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GATE 2008 SOLUTIONS

AEROSPACE ENGINEERING

IISc Bangalore
Organizing Institute

Solution By Team IGC
Special Thanks to Mr Bhajan Lal J and Mr Sasmit Sanjay

Q. 1 – Q. 20 carry one mark each.

Q.No. 1 The function defined by

$$f(x) = \sin x, \quad x < 0$$
$$= 0, \quad x = 0$$
$$= 3x^3, \quad x > 0$$

(A) is neither continuous nor differentiable at $x = 0$
(B) is continuous and differentiable at $x = 0$
(C) is differentiable but not continuous at $x = 0$
(D) is continuous but not differentiable at $x = 0$

Sol. D

$$f(x) = \begin{cases} \sin x, & x < 0 \\ 0, & x = 0 \\ 3x^3, & x > 0 \end{cases}$$

For Limit –

$\rightarrow \lim_{x\to 0^+} f(x) = \lim_{x\to 0} 3x^3 = 0$

$\rightarrow \lim_{x\to 0^-} f(x) = \lim_{x\to 0} \sin x = 0$

$\rightarrow \lim_{x\to 0} f(x) = \lim_{x\to 0} 0 = 0$

So f(x) is continuous at x = 0

For Differentiability –

$\rightarrow$ Left hand derivative = $\lim_{x\to 0^-} \frac{f(x)-f(0)}{x-0} = \lim_{x\to 0} \frac{\sin x - 0}{x-0} \rightarrow \left(\frac{0}{0}\right)$

Applying L-Hospital,

$$= \lim_{x\to 0} \frac{\cos x}{1} = 1$$

$\rightarrow$ Right hand derivative = $\lim_{x\to 0^+} \frac{f(x)-f(0)}{x-0} = \lim_{x\to 0} \frac{3x^3 - 0}{x-0} = 0$

$\because$ LHD $\neq$ RHD

So f(x) is not differentiable at x = 0

Q.No. 2 The product of the eigenvalues of the matrix

$$\begin{bmatrix} 1 & 0 & 1 \\ 0 & 2 & 1 \\ 1 & 1 & -3 \end{bmatrix}$$

is

(A) 4 (B) 0 (C) −6 (D) −9

Sol. D

Eigen values → $\lambda_1, \lambda_2, \lambda_3$

$\lambda_1 . \lambda_2 . \lambda_3 = |A|$

$$A = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 2 & 1 \\ 1 & 1 & -3 \end{bmatrix}$$

$\lambda_1 . \lambda_2 . \lambda_3 = |A|$ = - 6 + 0 + 0 – 2 – 0 – 1 = - 9

Q.No. 3 Which of the following equations is a LINEAR ordinary differential equation?

(A) $\frac{d^2y}{dx^2} + \frac{dy}{dx} + 2y^2 = 0$

(B) $\frac{d^2y}{dx^2} + y\frac{dy}{dx} + 2y = 0$

(C) $\frac{d^2y}{dx^2} + x\frac{dy}{dx} + 2y = 0$

(D) $\left(\frac{dy}{dx}\right)^2 + \frac{dy}{dx} + 2y = 0$

Sol. C

Q.No. 4 To transfer a satellite from an elliptical orbit to a circular orbit having radius equal to the apogee distance of the elliptical orbit, the speed of the satellite should be

(A) increased at the apogee
(B) decreased at the apogee
(C) increased at the perigee
(D) decreased at the perigee

Sol. A

$$V_{e,a} = \sqrt{\frac{2\mu r_p}{r_a(r_a+r_p)}}$$

$$V_a = \sqrt{\frac{\mu}{r_a}}$$

$$\Delta V = V_a - V_{e,a} > 0$$

Q.No. 5 The service ceiling of a transport aircraft is defined as the altitude

(A) that is halfway between sea-level and absolute ceiling
(B) at which it can cruise with one engine operational
(C) at which its maximum rate of climb is zero
(D) at which its maximum rate of climb is 0.508 m/s

Sol. D

At service ceiling for piston engine a/c, the R/C is 100 ft/min or 0.508 m/s.

Q.No. 6 The drag of an aircraft in steady climbing flight at a given forward speed is

(A) inversely proportional to climb angle
(B) higher than drag in steady level flight at the same forward speed
(C) lower than drag in steady level flight at the same forward speed
(D) independent of climb angle

Sol. C

Aircraft in steady climbing flight at given forward speed,

L = $W\cos\gamma$

T = $W\sin\gamma$ + D

D = T - $W\sin\gamma$

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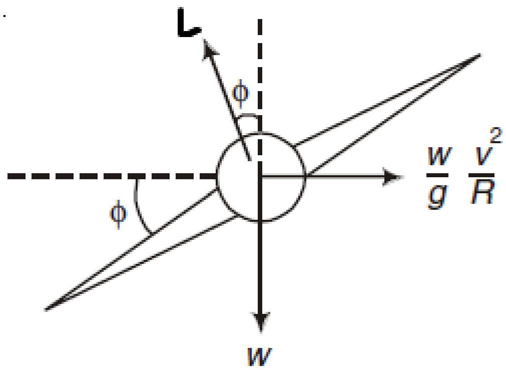
Q.No. 7 In steady, level turning flight of an aircraft at a load factor 'n', the ratio of the horizontal component of lift and aircraft weight is

(A) $\sqrt{n-1}$ (B) $\sqrt{n+1}$ (C) $\sqrt{n^2-1}$ (D) $\sqrt{n^2+1}$

Sol. C



L cos ∅ = W

$\frac{L}{W} = \frac{1}{\cos\emptyset} = n$

$\cos\emptyset = \frac{1}{n}$

$\sin\emptyset = \sqrt{1 - cos^2\emptyset} = \frac{\sqrt{n^2-1}}{n}$

So, $\frac{L\sin\emptyset}{W} = n\times\frac{\sqrt{n^2-1}}{n} = \sqrt{n^2-1}$

Q.No. 8 The parameters that remain constant in a cruise-climb of an aircraft are

(A) equivalent airspeed and lift coefficient (B) altitude and lift coefficient
(C) equivalent airspeed and altitude (D) lift coefficient and aircraft mass

Sol. A

Equivalent air speed does not change with altitude.

C_L does not depends upon altitude.

Q.No. 9 The maximum thickness to chord ratio for the NACA 24012 airfoil is

(A) 0.01 (B) 0.12 (C) 0.24 (D) 0.40

Sol. B

NACA 24012

$\left(\frac{t}{c}\right)_{max}$ = 0.12

Q.No. 10 The maximum possible value of pressure coefficient C_p in incompressible flow is

(A) 0.5 (B) 1 (C) π (D) ∞

Sol. B

Pressure coefficient, $C_P = \frac{P - P_\infty}{\frac{1}{2}\rho_\infty V_\infty^2} = 1 - 4sin^2\theta$

$-3 < C_P < 1$

Q.No. 11 An irrotational and inviscid flow can become rotational on passing through a

(A) normal shock wave (B) oblique shock wave
(C) curved shock wave (D) Mach wave

Sol. C

From Crocco's theorem,

$\vec{V} \times (\vec{\nabla} \times \vec{V}) = \vec{\nabla} h_0 - T\vec{\nabla} s$

Hence $\vec{\nabla} \times \vec{V} \neq 0$

↳ The flow is rotational due to curved shock wave.

Q.No. 12 Laminar flow airfoils are used to reduce

(A) trim drag
(B) skin friction drag
(C) induced drag
(D) wave drag

Sol. B

Q.No. 13 The degree of reaction of an impulse turbine is

(A) 1 (B) 0.75 (C) 0.5 (D) 0

Sol. D

In impulsive turbine there is no enthalpy change of the gas in turbine blade or rotor stage.

Q.No. 14 In a convergent-divergent (CD) nozzle of a rocket motor, the wall heat flux is maximum at

(A) the exit of the divergent portion of the CD nozzle
(B) the entry to the convergent portion of the CD nozzle
(C) the throat of the CD nozzle
(D) the mid-length of the divergent portion of the CD nozzle

Sol. B

Area velocity relation for C-D nozzle,

$\frac{dA}{A} = -\frac{dV}{V}(1 - M^2)$ (M $<$ 1)

Mach number increases continuously, so temperature decreases.

The wall heat flux, q = $k\frac{\partial T}{\partial y}$

If T decreases, heat flux will also decreases.

So heat flux is maximum at inlet of C-D nozzle.

Q.No. 15 In a scramjet engine, the Mach number at the entry to the combustion chamber is around

(A) 0 (B) 0.3 (C) 2 (D) 6

Sol. C

Q.No. 16 DB denotes double base solid propellant.
LOX-RP1 denotes liquid oxygen – kerosene combination.
LOX-LH_2 denotes liquid oxygen – hydrogen combination.

