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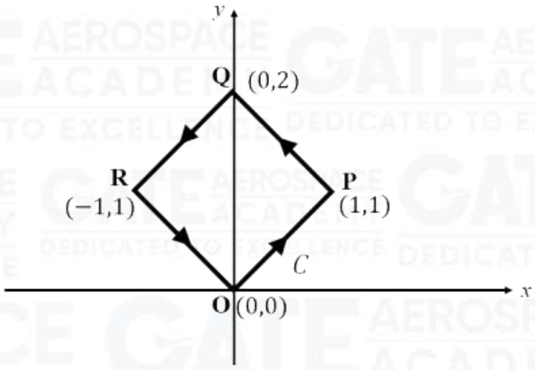
NEW BATCH FOR

GATE AEROSPACE 27/28

Aerospace Engineering section

Q.1 – Q.25 Carry ONE mark Each

Q.1) Consider the contour C shown in the figure below. For the vector $\vec{F} = (x+2y)\hat{e}_x + (2x+4y)\hat{e}_y$, the integral $\oint_C \vec{F}\cdot d\vec{l} =$ ___ . Here $d\vec{l}$ represents an infinitesimal length along the contour C.



(A) 0
(B) 2
(C) 4
(D) 6

Solution: (A)

$$\oint_c \vec{F}\,.\,\vec{dl}$$

For closed contour we need to apply Green's theorem

$$\vec{F} = P\,\hat{\imath} + Q\,\hat{\jmath}$$

$$\frac{\partial Q}{\partial x} = \frac{\partial P}{\partial y}$$

$$P = x + 2y, Q = 2x + 4y$$

$$\frac{\partial P}{\partial y} = \frac{\partial}{\partial y}(x+2y) = 2$$

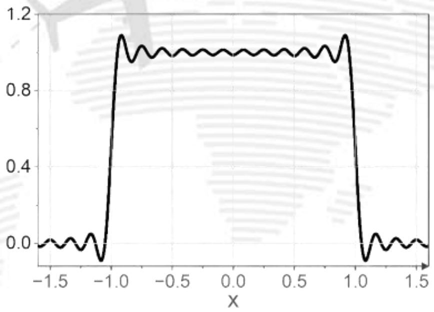
$$\frac{\partial Q}{\partial x} = \frac{\partial}{\partial x}(2x+4y) = 2$$

Since $\frac{\partial Q}{\partial x} = \frac{\partial P}{\partial y}$

The vector field $\vec{F}$ is conservative

i.e., for a conservative vector field, the line integral around any closed contour/loop is zero.

Q.2) The Fourier series representation of a square wave is shown in the figure below. The fluctuations seen near x = ±1 are named after which one of the following scientists?



(A) Cauchy (B) Fourier
(C) Gibbs (D) Laplace

Solution: (C) Gibbs

Q.3) The following equation with respect to $\varphi(x,t)$, where a is a non-zero constant, represents _________.

$$\frac{\partial \varphi}{\partial t} + a\frac{\partial \varphi}{\partial x} = 0$$

(A) Linear wave propagation (B) Transient heat conduction
(C) Newton's law of cooling (D) radiative transfer

Solution: (A) Linear wave Propagation

Q.4) Which one of the following makes an ideal air-standard Stirling cycle?
(A) Two reversible isobars, and two reversible adiabatics
(B) Two reversible isotherms, and two reversible isobars
(C) Two reversible isotherms, and two reversible isochores
(D) Isentropic compression, constant volume heat addition, isentropic expansion, and constant volume heat rejection

Solution: (C) Stirling cycle consists of isothermal compression, constant volume heat addition, isothermal expansion and constant volume heat rejection. Hence two reversible isotherms and two reversible isochores.

Q.5) In fluid dynamics, d'Alembert's paradox refers to which one of the following?
(A) Deviation of drag from $D \propto v^2$ at very low speeds
(B) Deviation of drag from $D \propto v^2$ at high subsonic speeds
(C) Prediction of zero drag by potential flow theory
(D) Presence of shocks in transonic flows

Solution: (C) Potential flow theory predicts symmetrical distribution of flow about vertical axis and hence drag comes out to be zero which is known as D'Alembert's paradox.

Q.6) The number of independent elastic constants that a fully anisotropic linear elastic material can have is _______.

