2}(\delta\times U)$$

$$= 1\times 1\times\frac{1}{2}\times 10\times 10^{-3}\times 10$$
$$= 0.05 \text{ kg/sec}$$

$\therefore$ Mass leaving (QR)
$= m_1 - m_2 = 0.1 - 0.05$
$= 0.05$ kg/sec

17. (d)

Drag force $F_D = C_f\times\frac{1}{2}\rho AV^2$

$$= \frac{1.328}{\sqrt{Re_L}}\times\frac{1}{2}\rho AV^2$$

$$= \frac{1.328}{\sqrt{\frac{\rho LV}{\mu}}}\times\frac{1}{2}\rho\times A\times L\times V^2$$

i.e. $F_D \propto \sqrt{L}$

Now Drag force on front half

$$F_{D/2} \propto \sqrt{\frac{L}{2}}$$

$$\therefore \quad F_{D/2} = \frac{F_D}{\sqrt{2}}$$

Drag force on rear half

$$F_{D2} = F_D - F_{D/2} = \left(1-\frac{1}{\sqrt{2}}\right)F_D$$

Now $F = \frac{F_{D/2}}{F_{D2}}$

$$= \frac{\frac{F_D}{\sqrt{2}}}{\left(1-\frac{1}{\sqrt{2}}\right)F_D} = \frac{1}{\sqrt{2}-1} > 1$$

$\therefore \quad F > 1$

21. (c)

$$C_{df} \propto \frac{1}{\sqrt{R_{eL}}}$$

Now, $R_{eL} = \frac{VL}{\nu}$

$\therefore$ $C_{df} \propto \frac{1}{\sqrt{L}}$

Hence if the length of plate is decreased to $\frac{1}{4}$ of its original value, the value of drag coefficient

$$C_{df}' = 2 \times C_{df}$$
$$= 2 \times 0.15$$
$$= 0.030$$

30. (c)

$$F_{drag} \propto \tau_{avg} \times B \times \frac{L}{2}$$

$$= \frac{1.328}{(Re_{L/2})^2} \times B \times \frac{L}{2}$$

$\therefore$ $F_{drag} = (1^{st}\text{half}) = k\sqrt{\frac{L}{2}}$

$$F_{drag} = (2^{nd}\text{half}) = k\left[\sqrt{L} - \sqrt{\frac{L}{2}}\right]$$

$\therefore$ Ratio $= \dfrac{\sqrt{\frac{L}{2}}}{\sqrt{L} - \sqrt{\frac{L}{2}}} = \dfrac{1}{\sqrt{2}-1} = \sqrt{2}+1$

31. (a)

Displacement thickness for laminar boundary layer is given as

$$\delta^* = \frac{1.72x}{\sqrt{R_{ex}}}$$

$$= \frac{1.72 \times 0.6}{\sqrt{\frac{2 \times 0.6}{1.516 \times 10^{-5}}}} = 3.67$$

Due to mass conservation,

$$A_1V_1 = A_2V_2$$

$$\frac{\pi}{4}d^2 \times (2) = \frac{\pi}{4} \times (d - 2 \times \delta^*)^2 \times V_2$$

$\Rightarrow$ $V_2 = 2.075$ m/sec

$\therefore$ Percentage increase

$$= \frac{V_1 - V_2}{V_1} \times 100\%$$

$$= \frac{2.075 - 2}{2} \times 100\% = 3.75\%$$

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