The correct order of increasing specific impulse is

(A) DB < LOX-RP1 < LOX-LH_2
(B) LOX-RP1 < DB < LOX-LH_2
(C) LOX-LH_2 < DB < LOX-RP1
(D) DB < LOX-LH_2 < LOX-RP1

Sol. A

Q.No. 17 In the absence of body moments, the symmetry of the stress tensor is derived from

(A) force equilibrium conditions
(B) moment equilibrium conditions
(C) linear relations between stresses and strains
(D) compatibility conditions

Sol. B

By taking moment equilibrium condition in an infinitesimal 3-D element, we can get complementary stress.

$\tau_{xy} = \tau_{yx}$

$\tau_{yz} = \tau_{zy}$

$\tau_{zx} = \tau_{xz}$

Q.No. 18 In a 3-D orthotropic material, the number of elastic constants in linear stress-strain relationship is

(A) 3 (B) 5 (C) 9 (D) 21

Sol. C

Q.No. 19 The compatibility conditions in theory of elasticity ensure that

(A) there is compatibility between various direct and shear stresses
(B) relationships between stresses and strains are consistent with constitutive relations
(C) displacements are single-valued and continuous
(D) stresses satisfy bi-harmonic equation

Sol. C

Q.No. 20 In a spring-mass-damper single degree of freedom system, the mass is 2 kg and the undamped natural frequency is 20 Hz. The critical damping constant of the system is

(A) 160π N.s/m (B) 80π N.s/m (C) 1 N.s/m (D) 0 N.s/m

Sol. A

m = 2 kg, f_n = 20 Hz

$C_C = 2\sqrt{mk} = 2m\omega_n$

$\omega_n = 2\pi f_n$

$C_C = 160\pi$ N.s/m

Q. 21 to Q.75 carry two marks each.

Q.No. 21 Which of the following quantities remains constant for a satellite in an elliptical orbit around the earth?

(A) Kinetic energy
(B) Product of speed and radial distance from the center of the earth
(C) Rate of area swept by the radial vector from the center of the orbit
(D) Rate of area swept by the radial vector from the center of the earth

Sol. D

→ K.E. changes for a satellite in an elliptical orbit around the earth.

→ Angular momentum is constant,

$\vec{r} \times \vec{v}$ = constant

→ Rate of area swept by the radial vector from the center of the earth is constant.

Q.No. 22 A planet is observed to be at its slowest when it is at a distance r_1 from the sun and at its fastest when it is at a distance r_2 from the sun. The eccentricity e of the planet's orbit is given by

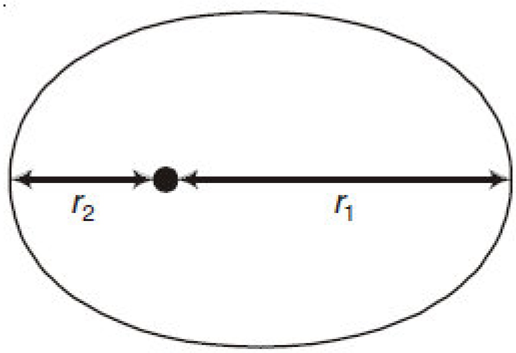
(A) $e = \frac{r_1}{r_2}$

(B) $e = \frac{r_1 - r_2}{r_1 + r_2}$

(C) $e = \frac{r_2}{r_1}$

(D) $e = \frac{r_1 + r_2}{r_1 - r_2}$

Sol. B



e = $\frac{r_1 - r_2}{r_1 + r_2}$

Q.No. 23 The function $f(x,y,z) = \frac{1}{2}x^2y^2z^2$ satisfies

(A) grad $f = 0$

(B) div(grad f) = 0

(C) curl(grad f) = 0

(D) grad(div(grad f)) = 0

Sol. C

f(x, y, z) = $\frac{1}{2}x^2y^2z^2$

Grad f = $\nabla f = \frac{\partial}{\partial x}(\frac{1}{2}x^2y^2z^2)\hat{\imath} + \frac{\partial}{\partial y}(\frac{1}{2}x^2y^2z^2)\hat{\jmath} + \frac{\partial}{\partial z}(\frac{1}{2}x^2y^2z^2)\hat{k}$

∇f = x$y^2z^2\hat{\imath} + x^2yz^2\hat{\jmath} + x^2y^2z\hat{k}$

Curl (grad f) = $\nabla \times \overrightarrow{\nabla f} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ xy^2z^2 & x^2yz^2 & x^2y^2z \end{vmatrix} = 0\hat{\imath} + 0\hat{\jmath} + 0\hat{k}$

Note – Go through vector calculus properties.

Q.No. 24 Which of the following is true for all choices of vectors $\vec{p}, \vec{q}, \vec{r}$?

(A) $\vec{p}\times\vec{q}+\vec{q}\times\vec{r}+\vec{r}\times\vec{p}=0$

(B) $(\vec{p}\cdot\vec{q})\vec{r}+(\vec{q}\cdot\vec{r})\vec{p}+(\vec{r}\cdot\vec{p})\vec{q}=0$

(C) $\vec{p}\cdot(\vec{q}\times\vec{r})+\vec{q}\cdot(\vec{r}\times\vec{p})+\vec{r}\cdot(\vec{p}\times\vec{q})=0$

(D) $\vec{p}\times(\vec{q}\times\vec{r})+\vec{q}\times(\vec{r}\times\vec{p})+\vec{r}\times(\vec{p}\times\vec{q})=0$

Sol. D

$\rightarrow \vec{p}\times(\vec{q}\times\vec{r}) + \vec{q}\times(\vec{r}\times\vec{p}) + \vec{r}\times(\vec{p}\times\vec{q})$

$= (\vec{p}.\vec{r})\,\vec{q} - (\vec{p}.\vec{q})\,\vec{r} + (\vec{q}.\vec{p})\,\vec{r} - (\vec{q}.\vec{r})\,\vec{p} + (\vec{r}.\vec{q})\,\vec{p} - (\vec{r}.\vec{p})\,\vec{q} = 0$

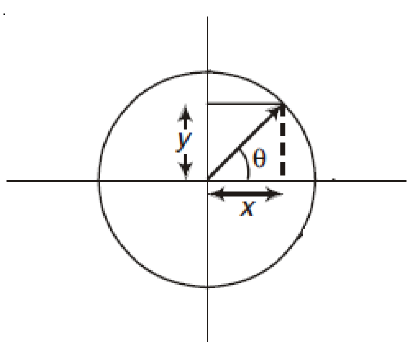
$\because \vec{a}.\vec{b} = \vec{b}.\vec{a}$

Note – Go through vector calculus properties.

Q.No. 25 The value of the line integral $\frac{1}{2\pi}\oint(x\,dy - y\,dx)$ taken anticlockwise along a circle of unit radius is

(A) 0.5 (B) 1 (C) 2 (D) π

Sol. B



x = $\cos\theta$

y = $\sin\theta$

dx = - $\sin\theta$. dθ

dy = $\cos\theta$. dθ

$\frac{1}{2\pi}\oint(xdy - ydx) = \frac{1}{2\pi}\oint(\cos\theta\,.\cos\theta\,.d\theta\ + \sin\theta\,.\sin\theta\,.d\theta\ )$

$= \frac{1}{2\pi}\oint(cos^2\theta + sin^2\theta)\ d\theta$

$= \frac{1}{2\pi}\oint d\theta = 1$

Q.No. 26 Which of the following is a solution of $\frac{d^2y}{dx^2} + 2\frac{dy}{dx} + y = 0$?

(A) $e^{-x} + xe^{-x}$

(B) $e^{x} + xe^{-x}$

(C) $e^{x} + e^{-x}$

(D) $e^{-x} + xe^{x}$

Sol. A

$\frac{d^2y}{dx^2}$ + 2 $\frac{dy}{dx}$ + y= 0

$(D^2 + 2D + 1)$y = 0

$m^2 + 2m + 1$ = 0

m = - 1, - 1

y = $(c_1 + c_2x)e^{-x}$

$Let, c_1 = c_2$ = 1

y = e^{-x} + xe^{-x}

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Q.No. 27 Suppose the non-constant functions $F(x)$ and $G(t)$ satisfy

$$\frac{d^2F}{dx^2} + p^2F = 0, \quad \frac{dG}{dt} + c^2p^2G = 0, \quad \text{where } p \text{ and } c \text{ are constants.}$$

Then the function $u(x,t) = F(x)G(t)$ definitely satisfies

(A) $\frac{\partial^2 u}{\partial t^2} = c^2\frac{\partial^2 u}{\partial x^2}$

(B) $\frac{\partial u}{\partial t} = c^2\frac{\partial^2 u}{\partial x^2}$

(C) $\nabla^2 u = 0$

(D) $\frac{\partial^2 u}{\partial t^2} + c^2u^2 = 0$

Sol. B

$\frac{d^2F}{dx^2} + p^2F = 0$

$\frac{dG}{dt} + c^2p^2$G = 0, Where p and c are constants.