(A) 36 (B) 21
(C) 10 (D) 2

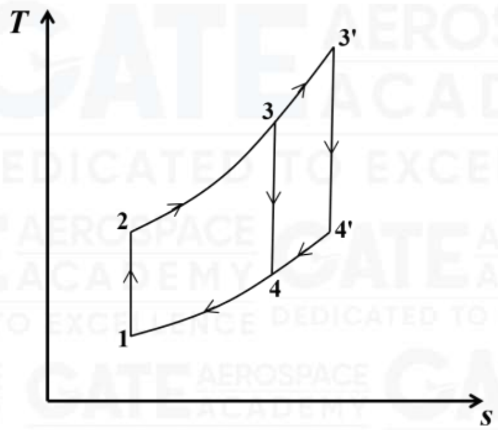
Solution: (B) There are 21 independent elastic constants for fully anisotropic linear elastic material.

Q.7) A cantilever beam with an unsymmetric cross-section is subjected to a transverse shear force (P) at its free end. P acts at the shear center of the beam cross-section.
Which one of the following statements is TRUE about the deformation of this beam?

(A) The beam undergoes only torsion
(B) The beam undergoes only bending
(C) The beam undergoes both torsion and bending
(D) The beam undergoes neither torsion nor bending

Solution: (B) When shear load act at shear center then it causes pure bending with no twisting.

Q.8) The figure below depicts two ideal gas turbine cycles, cycle 1-2-3-4-1 and cycle 1-2-3'-4'-1, on a T-s diagram. Which one the following statements is FALSE?



(A) The thermal efficiency of the two cycles is the same
(B) The specific work of the two cycles is the same
(C) The processes 2-3 and 2-3' are isobaric
(D) The amount of heat added in the combustion process is greater for the cycle 1-2-3'-4'-1

Solution: (B) From cycle, it's clear that both cycles have same pressure ratio. Thermal efficiency depends on pressure ratio

$$\eta_{th} = 1 - \frac{1}{r_p^{\frac{\gamma}{\gamma-1}}}$$

Since pressure ratio is same, thermal efficiency is same for both the cycles. Process 2-3 and 2-3′ are constant pressure heat addition process so both are isobaric process. Since maximum temperature is more for cycle 1-2-3′-4′-1 so amount of heat added is more for this cycle. Hence specific work of two cycles is not same.

Q.9) The velocity potential function (ϕ) given below represents which one of the following?

$$\phi = 5x - 12y$$

(A) Doublet (B) Irrotational vortex
(C) Source (D) Uniform flow

Solution: (D)

$$\phi = 5x - 12y$$

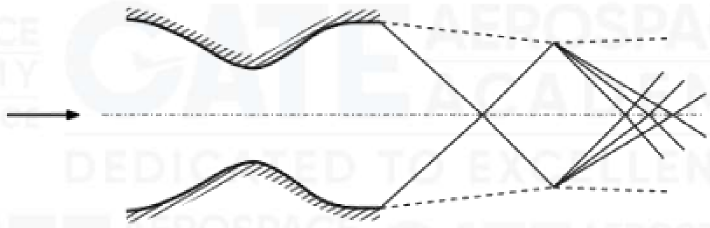
$u = \frac{\partial \phi}{\partial x} = 5,\ v = \frac{\partial \phi}{\partial y} = -12$

Velocity components are constant hence it is uniform flow.

Q.10) The fundamental purpose of the Kutta condition in the thin airfoil theory is________.
(A) to determine the total strength of the source distribution
(B) to determine the speed of the uniform flow
(C) to incorporate the essential effect of viscosity in the potential flow theory
(D) to incorporate the concept of induced drag in the inviscid theory

Solution: (C) Thin airfoil theory assumes flow to be inviscid, however as per Kutta condition flow should leave the trailing edge smoothly. This condition is met due to viscous nature of medium. Hence Kutta condition incorporate the essential effect of viscosity in the potential flow theory.

Q.11) In the figure shown below, the flow at the nozzle exit is ________.



(A) Overexpanded (B) Underexpanded
(C) Ideally expanded (D) Subsonic

Solution: (A) Since there is formation of oblique shock at exit of nozzle it's the case of over expansion where pressure at exit fall below the back pressure and oblique shock gets formed to increase the pressure.