→u(x, t) = F(x)G(t)

$\frac{\partial u}{\partial t}$ = F(x). $\frac{dG(t)}{dt}$ = - c^2p^2 F(x).G(t)

$c^2\frac{\partial^2 u}{\partial x^2}$ = c^2G(t) $\frac{d^2F}{dx^2}$ = - c^2p^2 F(x).G(t)

$\frac{\partial u}{\partial t} = c^2\frac{\partial^2 u}{\partial x^2}$

Q.No. 28 The following set of equations

$$\begin{bmatrix} 1 & 1 & 2 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 \\ -1 \\ 0 \end{bmatrix}$$

has

(A) no solution

(B) a unique solution

(C) two solutions

(D) infinite solutions

Sol. A

→AX = B

A: B = $\begin{bmatrix} 1 & 1 & 2 & : & 1 \\ 1 & 0 & 1 & : & -1 \\ 0 & 1 & 1 & : & 0 \end{bmatrix}$

= $\begin{bmatrix} 1 & 1 & 2 & : & 1 \\ 0 & 1 & 1 & : & 0 \\ 1 & 0 & 1 & : & -1 \end{bmatrix}$ $\quad \rightarrow (R_2 \leftrightarrow R_3)$

= $\begin{bmatrix} 1 & 1 & 2 & : & 1 \\ 0 & 1 & 1 & : & 0 \\ 0 & -1 & -1 & : & -2 \end{bmatrix}$ $\quad \rightarrow (R_3 \rightarrow R_3 - R_1)$

= $\begin{bmatrix} 1 & 0 & 1 & : & 1 \\ 0 & 1 & 1 & : & 0 \\ 0 & 0 & 0 & : & -2 \end{bmatrix}$ $\quad \rightarrow (R_1 \rightarrow R_1 - R_2)$ and $(R_3 \rightarrow R_3 + R_2)$

$\rho(A)$ = 2

$\rho(A{:}B)$ = 3

$\rho(A) < \rho(A{:}B)$ → No solution

Q.No. 29 The function $f(x) = x^2 - 5x + 6$

(A) has its maximum value at $x = 2.0$
(B) has its maximum value at $x = 2.5$
(C) is increasing on the interval (2.0, 2.5)
(D) is increasing on the interval (2.5, 3.0)

Sol. D

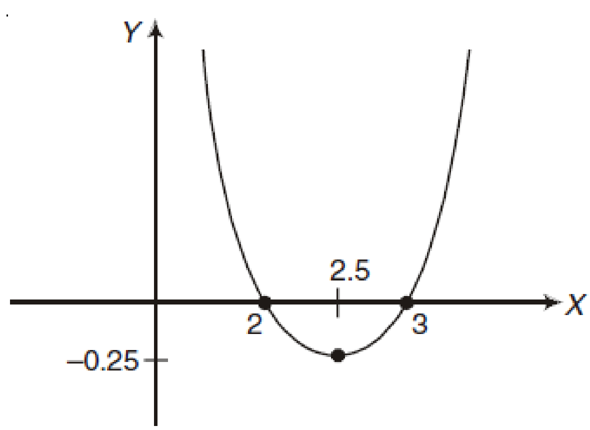
f(x) = x^2 – 5x + 6

f'(x) = 2x - 5 = 0

x = 5/2

f''(x) = 2

So at x = 2.5, f(x) has minimum value.



Q.No. 30 Let $Y(s)$ denote the Laplace transform $L(y(t))$ of the function $y(t) = \cosh(at)\sin(at)$. Then

(A) $L\left(\frac{dy}{dt}\right) = \frac{dY}{ds},\ L(t\,y(t)) = sY(s)$

(B) $L\left(\frac{dy}{dt}\right) = sY(s),\ L(t\,y(t)) = -\frac{dY}{ds}$

(C) $L\left(\frac{dy}{dt}\right) = \frac{dY}{ds},\ L(t\,y(t)) = Y(s-1)$

(D) $L\left(\frac{dy}{dt}\right) = sY(s),\ L(t\,y(t)) = e^{as}Y(s)$

Sol. B

y(t) = $\cosh(at)\sin(at)$

L{ y'(t) } = s y(s) - y(0) = s y(s)

L{ t y(t) } = (-1). $\frac{d}{ds}[y(s)]$

y(0) = 0

Note - Go through Laplace's properties.

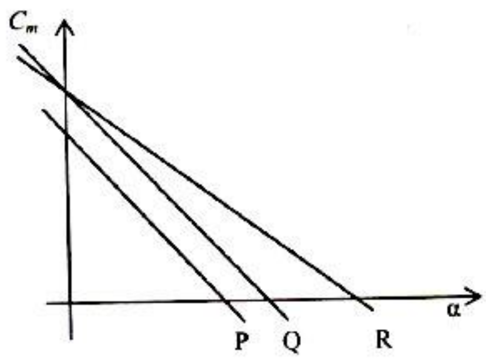
Q.No. 31 The velocity required for a spacecraft to escape earth's gravitational field depends on

(A) the mass of the spacecraft
(B) the distance between earth's center and the spacecraft
(C) the earth's rotational speed about its own axis
(D) the earth's orbital speed

Sol. B

$V_{esc} = \sqrt{\frac{2GM}{R_e+h}}$

Q.No. 32 The figure below shows the variation of C_m versus α for an aircraft for three combinations of elevator deflections and locations of centre of gravity. In the figure, lines P and Q are parallel, while lines Q and R have the same intercept on the C_m axis.



Which of the following statements is true?

(A) Lines P and Q correspond to the same centre of gravity location.
(B) Lines Q and R correspond to the same centre of gravity location.
(C) Lines P and Q correspond to the same elevator deflection.
(D) Lines P and R correspond to the same centre of gravity location.

Sol. A

For wing,

$C_{m_{cg}} = C_{m_{ac}} + C_L[\bar{X}_{cg} - \bar{X}_{ac}]$

$= C_{m_{ac}} + (C_{L0} + C_{L_\alpha}.\alpha)\ [\bar{X}_{cg} - \bar{X}_{ac}]$

$= C_{m_{ac}} + C_{L0}\ [\bar{X}_{cg} - \bar{X}_{ac}] \ + \ C_{L_\alpha}[\bar{X}_{cg} - \bar{X}_{ac}]\ \alpha$

$C_{m_{cg}} = C_{m0} + C_{m_\alpha}.\alpha$

So C_{m_α} depends upon only centre of gravity.

The C_{m_α} of P and Q is same.

Q.No. 33 Which of the following statements is TRUE as the altitude increases in stratosphere of International Standard Atmosphere?

(A) Temperature increases and dynamic viscosity decreases.
(B) Temperature remains constant and pressure increases.
(C) Temperature decreases and sound speed decreases.
(D) Temperature remains constant and density decreases.

Sol. D

Temperature is constant in stratosphere from 11 to 25 km. So dynamic viscosity remains constant but pressure and density decreases with altitude.

Q.No. 34 Which of the following statements is TRUE?

(A) Wing dihedral reduces roll stability while a low wing increases roll stability.
(B) Wing dihedral increases roll stability while a low wing reduces roll stability.
(C) Wing dihedral, as well as low wing reduces roll stability.
(D) Wing dihedral, as well as low wing increases roll stability.

Sol. B

Q.No. 35 An aircraft has a level flight stalling speed of 60 m/s EAS (equivalent air speed). As per the V-n diagram, what is the minimum speed at which it should be designed to withstand the maximum vertical load factor of 9?

(A) 20 m/s (B) 60 m/s (C) 120 m/s (D) 180 m/s

Sol. D

V_{stall} = 60 m/s = $V_{eq} = \sqrt{\frac{2W}{\rho S C_{L,max}}}$

$V^* = \sqrt{\frac{2W n_{max}}{\rho S C_{L,max}}} = V_{stall}\sqrt{n_{max}}$

$= 60\times\sqrt{9} = 180$ m/s

Q.No. 36 Match each mode of aircraft motion listed in Group I to its corresponding property from Group II.

Group I: Aircraft mode	Group II: Property
P: Short period mode	1: Coupled roll-yaw oscillations
Q: Wing rock	2: Angle of attack remains constant
R: Phugoid mode	3: Roll oscillations
S: Dutch roll	4: Speed remains constant

(A) P-2, Q-1, R-4, S-3
(B) P-4, Q-3, R-2, S-1
(C) P-4, Q-1, R-2, S-3
(D) P-2, Q-3, R-4, S-1

Sol. B

Q.No. 37 An aircraft is cruising at a true air speed (TAS) of 100 m/s under ISA conditions, at an altitude at which the density of free stream is 0.526 kg/m^3. What will be the equivalent air speed (EAS)?