Q.12) An $n \times n$ square matrix A satisfies $A^T = A^{-1}$. The determinant of this matrix may take which of the following value(s)?

(A) 1 (B) -1
(C) n (D) 0

Solution: (A), (B)
For Orthogonal matrix
Determinant of an orthogonal matrix is ± 1
Alternate method

$$A^T = A^{-1}$$
$$A^T . A = I$$

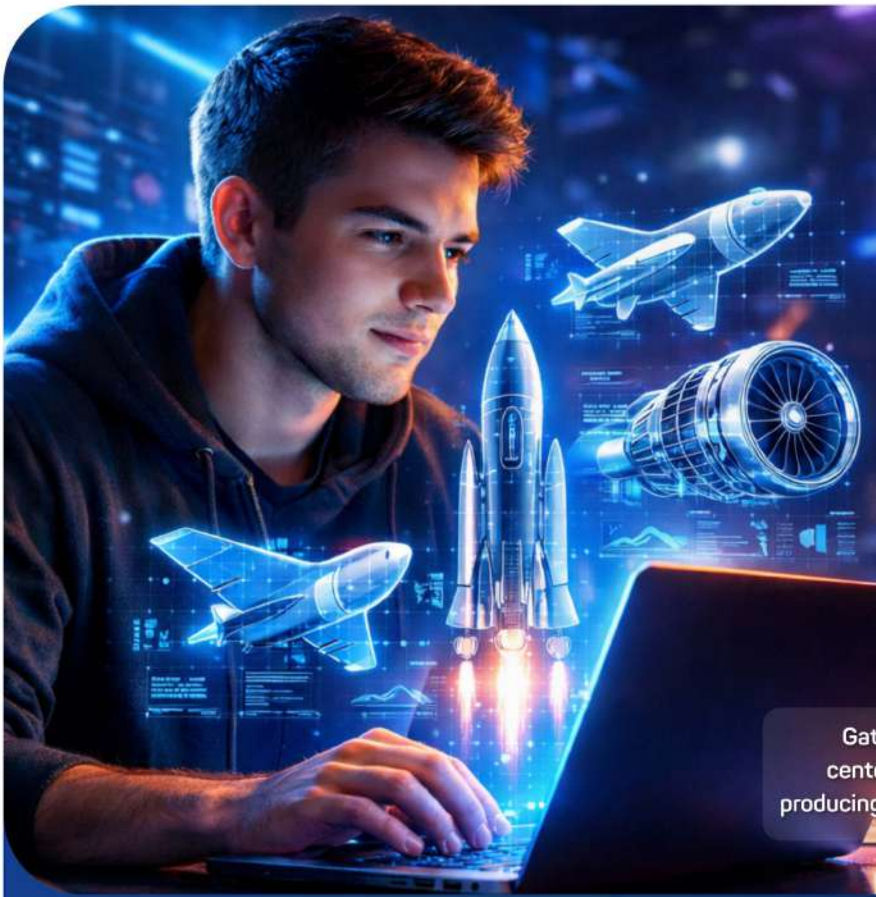
Taking determinant on both sides

$$|A^T . A| = |I|$$
$$|A^T| . |A| = |I|$$
$$|A| . |A| = 1$$
$$|A|^2 = 1$$
$$|A| = \pm 1$$

Q.13) Which of the following statements is/are TRUE about the stability of an aircraft?
(A) Static stability of an aircraft is sufficient to guarantee its dynamic stability
(B) Static stability of an aircraft is related only to its initial tendency to return towards the equilibrium position from which it is disturbed
(C) An aircraft may be dynamically unstable even if it is statically stable
(D) Dynamic stability is related to the time history of aircraft motion after being disturbed from its equilibrium position

Solution: (B), (C), (D)
Static stability of an aircraft is related initial tendency to return towards the equilibrium position from which it is disturbed. Static stability is prerequisite for dynamic stability but if aircraft is statically stable then it may be dynamically stable, unstable or neutral. So, existence of static stability doesn't mean that aircraft will be dynamically stable too. An aircraft may be dynamically unstable even if it is statically stable. Dynamic stability is related to the time history of aircraft motion after being disturbed from its equilibrium position.