(A) 65.5 m/s (B) 72.5 m/s (C) 110.5 m/s (D) 152.7 m/s

Sol. A

True air speed, V_T = 100 m/s

ρ = 0.526 kg/m^3

ρ_∞ = 1.225 kg/m^3

$\rightarrow \frac{1}{2}\rho V_T^2 = \frac{1}{2}\rho_\infty V_{eq}^2$

$V_{eq} = \sqrt{\frac{\rho}{\rho_\infty}} V_T$ = 65.52 m/s

Q.No. 38 In the definition of the aircraft Euler angles φ (roll), θ (pitch), and ψ (yaw), the correct sequence of rotations required to make the inertial frame coincide with the aircraft body frame is

(A) first ψ about z axis, second θ about y axis, third φ about x axis
(B) first θ about y axis, second φ about x axis, third ψ about z axis
(C) first φ about x axis, second θ about y axis, third ψ about z axis
(D) first ψ about z axis, second φ about x axis, third θ about y axis

Sol. A

Q.No. 39 To maximize range of a jet engine aircraft, it should be flown at a velocity that maximizes

(A) C_L/C_D (B) $C_L^{0.5}/C_D$ (C) $C_L^{1.5}/C_D$ (D) C_L^2/C_D

Sol. B

Range for jet engine,

$R = \frac{1}{TFSC} \cdot \frac{C_L^{1/2}}{C_D} \cdot 2\sqrt{\frac{2}{\rho S}} \cdot [\sqrt{W_0} - \sqrt{W_1}]$

$R_{max} \propto \left(\frac{C_L^{1/2}}{C_D}\right)_{max}$

Q.No. 40 The primary function of the fin in the vertical tail of an aircraft is to provide

(A) yaw control
(B) yaw stability
(C) roll damping
(D) roll stability

Sol. B

Q.No. 41 An aircraft requires the trailing edge of the elevator to be deflected upwards from its initial position to lower the trim speed. Which of the following statements about the static stick-fixed stability of this aircraft is true?

(A) The aircraft is unstable.
(B) The aircraft is neutrally stable.
(C) The aircraft is stable.
(D) The stability of the aircraft cannot be determined from the given information.

Sol. A

$\frac{1}{2}\rho V_{trim}^2 S.C_{L,trim}$ = L = W

$$\frac{d\delta_e}{dC_{L,trim}} < 0$$

$$\frac{d\delta_e}{dC_{L,trim}} = \frac{S.M.}{C_{m_{\delta_e}}} = \frac{\bar{X}_{NP}-\bar{X}_{CG}}{C_{m_{\delta_e}}} < 0$$

$\bar{X}_{NP} < \bar{X}_{CG}$ → Unstable

Q.No. 42 Which of the following statements is true for an aircraft flying at a low angle of attack?

(A) Yawing motion generates yawing moment and pitching moment.
(B) Rolling motion generates rolling moment and pitching moment.
(C) Yawing motion generates yawing moment and rolling moment.
(D) Pitching motion generates yawing moment and rolling moment.

Sol. C

Q.No. 43 Consider 2-D flow with stream function $\psi = \frac{1}{2}\ln\left(\sqrt{x^2+y^2}\right)$. The absolute value of circulation along a unit circle centered at $(x = 0, y = 0)$ is

(A) 0 (B) 1 (C) $\pi/2$ (D) π

Sol. D

$-\frac{\partial\psi}{\partial x} = \text{v}, \quad \frac{\partial\psi}{\partial y} = \text{u}$

$-\frac{\partial\psi}{\partial r} = V_\theta, \quad \frac{1}{r}\frac{\partial\psi}{\partial\theta} = V_r$

$\psi = \frac{1}{2}\ln(\sqrt{x^2+y^2})$

Circulation, Γ = - $\oint V.ds$

x = r$\cos\theta$, y = r$\sin\theta$

$\psi = \frac{1}{2}\ln(r)$

V_θ = - $\frac{1}{2r}$

Circulation, Γ = - $\int_0^{2\pi r} V_\theta.ds = \frac{1}{2r} \times 2\,\pi r = \pi$

Q.No. 44 Consider a symmetric airfoil at an angle of attack of 4 degrees. Using thin airfoil theory, the magnitude of the moment coefficient about the leading edge is

(A) 2π (B) π (C) $\pi^2/60$ (D) $\pi^2/90$

Sol. D

Angle of attack, $\alpha = 4°$

$C_{m,le}$ = - $\frac{\pi}{2}\alpha$ (For thin symmetrical airfoil)

= - $\frac{\pi}{2} \times 4 \times \frac{\pi}{180}$ = - $\frac{\pi^2}{90}$

Magnitude of $C_{m,le}$ = $\left|-\frac{\pi^2}{90}\right| = \frac{\pi^2}{90}$

Q.No. 45 Consider steady, inviscid flow in a convergent-divergent (CD) nozzle, with a normal shock in the divergent portion. The static pressure along the nozzle downstream of the normal shock

(A) remains constant
(B) increases isentropically to the static pressure at the nozzle exit
(C) decreases isentropically to the static pressure at the nozzle exit
(D) can increase or decrease, depending on the magnitude of the static pressure at the nozzle exit

Sol. B

Q.No. 46 For a free stream Mach number of 0.7 the critical pressure coefficient ($C_{p,cr}$) is -0.78. If the minimum pressure coefficient for a given airfoil in incompressible flow is -0.6, then the flow over the airfoil at a free stream Mach number of 0.7 is

(A) subsonic and compressible
(B) completely supersonic
(C) incompressible
(D) partly subsonic and partly supersonic

Sol. D

M_∞ = 0.7

$C_{p,cr}$ = - 0.78

$C_{P,Incomp.}$ = - 0.6

$C_{P,comp.} = \frac{C_{P,Incomp.}}{\sqrt{1-M_\infty^2}}$ = - 0.8402

$C_{P,comp.} < C_{p,cr}$

So flow will be partly subsonic and partly supersonic.

Q.No. 47 If the flow Mach number in a turbulent boundary layer over a flat plate is increased keeping the Reynolds number unchanged, the skin friction coefficient C_f

(A) decreases
(B) increases
(C) remains constant
(D) initially decreases, followed by a rapid increase

Sol. A

Skin friction coefficient, $C_f = \frac{\tau_w}{\frac{1}{2}\rho V^2}$

Q.No. 48 In supersonic wind-tunnel design, an oblique shock diffuser is preferred over a normal shock diffuser because

(A) it reduces total pressure loss
(B) the flow is slowed down more rapidly
(C) the flow is accelerated more rapidly
(D) it increases total pressure loss

Sol. A

Q.No. 49 The variation of downwash along the span of an untwisted wing of elliptic planform is

(A) sinusoidal (B) parabolic (C) elliptic (D) constant

Sol. D

Q.No. 50 Flow past an airfoil is to be modeled using a vortex sheet. The strength of the vortex sheet at the trailing edge will be

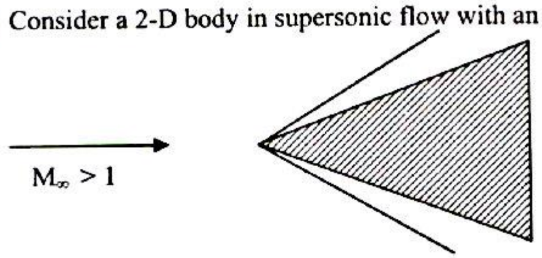
(A) 0 (B) 1 (C) 2π (D) ∞

Sol. A

According to Kutta's condition, the velocity on upper and lower surface should be same.

So strength of vortex sheet, $\gamma(T.E) = V_1 - V_2 = 0$

Q.No. 51 Consider a 2-D body in supersonic flow with an attached oblique shock as shown below



An increase in free stream Mach number M_∞ will cause the oblique shock wave to

(A) move closer to the body
(B) move away from the body
(C) detach from the body
(D) become a normal shock

Sol. A

For constant θ, as Mach number increases β decreases and shock will become stronger and will more closely to the body.

Q.No. 52 The geometrical features of a supercritical airfoil are

(A) rounded leading edge, flat upper surface and high camber at the rear
(B) sharp leading edge, curved upper surface and high camber at the rear
(C) rounded leading edge, curved upper surface and no camber at the rear
(D) sharp leading edge, flat upper surface and no camber at the rear

Sol. A

The super-critical airfoil is used for increasing $M_{drag-divergence}$.

The shock wave strength reduces at upper surface.

Q.No. 53 Which one of the following high lift device results in higher stalling angle?

(A) split flap
(B) Fowler flap
(C) plain flap
(D) leading edge flap

Sol. A

Note – Go through high lift devices.

Q.No. 54 A turbofan engine has a bypass ratio of 5 and a total mass flow rate of 120 kg/s. The mass flow rate through the bypass duct is

(A) 20 kg/s (B) 100 kg/s (C) 120 kg/s (D) 600 kg/s

Sol. B

Total mass flow rate, $\dot{m}_a = \dot{m}_c + \dot{m}_h = 120$ kg/s

By pass ratio, $\beta = \frac{\dot{m}_c}{\dot{m}_h} = 5$

$\dot{m}_c = 100$ kg/s

Q.No. 55 A turbojet engine is operating with afterburner off. If the afterburner is switched on, then

(A) both thrust and *sfc* decrease
(B) thrust increases and *sfc* decreases
(C) thrust decreases and *sfc* increases
(D) both thrust and *sfc* increase

Sol. D

After-burner is used to increase thrust.