Q.14) For a given air-standard power, the propulsive efficiency of a turbofan engine is more than that of a turbojet engine. Which of the following is/are the reason(s) for this?
(A) The mass flow rate is more for a turbofan engine
(B) The exit velocity is lower for a turbofan engine



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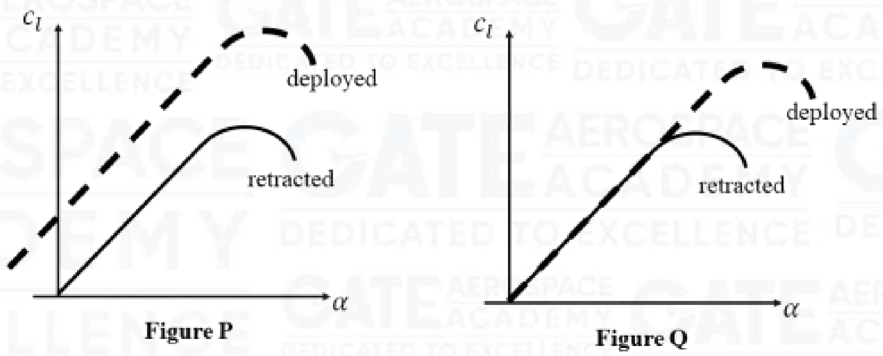
(C) A turbofan engine operates at a lower altitude
(D) The fan of a turbofan engine consumes lesser power

Solution: (A), (B)
Turbofan accelerates large amount of mass through comparatively less change in velocity than in turbojet engine. So mass flow rate is more for a turbofan engine and exhaust velocity is less which results in higher propulsive efficiency.

Q.15) Shown below are qualitative illustrations of the lift curve for an airfoil when two different control surfaces are in their respective retracted and deployed configurations. Which of the following is/are TRUE?



(A) Figure P is for a flap
(B) Figure P is for a slat
(C) Figure Q is for a slat
(D) Figure Q is for a flap

Solution: (A), (C)
Slat doesn't alter the lift curve slope of wing. High pressure air travels from bottom surface to upper surface through the slot and thereby energizing the air on top surface and delays the separation, so it increases the max lift and stalling angle. Hence Figure Q is for a slat. Whereas flap changes the camber and zero lift angle of attack gets changed and curve gets shifted to left side. Hence Figure P is for a flap.

Q.16) The state of stress at a point in a 2-D body, in the $x-y$ Cartesian coordinate system, is represented in matrix form as $[\sigma]$. The transformation matrix [Q] rotates the coordinate system to a new $x'-y'$ Cartesian coordinate system. Select the CORRECT option(s) that represent(s) the state of stress in the new coordinate system.

(A) $[Q][\sigma][Q]^T$

(B) $[Q]\,[\sigma]\,[Q]^{-1}$

(C) $([Q]^{-1})^T[\sigma][Q]^T$

(D) $[Q]^{-1}[\sigma][Q]$

Solution: (A), (B), (C)

$$\sigma = \begin{bmatrix} \sigma_{xx} & \tau_{xy} \\ \tau_{xy} & \sigma_{yy} \end{bmatrix}$$

Stress on inclined plane is given by

$$\sigma_{x'x'} = \sigma_{xx}\cos^2\theta + \sigma_{yy}\sin^2\theta + 2\tau_{xy}\sin\theta\cos\theta$$
$$\sigma_{y'y'} = \sigma_{xx}\sin^2\theta + \sigma_{yy}\cos^2\theta - 2\tau_{xy}\sin\theta\cos\theta$$
$$\tau_{x'y'} = (\sigma_{yy} - \sigma_{xx})sin\theta cos\theta + \tau_{xy}(cos^2\theta - sin^2\theta)$$

This can be written in matrix form

$$\begin{bmatrix}\sigma_{x'x'} & \tau_{x'y'}\\ \tau_{x'y'} & \sigma_{y'y'}\end{bmatrix} = \begin{bmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{bmatrix}\begin{bmatrix}\sigma_{xx} & \tau_{xy}\\ \tau_{xy} & \sigma_{yy}\end{bmatrix}\begin{bmatrix}\cos\theta & -\sin\theta\\ \sin\theta & \cos\theta\end{bmatrix}$$