Q.No. 56 A centrifugal compressor operates with a tip blade speed of 340 m/s. The air leaves the impeller with a radial velocity of 88 m/s. If the slip factor is 0.85, the relative velocity at the blade tip is

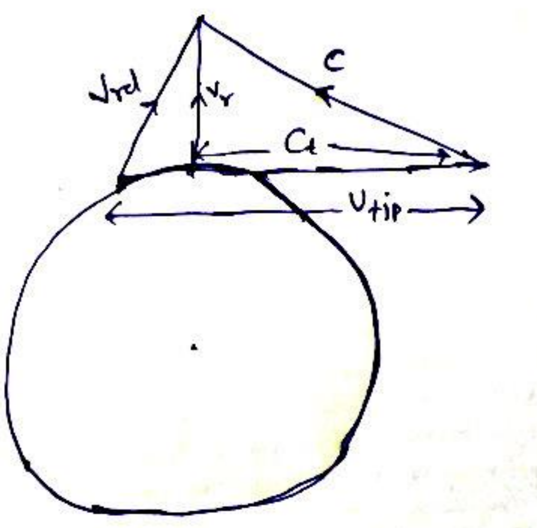
(A) 101.7 m/s (B) 120.3 m/s (C) 132.6 m/s (D) 135.8 m/s

Sol. A

U_{tip} = 340 m/s

V_r = 88 m/s

Slip factor, μ = 0.85 = $\frac{C_t}{U_{tip}}$



$$V_{rel} = \sqrt{V_r^2 + (U_{tip} - C_t)^2}$$

$= \sqrt{V_r^2 + (U_{tip} - \mu U_{tip})^2}$ = 101.7 m/s

Q.No. 57 An ideal ramjet engine is flying at a Mach number M. The exhaust gas static temperature at the outlet of the nozzle is T_e. The ambient static temperature is T_a. Gas constant R and specific heat ratio γ do not vary through the ramjet. Assuming that nozzle exhaust static pressure is equal to the ambient pressure and fuel air ratio $f << 1$, the thrust per unit mass flow rate is

(A) $\sqrt{\gamma R T_a}\left[\sqrt{\frac{T_e}{T_a}}\right]$

(B) $\sqrt{\gamma R T_a}\left[\sqrt{\frac{T_e}{T_a}} - 1\right]$

(C) $M\sqrt{\gamma R T_a}\left[\sqrt{\frac{T_e}{T_a}} - 1\right]$

(D) $M\sqrt{\gamma R T_a}\left[\sqrt{\frac{T_e}{T_a}}\right]$

Sol. C

$P_e = P_a$ → Optimum expansion

f = $\frac{\dot{m}_f}{\dot{m}_a} << 1$

We know,

$M_a = M_e$

$\frac{V_a}{\sqrt{\gamma R T_a}} = \frac{V_e}{\sqrt{\gamma R T_e}}$

$V_e = \sqrt{\frac{T_e}{T_a}} V_a$ $\quad (V_a = M\sqrt{\gamma R T_a})$

F = $(\dot{m}_a + \dot{m}_f)V_e - \dot{m}_a V_a$

$= \dot{m}_a V_e - \dot{m}_a V_a$

$\frac{F}{\dot{m}_a} = V_e - V_a = \sqrt{\frac{T_e}{T_a}} V_a - V_a$ = M$\sqrt{\gamma R T_a}\left(\sqrt{\frac{T_e}{T_a}} - 1\right)$

Q.No. 58 A 50 percent degree of reaction axial flow turbine operates with a mean blade speed of 180 m/s. The flow leaves the stator and enters the rotor at an angle of 60 degrees to the axial direction. The axial velocity is 150 m/s, and remains constant throughout the stage. The turbine power per unit mass flow is

(A) 29.76 kJ/kg (B) 41.12 kJ/kg (C) 58.33 kJ/kg (D) 61.13 kJ/kg

Sol. D

Degree of reaction, $°R$ = 0.5 (for turbine)

$\beta_2 = \alpha_3$

$\alpha_2 = \beta_3$ = 60°

Mean blade speed, u = 180 m/s

Axial velocity, C_a = 150 m/s

$\rightarrow °R$ = - $\frac{\emptyset}{2}[\tan\beta_2 - \tan\beta_3]$ = - $\frac{C_a}{2u}[\tan\beta_2 - \tan\beta_3]$

0.5 = - $\frac{150}{2\times180}$ $[\tan\beta_2 - \tan 60]$

β_2 = 27.92°

So turbine power per unit mass flow, w = u.$C_a[\tan\beta_2 + \tan\beta_3]$ = 61.07 kJ/kg

Q.No. 59 The chamber stagnation temperature inside a rocket motor is T_c. Only a convergent nozzle is used, and the flow at the exit of this nozzle is choked. Assume that the nozzle exhaust static pressure is equal to ambient static pressure. Gas constant for exhaust gases is R and ratio of specific heats is γ. The specific impulse of the rocket motor is

(A) $\sqrt{\frac{2\gamma RT_c}{\gamma-1}}$ (B) $\sqrt{\frac{\gamma RT_c}{\gamma-1}}$ (C) $\sqrt{\frac{\gamma RT_c}{\gamma+1}}$ (D) $\sqrt{\frac{2\gamma RT_c}{\gamma+1}}$

Sol. D

Stagnation temperature inside a rocket motor = T_c

$P_e = P_a$ (given)

Specific impulse, $I_{sp} = \frac{Thrust}{weight\ flow\ rate}$

$= \frac{\dot{m}V_e}{\dot{m}g} = \frac{V_e}{g}$ second

Total thrust, F = $\dot{m}V$ + (P_e - P_a) V_e = $\dot{m}V$

$\therefore V_e$ = V

Assuming isentropic flow,

T_0 = T + $\frac{V^2}{2C_P}$ = Constant

V_e = V = $\sqrt{2(T_0 - T)C_P}$ $(T_0 = T_c)$

= $\sqrt{2T_C C_P(1 - \frac{T}{T_c})}$

= $\sqrt{\frac{2\gamma R}{\gamma - 1} T_C(1 - \frac{T}{T_c})}$

$\frac{T_C}{T}$ = 1 + $\frac{\gamma-1}{2}M^2$

For chocked flow, M = 1

$\frac{T_C}{T}$ = $\frac{\gamma+1}{2}$

V_e = $\sqrt{\frac{2\gamma R}{\gamma-1} T_C(1 - \frac{2}{\gamma+1})}$ = $\sqrt{\frac{2\gamma R}{\gamma+1} T_C}$

So, Specific impulse, I_{sp} = $\frac{\sqrt{\frac{2\gamma R}{\gamma+1} T_C}}{g}$

Here g is missing in options.

Q.No. 60 Air enters the combustor of a gas turbine engine at total temperature of 500 K and leaves the combustor at total temperature of 1800 K. If c_p remains constant at 1.005 kJ/kgK and heating value of the fuel used is 44 MJ/kg, the fuel to air ratio is

(A) 0.003 (B) 0.012 (C) 0.031 (D) 0.074

Sol. C

T_{01} = 500 K

T_{02} = 1800 K

C_p = 1.005 kJ/kg.K

Heating value of the fuel, ΔH_{rp} = 44 MJ/kg

Energy equation for chamber,

$\dot{m}_a h_{01} + \dot{m}_f \eta_b \Delta H_{rp} = (\dot{m}_a + \dot{m}_f)\, h_{02}$

$\therefore \eta_b = 1$

$C_p\, T_{01}$ + f. ΔH_{rp} = (1+f) $C_p\, T_{02}$

So, f = 0.0309 ≅ 0.031

Q.No. 61 The initial temperature sensitivity of burn rate of a solid rocket motor propellant is positive. If the initial temperature increases then

(A) thrust increases but burn time decreases
(B) thrust decreases and burn time decreases too
(C) thrust remains same but burn time increases
(D) thrust increases but burn time remains same

Sol. D

Let, r = burn rate

T = temperature

Temperature sensitivity, $\left.\frac{\partial r}{\partial T}\right|_{T=T_0} > 0$

T_0 = initial temperature

We know, r = a.P_i^n

Here, n = exponent (independent of initial temperature)

Assuming no other parameter changes,

→ a is defined based on ambient conditions.

Hence if initial temperature increases then thrust will also increases.

Bur r is independent of initial temperature. Hence burn time remains same.