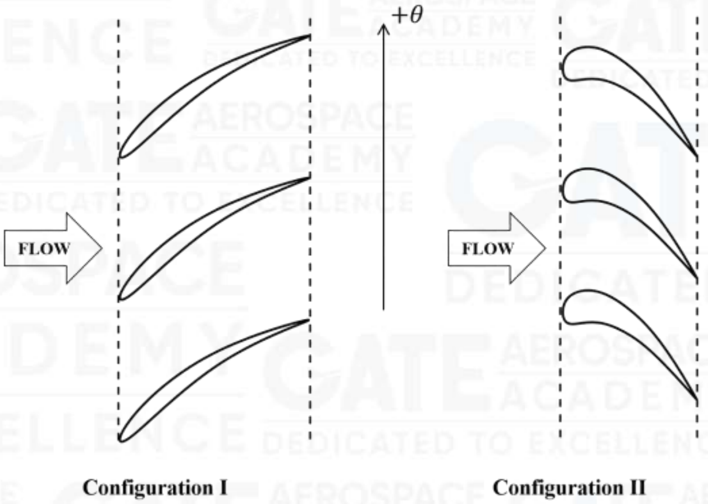
$$[Q] = \begin{bmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{bmatrix}, [Q^T] = \begin{bmatrix}\cos\theta & -\sin\theta\\ \sin\theta & \cos\theta\end{bmatrix}$$

$$\begin{bmatrix}\sigma_{x'x'} & \tau_{x'y'}\\ \tau_{x'y'} & \sigma_{y'y'}\end{bmatrix} = [Q][\sigma][Q^T]$$

Since $[Q]$ is orthogonal matrix, $[Q]^{-1} = [Q]^T$, hence

$$\begin{bmatrix}\sigma_{x'x'} & \tau_{x'y'}\\ \tau_{x'y'} & \sigma_{y'y'}\end{bmatrix} = [Q][\sigma][Q^T] = [Q][\sigma][Q]^{-1} = ([Q]^{-1})^T[\sigma][Q^T]$$

Q.17) The figure below shows the blading of the rotors of two different axial turbo machines under their typical operating conditions, labelled as Configuration I and Configuration II. Which of the following statements is/are TRUE?



(A) Configuration I corresponds to the rotor of a compressor and Configuration II corresponds to the rotor of a turbine

(B) Configuration I corresponds to the rotor of a turbine and Configuration II corresponds to the rotor of a compressor

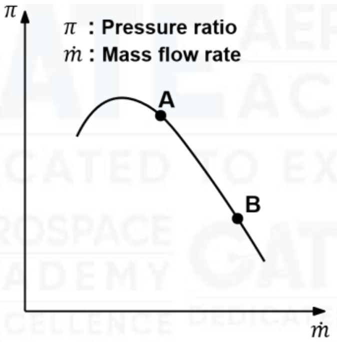
(C) The rotor blades of the turbomachine in Configuration I move along the $+\theta$ direction

(D) The rotor blades of the turbomachine in Configuration II move along the $+\theta$ direction

Solution: (A), (D)

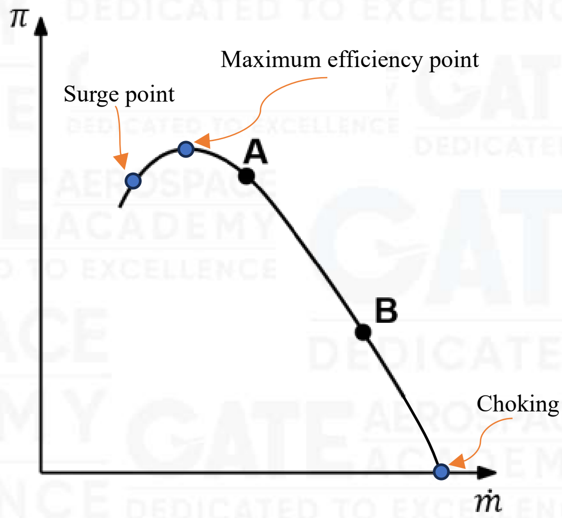
Configuration I corresponds to compressor, its profile thinner than turbine blade given in configuration II because of adverse pressure gradient. Turbine blades given in configuration II move along $+\theta$ direction.