Q.No. 62 An aircraft is cruising at a Mach number of 0.8 at an altitude where the ambient static pressure is 95 kPa. The diffuser exit total pressure is 140 kPa. Assuming there is no change in the specific heat at constant pressure across the diffuser, and ratio of specific heats is 1.4, the adiabatic efficiency of the intake is

(A) 0.988 (B) 0.915 (C) 0.722 (D) 0.684

Sol. B

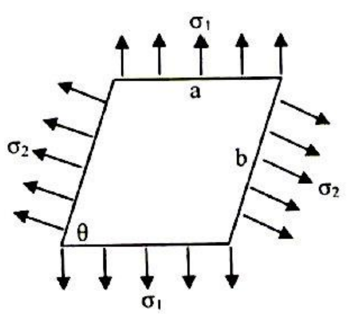
M_a = 0.8, P_a = 95 kPa, P_{01} = 140 kPa, γ = 1.4

We know,

$$\frac{P_{01}}{P_a} = \left[1 + \eta_d \left(\frac{\gamma - 1}{2}\right) M_a^2\right]^{\frac{\gamma}{\gamma-1}}$$

So, η_d = 0.915

Q.No. 63 A parallelogram shaped plate of dimensions 'a' and 'b' as shown in the figure, is subjected to a uniform loading of normal stresses σ_1 and σ_2. The plate is in equilibrium for



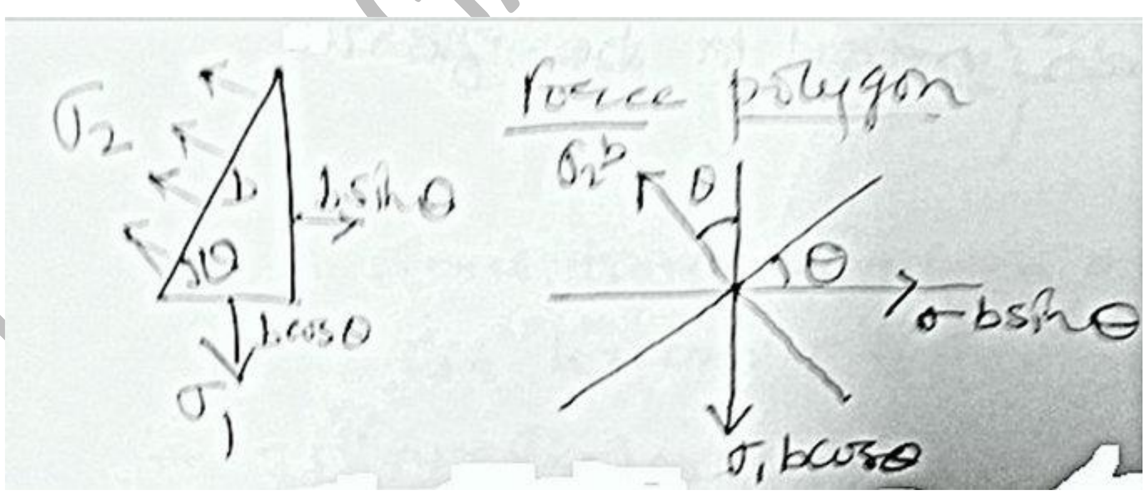
(A) any value of σ_1 and σ_2

(B) $\sigma_2 = \sigma_1 \cos\theta$

(C) $\sigma_1 = \sigma_2 \cos\theta$

(D) $\sigma_2 = \sigma_1$

Sol. D



Resolving forces in y – direction,

$\sigma_2 \text{b}.\cos\theta = \sigma_1 \text{b}.\cos\theta$

$$\sigma_2 = \sigma_1$$

Q.No. 64 A column of solid circular cross-section and length L can have various end conditions. Choose the correct set that matches the end conditions (listed in Group I) with the corresponding effective length for buckling (listed in Group II).

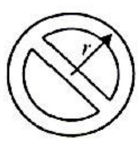
Group I (end conditions)	Group II (effective length)
(P) one end built-in and other end free	(1) 1.0 L
(Q) both ends pinned	(2) 0.7 L
(R) both ends built-in	(3) 2.0 L
(S) one end built-in and other end pinned	(4) 0.5 L

(A) P - 3, Q - 1, R - 4, S - 2
(B) P - 4, Q - 1, R - 2, S - 3
(C) P - 2, Q - 1, R - 3, S - 4
(D) P - 3, Q - 1, R - 2, S - 4

Sol. A

Note – Go through buckling of column with different type of boundary conditions.

Q.NO. 65 A thin walled tube of circular cross-section with mean radius r has a central web which divides it into two symmetric cells as shown. A torque M is acting on the section. The shear flow q in the central web is



(A) $q = \frac{M}{2\pi r^2}$ (B) $q = 0$ (C) $q = \frac{M}{4\pi r^2}$ (D) $q = \frac{M}{\pi r^2}$

Sol. B

From below figure, the twist per length for section (1) and section (2) is same.

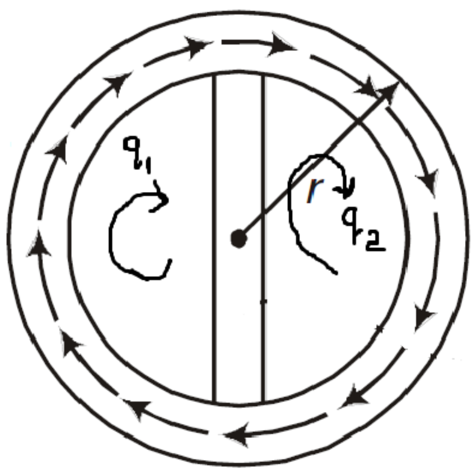
$\theta'_1 = \theta'_2$ .... (1)

$$\theta'_1 = \frac{1}{2AG}\left[\frac{q_1 \pi r}{t} + \frac{(q_1 - q_2)2r}{t}\right]$$

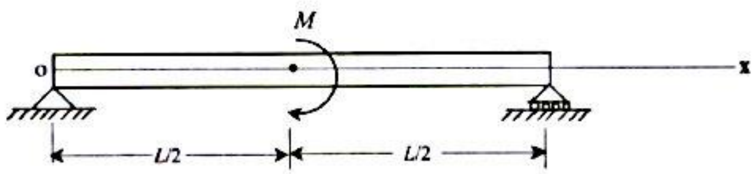
$$\theta'_2 = \frac{1}{2AG}\left[\frac{q_2 \pi r}{t} + \frac{(q_2 - q_1)2r}{t}\right]$$

From equation (1), $q_1 = q_2$

So the shear flow q in the centered web = $q_1 - q_2$ = 0

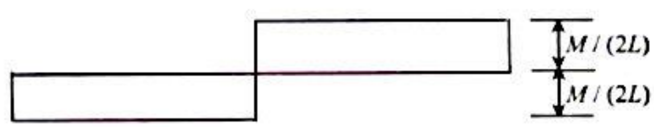


Q.No. 66 A concentrated bending moment M is acting at mid-span of a beam as shown. The shear force diagram for the beam is:

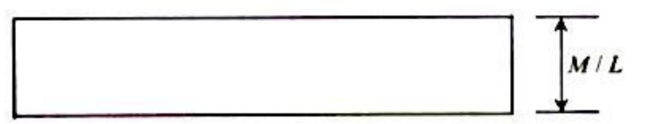


(A)

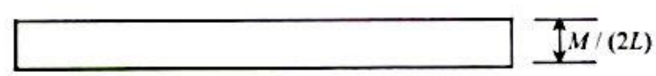
(B)



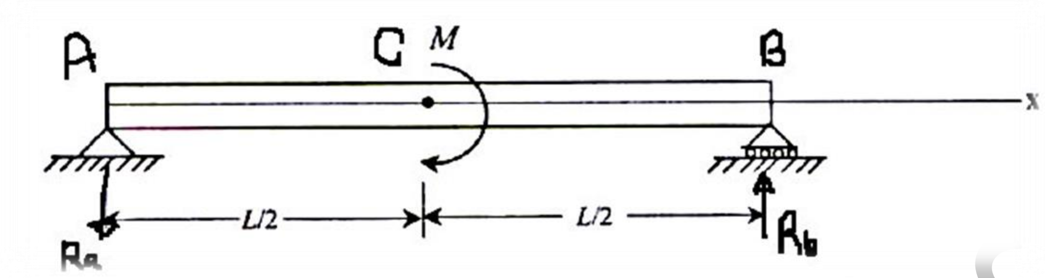
(C)



(D)



Sol. C



$R_a + R_b$ = 0...... (1)

$\sum M_a = R_b \times L$ - M = 0........ (2)

$R_b = \frac{M}{L}$

$R_a = -\frac{M}{L}$

→From left hand side,

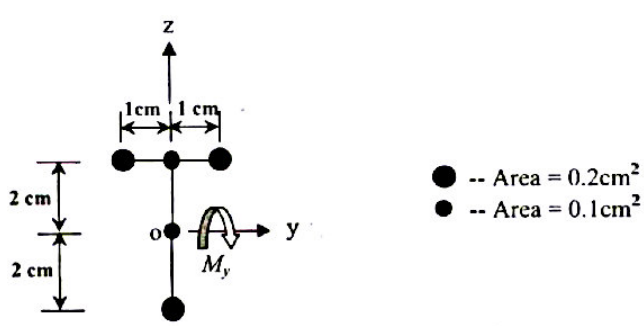
<u>Section BC-</u>

$F_x = R_b = \frac{M}{L}$

<u>Section CA-</u>

$F_x = R_b = \frac{M}{L}$

Q.No. 67 An idealized thin-walled cross-section of a beam and the respective areas of the booms are as shown. A bending moment M_y is acting on the cross-section. The ratio of the magnitude of normal stress in the top booms to that of the bottom boom is



(A) 5/11 (B) 2/5 (C) 1 (D) 5/2

Sol. A

For CG,

$\bar{y}$ = 0 cm

$\bar{z} = \frac{0.2\times2\times2+0.1\times2-0.2\times2}{0.2\times3+0.1\times2}$ = 0.75 cm

$\sigma_x = \frac{M_y}{I_{yy}}.z$

$(\sigma_x)_{top} = \frac{M_y}{I_{yy}}.z_{top}$

$(\sigma_x)_{bottom} = \frac{M_y}{I_{yy}}.z_{bottom}$

$\frac{(\sigma_x)_{top}}{(\sigma_x)_{bottom}} = \left|\frac{z_{top}}{z_{bottom}}\right| = \left|\frac{2-0.75}{2+0.75}\right| = \frac{5}{11}$

Q.No. 68 An engineer is asked to test a system which can be idealized as SDOF (single degree of freedom) with viscous damping. A frequency response test was conducted and it is found that the quality factor Q is equal to 10. What will be the logarithmic decrement if a free vibration test is performed?

(A) $\pi/40$ (B) $\pi/20$ (C) $\pi/10$ (D) $\pi/5$

Sol. C

Quality factor, Q = 10 = $\frac{1}{2\xi}$

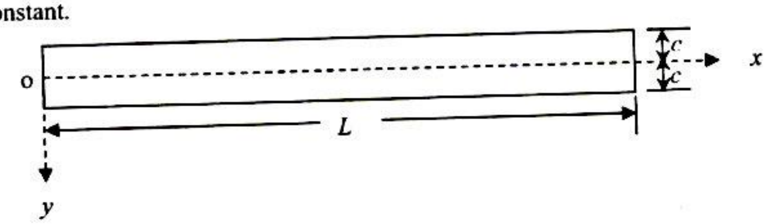
ξ = 0.05

Longitudinal decrement, $\delta = \frac{2\pi\xi}{\sqrt{1-\xi^2}} = \frac{\pi}{10}$

Q.No. 69 A beam occupies a region $0 \leq x \leq L$; $-c \leq y \leq c$; $-0.5 \leq z \leq 0.5$ as shown below. The beam can be considered to be in plane stress condition in x-y plane. Airy's stress function for the beam is given as:

$$\phi(x,y) = -\frac{Pxy^3}{4c^3} + \frac{3Pxy}{4c}$$

where P is a constant.



The above stress function pertains to a

(A) simply supported beam carrying a point load P at mid span
(B) simply supported beam carrying a uniform distributed load of intensity P per unit length
(C) cantilever beam clamped at end $x = L$ and carrying a shear load P at $x = 0$
(D) cantilever beam clamped at end $x = 0$ and carrying a shear load P at $x = L$

Sol. C

$\emptyset(x,y)$ = - $\frac{Pxy^3}{4c^3} + \frac{3Pxy}{4c}$

$\sigma_{xx} = \frac{\partial^2\emptyset}{\partial y^2}$ = - $\frac{3Pxy}{2c^3}$

$\sigma_{xx} = \frac{M_z}{I_{zz}}$.y

For the c/s,

$I_{zz} = \frac{1\times(2c)^3}{12} = \frac{2c^3}{3}$

$M_z = \frac{\sigma_{xx}\times I_{zz}}{y} = \frac{-\frac{3Pxy}{2c^3}\times\frac{2c^3}{3}}{y}$ = - Px

At x = 0 $\rightarrow M_z$ = 0

At x = L $\rightarrow M_z$ = - PL

So it is cantilever beam clamped at end x = L and carrying a shear load P at x = 0.

Q.No. 70 The equation of motion of a uniform slender beam of length L in flexural vibration is given as $EI\dfrac{\partial^4 w}{\partial x^4} + \rho A\dfrac{\partial^2 w}{\partial t^2} = 0$, where EI is the flexural rigidity, w is the lateral displacement and ρA is the mass per unit length. The beam is simply supported at the two ends $x = 0$ and $x = L$. Assuming the mode shape in fundamental mode to be $\sin\left(\dfrac{\pi x}{L}\right)$, the natural frequency in fundamental mode is

(A) $0.5\sqrt{\dfrac{EI}{\rho AL^4}}\pi^2$ (B) $\sqrt{\dfrac{EI}{\rho AL^4}}\pi^2$ (C) $2\sqrt{\dfrac{EI}{\rho AL^4}}\pi^2$ (D) $4\sqrt{\dfrac{EI}{\rho AL^4}}\pi^2$

Sol. B

Natural frequency, $\omega_n = \frac{n^2\pi^2}{L^2}\sqrt{\frac{EI}{\rho A}}$

For first mode of vibration, n = 1

$\omega_n = \sqrt{\frac{EI}{\rho AL^4}}.\pi^2$

Common Data Questions

Common Data for Questions 71, 72 and 73: A two-dimensional state of stress in an isotropic material is given by

$$[\sigma] = c\begin{bmatrix} -8 & 5 \\ 5 & 16 \end{bmatrix} \text{MPa}$$

where c is linearly proportional to the applied loading. The failure stress is σ_f = 350 MPa (which is 0.2 % offset yield stress).

Q.No. 71 The principal stresses are

(A) σ_1 = 17c MPa, σ_2 = −9c MPa
(B) σ_1 = 9c MPa, σ_2 = 17c MPa
(C) σ_1 = −17c MPa, σ_2 = −9c MPa
(D) σ_1 = −17c MPa, σ_2 = 9c MPa

Sol. A

$[\sigma] = c\begin{bmatrix} -8 & 5 \\ 5 & 16 \end{bmatrix}$ MPa = $\begin{bmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{xy} & \sigma_{yy} \end{bmatrix}$

σ_f = 350 MPa

$\sigma_{1,2} = \frac{\sigma_{xx}+\sigma_{yy}}{2} \pm \sqrt{\left(\frac{\sigma_{xx}-\sigma_{yy}}{2}\right)^2 + \tau_{xy}^2}$

$= \frac{-8c+16c}{2} \pm \sqrt{\left(\frac{-8c-16c}{2}\right)^2 + (5c)^2}$ = 17c, -9c

σ_1 = 17c MPa

σ_2 = -9c MPa

Q.No. 72 The maximum shear stress is

(A) $\tau_{max} = 7c$ MPa (B) $\tau_{max} = 10c$ MPa (C) $\tau_{max} = 13c$ MPa (D) $\tau_{max} = 15c$ MPa

Sol. C

$\tau_{max} = \sqrt{\left(\frac{\sigma_{xx}-\sigma_{yy}}{2}\right)^2 + \tau_{xy}^2}$ = 13c MPa

Q.No. 73 The maximum value of c for safe loading of the structure, based on von-Mises failure criterion is

(A) 10.2 (B) 15.3 (C) 25.4 (D) 31.8

Sol. B

By von-mises failure criterion,

$[(\sigma_1 - \sigma_2)^2 + \sigma_1^2 + \sigma_2^2] = 2\sigma_f^2$

$[(17c + 9c)^2 + (17c)^2 + (-9c)^2] = 2\times 350^2$

c = 15.3

Common Data for Questions 74 and 75: A liquid rocket engine with oxidizer to fuel ratio of 5:1 produces a thrust of 1 MN. The initial mass of the rocket engine is 100,000 kg and its mass at burn out is 10,000 kg. The characteristic velocity C^* and thrust coefficient C_F for the engine are 2386 m/s and 1.4, respectively.

Q.No. 74 The mass flow rate of fuel is

(A) 300.3 kg/s (B) 269.5 kg/s (C) 87.4 kg/s (D) 49.9 kg/s

Sol. D

F = 1MN, M_i = 100,000 kg, M_f = 10,000 kg

$M_p = M_i - M_f$ = 90,000 kg

C^* = 2386 m/s, C_F = 1.4

Thrust, F =$C_F.P_C A_{th}$

$\rightarrow P_C A_{th} = \dot{m}_p C^*$

Thrust, F =$C_F.P_C A_{th} = C_F.\dot{m}_p C^*$

$\dot{m}_p$ = 299.36 kg/s

$\frac{\dot{m}_o}{\dot{m}_f} = \frac{5}{1}$

$\dot{m}_p = \dot{m}_o + \dot{m}_f$

$\dot{m}_f$ = 49.89 kg/s

Q.No. 75 Neglecting gravity and drag effects, if the initial velocity of the liquid rocket engine is 2.5 km/s, the velocity of the rocket at burnout is

(A) 1.2 km/s (B) 2.5 km/s (C) 10.2 km/s (D) 11.8 km/s

Sol. C

ΔV = c.ln$\frac{M_i}{M_f}$

F = $\dot{m}_p.c$

c = 3340.45 m/s

ΔV = c.ln$\frac{M_i}{M_f}$ = 7.69 km/s

V_f - V_i = 7.69 km/s

V_f = 7.69 + 2.5 = 10.19 m/s

Linked Answer Questions: Q.76 to Q. 85 carry two marks each.