Q.18) A multi-stage axial compressor can be operated at two points, A and B, both of which lie on the same speed line, as shown in the figure below. If η is the isentropic efficiency of the compressor, select the statements that is/are TRUE.



(A) $\eta_A > \eta_B$
(B) $\eta_B > \eta_A$
(C) In comparison to point B, point A is closer to the surge point
(D) In comparison to point A, point B is closer to the choke point

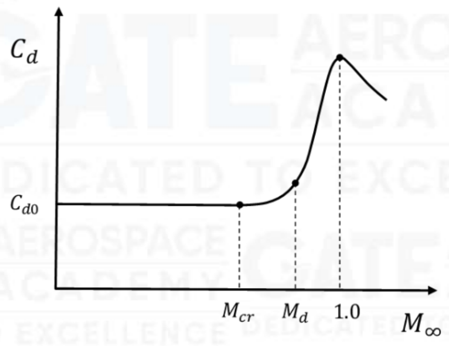
Solution: (A), (C), (D)



From graph it's clear that $\eta_A > \eta_B$. In comparison to point B, point A is closer to the surge point and in comparison, to point A, point B is closer to the choke point.

Q.19) Which of the following statements is/are TRUE regarding critical and drag divergence Mach numbers of a wing?
(A) Critical Mach number is the minimum freestream Mach number for which sonic condition is attained somewhere over the wing
(B) Drag divergence Mach number is always higher than the critical Mach number
(C) Drag divergence Mach number is the local Mach number over the wing at which the drag increases drastically
(D) Critical Mach number is independent of the angle of attack

Solution: (A), (B)
Critical Mach number is minimum free stream Mach number for which sonic condition is attained somewhere over the wing. If angle of attack changes, then perturbation will also be different and critical Mach number will change as angle of attack gets changed. So critical Mach number depends on angle of attack.



Drag divergence is the free stream Mach number over the wing at which the drag increases drastically and it is always more than critical Mach number.

Q.20) A flow is steady, inviscid and one-dimensional, with no shaft work or body forces. Which of the following is/are possible under the given conditions?

(A) Oblique shocks
(B) Sound propagation
(C) Rayleigh flow
(D) Fanno flow

Solution: (B), (C)

Given flow is flow is steady, inviscid and one-dimensional, with no shaft work or body forces. Since it is inviscid flow, Fanno flow is not possible. Oblique shock is 2D phenomenon. Hence its Rayleigh flow and sound propagation as per condition given in question.

Q.21) An aircraft starts gliding in power-off condition at an altitude of 4 km. Given that the maximum lift to drag ratio of the aircraft is 15, the maximum glide range that the aircraft can cover, measured along the ground, is __________ km (rounded off to the nearest integer).

Solution: Altitude $h = 4\ km$

$$\left(\frac{L}{D}\right)_{max} = 15$$

$$R = h \times \frac{L}{D}$$

$$R_{max} = h \times \left(\frac{L}{D}\right)_{max}$$

$$R_{max} = 4 \times 15$$
$$R_{max} = 60\ km$$

Q.22) If a matrix can be written as $A = uv^T$, where both u and v are n-dimensional realvalued non-zero column vectors, then the rank of the matrix A is ___ (answer in integer).

Solution: From property directly, we can write answer as 1

Given $A = u.v^T$

Key point: two non-zero column vectors

(i) If one of it is zero, then rank becomes zero
(ii) When a matrix is product of two non-zero column vectors, rank is always 1

For example,
Let's take $n = 2$

$$u = \begin{bmatrix}1\\2\end{bmatrix}, v = \begin{bmatrix}3\\4\end{bmatrix}$$

$$u.v^T = \begin{bmatrix}1\\2\end{bmatrix}\begin{bmatrix}3 & 4\end{bmatrix}$$

$$u.v^T = \begin{bmatrix}3 & 4\\6 & 8\end{bmatrix}$$

Let's find rank of $u.v^T$

$$R_2 \rightarrow R_2 - 2R_1$$

$$= \begin{bmatrix}3 & 4\\0 & 0\end{bmatrix}$$

Rank of $u.v^T = 1$

Q.23) The response $x(t)$ of a freely vibrating single degree of freedom underdamped system is given below. In the equation, A and ϕ are constants. The damping ratio of the system is __________ (rounded off to 3 decimal places).