Statement for Linked Answer Questions 76 and 77: The following two questions relate to Simpson's rule for approximating the integral $\int_a^b f(x)dx$ on the interval $[a, b]$.

Q.No. 76 Which of the following gives the correct formula for Simpson's rule?

(A) $\frac{(b-a)}{2}\left[f(b)+f\left(\frac{a+b}{2}\right)\right]$

(B) $\frac{(b-a)}{2}\left[\frac{f(a)+f(b)}{2}+f\left(\frac{a+b}{2}\right)\right]$

(C) $\frac{(b-a)}{2}\left[\frac{f(a)+f(b)}{3}+\frac{4}{3}f\left(\frac{a+b}{2}\right)\right]$

(D) $\frac{(b-a)}{2}\left[\frac{f(a)+f(b)}{3}+\frac{4}{3}f\left(\frac{a+b}{3}\right)\right]$

Sol. C

Q.No. 77 The percentage error (with respect to the exact solution) in estimation of the integral $\int_0^1 x^3\,dx$ using Simpson's rule is

(A) 5.3 (B) 3.5 (C) 2.8 (D) 0

Sol. D

f(x) = $\int_0^1 x^3 dx$

I_{exact} = $\int_0^1 x^3 dx$ = $\left[\frac{x^4}{4}\right]_0^1$ = 0.25

By Simpson's 1/3 rd rule,

$\int_{x_0}^{x_0+nh} \text{f(x)dx} = \frac{h}{3}[(y_0 + y_n) + 4(y_1 + y_3 + \cdots) + 2(y_2 + y_4 + \cdots)]$

h = $\frac{1-0}{4}$ = 0.25

x	0	0.25	0.50	0.75	1
f(x)	0	0.015625	0.125	0.421875	1

$I_{simp.}$ = $\int_0^1 x^3 dx$ = $\frac{0.25}{3}[(0 + 1) + 4(0.015625 + 0.421875) + 2(0.125)]$ =

= 0.25

% error = $\frac{I_{simp.} - I_{exact}}{I_{exact}} \times 100\% = 0\ \%$

Statement for Linked Answer Questions 78 and 79: An aircraft has a zero-lift drag coefficient $C_{D_0} = 0.0223$, wing aspect ratio $AR_w = 10.0$, and Oswald's efficiency factor $e = 0.7$

Q.No. 78 The thrust required for steady level flight will be minimum when the aircraft operates at a lift coefficient of

(A) 0.65 (B) 0.70 (C) 0.75 (D) 0.80

Sol. B

$C_{D0} = 0.0223$, $AR_w = 10$, e = 0.7

K = $\frac{1}{\pi e AR_w}$ = 0.0454

Minimum thrust required condition,

$C_{Di} = C_{D0}$

k$C_L^2 = C_{D0}$

$C_L = 0.70$

Q.No. 79 The glide angle that results in maximum range in a power-off glide is

(A) 1.82 degrees (B) 2.68 degrees (C) 3.64 degrees (D) 5.01 degrees

Sol. C

For gliding,

L = W$\cos\gamma$

D = W$\sin\gamma$

$\tan\gamma = \frac{D}{L} = \frac{1}{C_L/C_D} = \frac{H}{R}$ ..... (1)

R_{max} = H× $\left(\frac{C_L}{C_D}\right)_{max}$ → Minimum drag condition

$$C_{Di} = C_{D0}$$

$$kC_L^2 = C_{D0}$$

$$C_L = 0.70$$

$C_D = C_{D0} + kC_L^2 = 0.0445$

From equation (1),

$\gamma = 3.63°$

Statement for Linked Answer Questions 80 and 81: Consider an untwisted wing of elliptical planform in inviscid incompressible irrotational flow at an angle of attack of 4 degrees. The wing aspect ratio is 7 and the zero lift angle of attack is −2 degrees.

Q.No. 80 The wing lift coefficient C_L is

(A) 0.66 (B) 0.51 (C) 0.44 (D) 0.34

Sol. B

$\alpha = 4°$, e = 1, AR = 7, $\alpha_{L=0} = -2°$

$C_L = a.(\alpha - \alpha_{L=0})$

$a = \frac{a_0}{1+\frac{a_0}{\pi e \text{AR}}}$

$a_0 = 2\pi$ per rad. (For symmetrical thin airfoil)

a = 0.0852 per degree

$C_L = 0.51$

Q.No. 81 The induced drag coefficient of the wing C_{Di} is

(A) 0.0053 (B) 0.0087 (C) 0.0118 (D) 0.0197

Sol. C

$C_{Di} = kC_L^2 = \frac{C_L^2}{\pi eAR} = 0.0118$

Statement for Linked Answer Questions 82 and 83: A multi-stage axial flow compressor operating at an adiabatic efficiency of 0.9 develops a total pressure ratio of 11. The total temperature at inlet to the compressor is 335 K and the stagnation enthalpy rise across each stage is 37 kJ/kg. Ratio of specific heats is 1.4 and specific heat at constant pressure is 1.005 kJ/kg K.

Q.No. 82 The total temperature rise across the compressor is

(A) 310.1 K (B) 366.3 K (C) 392.1 K (D) 405.4 K

Sol. B

$\eta_{adi,c}$ = 0.9, γ = 1.4, c_P = 1.005 kJ/kg.K

$\frac{P_{02}}{P_{01}}$ = 11, T_{01} = 335 K

$$\eta_{adi,c} = \frac{T'_{02}-T_{01}}{T_{02}-T_{01}} = \frac{\frac{T'_{02}}{T_{01}}-1}{\frac{T_{02}}{T_{01}}-1}$$

$$\frac{T'_{02}}{T_{01}} = \left\{\frac{P_{02}}{P_{01}}\right\}^{\frac{\gamma-1}{\gamma}} = 11^{0.2857} = 1.9889$$

$\frac{T_{02}}{T_{01}}$ = 2.0932

T_{02} = 701.22 K

ΔT = T_{02} - T_{01} = 366.22 K

Q.No. 83 The total number of stages required are

(A) 9 (B) 10 (C) 11 (D) 12

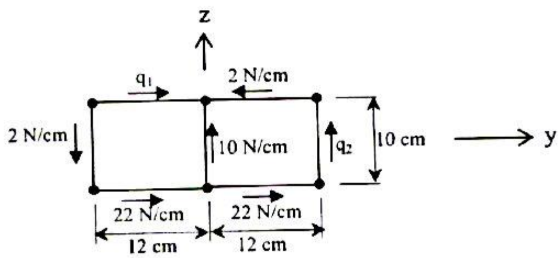
Sol. B

Total enthalpy rises, $(\Delta h_0)_c$ = h_{02} - h_{01} = $c_P(T_{02}$ - $T_{01})$ = 368.051 kJ/kg

$(\Delta h_0)_{stage}$ = 37kJ/kg

So no. of stages = $\frac{(\Delta h_0)_c}{(\Delta h_0)_{stage}}$ = 9.94 ≅ 10

Statement for Linked Answer Questions 84 and 85:
An idealized thin walled two cell symmetric box beam is as shown. The shear flows in the walls are due to the applied shear forces V_y = 480 N, V_z = 300 N, and a torque M, all acting at the shear center.



Q.No. 84 The shear flows q_1 and q_2 are

(A) $q_1 = -2$ N/cm, $q_2 = +22$ N/cm
(B) $q_1 = +2$ N/cm, $q_2 = +22$ N/cm
(C) $q_1 = +2$ N/cm, $q_2 = -22$ N/cm
(D) $q_1 = -2$ N/cm, $q_2 = -22$ N/cm

Sol. A

V_y = 480 N

V_Z = 300 N

$\sum F_y = V_y = q_1 \times 12 + 22\times 12 + 22\times 12 - 2\times 12 = 480$

q_1 = - 2N/cm

$\sum F_z = V_z = q_2 \times 10 + 10\times 10 - 2\times 10 = 300$

q_2 = 22N/cm

Q.No. 85 The torque M is

(A) 3360 N.cm (B) 5760 N.cm (C) 6960 N.cm (D) 8160 N.cm

Sol. B

Torque, M = 2Aq

Torque about C.G.,

M = $2A_1q_1 + 2A_2q_2$ (ACW)

= $2\times(12 \times 10) \times 2 + 2\times(12 \times 10) \times 22$ = 5760 N-cm

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