$$x(t) = Ae^{-5t}\sin(10t + \phi)$$

Solution: General response of a freely vibrating single degree of freedom underdamped system is given by

$$x(t) = Ae^{-\xi\omega_n t}\sin(\omega_d t + \phi)$$

Comparing it with given response we get

$\omega_d = 10\, rad/s$, $\xi\omega_n = 5$

$$\omega_d = \sqrt{1-\xi^2}\omega_n = 10$$

$$\frac{\sqrt{1-\xi^2}\omega_n}{\xi\omega_n} = \frac{10}{5} = 2$$

$$\frac{\sqrt{1-\xi^2}}{\xi} = 2$$

$$1 - \xi^2 = 4\xi^2$$

$$5\xi^2 = 1$$

$$\xi = \sqrt{\frac{1}{5}} = 0.447$$

Q.24) The vortex shedding frequency behind a landing gear model is found to be 50 Hz when tested in a wind tunnel operating at 5 m/s. If the actual landing gear size is 10 times that of the model, and it is designed to operate at 50 m/s, then the expected vortex shedding frequency behind it is __________ Hz (rounded off to the nearest integer).

Solution: $f_{model} = 50\, Hz, U = 5\, m/s$

Equating non dimensional combination (Strouhal number)

$$\left(\frac{fd}{U}\right)_{model} = \left(\frac{fd}{U}\right)_{prototype}$$

$$\frac{50 \times d_m}{5} = \frac{f_p \times d_p}{50}$$

$$d_p = 5d_m$$

$$\frac{50 \times d_m}{5} = \frac{f_p \times 10 \times d_m}{50}$$

$$f_p = 50\ Hz$$

Q.25) An elliptic wing has a span of 6 m and a planform area of 6 m^2. When generating a lift coefficient of 0.6, the induced drag coefficient it incurs is_________ $\times 10^{-3}$ (rounded off to 1 decimal place).

Solution: Induced drag coefficient is given by

$$C_{d_i} = \frac{C_l^2}{\pi e\ AR}$$

Aspect ratio (AR) is

$$AR = \frac{b^2}{s} = \frac{6^2}{6} = 6$$

$$C_{d_i} = \frac{0.6^2}{\pi \times 1 \times 6} = 0.01909$$

$$= 0.0191 = 19.1 \times 10^{-3}$$

$$19.1\ Answer$$

Q.26 – Q.55 Carry TWO marks Each

Q.26) An earth satellite has the instantaneous position vector $\vec{r}$ and velocity vector $\vec{v}$ as given below. Here $\hat{p}$ and $\hat{q}$ denote the unit vectors along the x and y axes of the perifocal frame, respectively. Assume that the value of gravitational parameter is 398600 km^3/s^2. Which one of the following trajectories does the satellite follow?

$$\vec{r} = (8000\hat{p} + 9000\hat{q})\text{km and } \vec{v} = (-6\hat{p} + 6\hat{q})\text{km/s}$$

(A) Circle
(B) Hyperbola
(C) Parabola
(D) Straight line

Solution: (B)

Position vector $\vec{r}$ and velocity vector $\vec{v}$

$$\vec{r} = (8000\,\hat{p} + 9000\,\hat{q})\ km, \vec{v} = (-6\,\hat{p} + 6\,\hat{q})\ km/s$$

$\hat{p}$ & $\hat{q}$ denotes the unit vectors along x and y axes

gravitational parameter is $398600 \frac{Km^3}{s^2}$

$$\varepsilon = \frac{V^2}{2} - \frac{\mu}{r}$$

Let's find the magnitude of position vector and magnitude vector

$$r = \sqrt{8000^2 + 9000^2} =$$

$$V = \sqrt{(-6)^2 + 6^2}$$

$$V^2 = 72$$

$$\varepsilon = \frac{V^2}{2} - \frac{\mu}{r}$$

$$\varepsilon = \frac{72}{2} - \frac{398600}{12041.6}$$

$$\varepsilon = 2.89 > 0$$

Hence satellite follow hyperbola trajectory.

Q.27) For the matrix $A = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$, if the relation $a + b = c + d$ holds and $a, b, c, d \neq 0$, then which one of the following statements about A is FALSE?

(A) $\begin{bmatrix} 1 \\ 1 \end{bmatrix}$ is an eigenvector
(B) $\lambda = a + b$ is an eigenvalue
(C) $\lambda = d - b$ is an eigenvalue
(D) $\lambda = d + b$ is an eigenvalue

Solution: (D)

$$A = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

if $\begin{bmatrix} 1 \\ 1 \end{bmatrix}$ is an eigen vector

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} a+b \\ c+d \end{bmatrix}$$

given condition $a + b = c + d$

$$= \begin{bmatrix} a+b \\ a+b \end{bmatrix}$$

$$= (a+b)\begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

From here we can say $\begin{bmatrix} 1 \\ 1 \end{bmatrix}$ is an eigen vector with one of the eigen value $\lambda_1 = (a + b)$

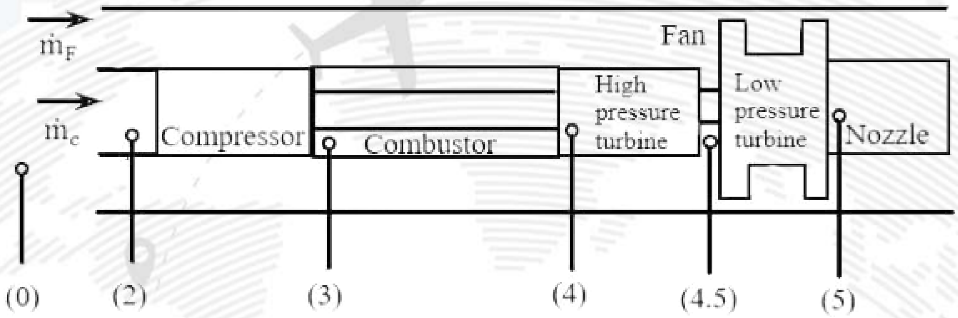
We can find second eigen value by property $\lambda_1 + \lambda_2 = Trace\ of\ A$

$$\lambda_1 + \lambda_2 = a + d$$

$$(a + b) + \lambda_2 = a + d$$

$$\lambda_2 = d - b$$

Q.28) In an ideal turbofan engine shown in the figure below, the compressor is driven by the high pressure turbine, and the fan is driven by the low pressure turbine. The stations 0,2,3,4,4.5, and 5 refer to free-stream, compressor inlet, compressor outlet, combustor exit, high pressure turbine exit, and low pressure turbine exit, respectively, and the subscript ' t ' refers to the total condition. Also, $\tau_r = T_{t0}/T_0$, $\tau_c = T_{t3}/T_{t2}$ and $\tau_\lambda = T_{t4}/T_0$. The total temperature ratio of the high pressure turbine ($T_{t4.5}/T_{t4}$) is given by __________ .



(A) $1-\frac{\tau_r}{\tau_\lambda}(\tau_c-1)$ (B) $1+\frac{\tau_r}{\tau_\lambda}(\tau_c+1)$

(C) $1-\frac{\tau_r}{\tau_\lambda}(\tau_c+1)$ (D) $1+\frac{\tau_r}{\tau_\lambda}(\tau_c-1)$

Solution: (A)

$\frac{T_{t3}}{T_{t2}}=\tau_c, \tau_r=T_{t0}/T_0, \tau_\lambda=T_{t4}/T_0$

Compressor is driven by the high-pressure turbine, balancing the specific power

$$w_c=w_T$$

$$c_p(T_{t3}-T_{t2})=c_p(T_{t4}-T_{t4.5})$$

$$T_{t2}\left(\frac{T_{t3}}{T_{t2}}-1\right)=T_{t4}\left(1-\frac{T_{t4.5}}{T_{t4}}\right)$$

$$\frac{T_{t2}}{T_{t4}}(\tau_c-1)=\left(1-\frac{T_{t4.5}}{T_{t4}}\right)$$

$$\frac{T_{t4.5}}{T_{t4}}=1-\frac{T_{t2}}{T_{t4}}(\tau_c-1)\ldots\ldots\ldots eq(1)$$

$$\frac{T_{t2}}{T_{t4}}=\frac{T_{t2}}{T_0}\times\frac{T_0}{T_{t4}}$$

$\frac{T_{t2}}{T_0}=\frac{T_{t0}}{T_0}=\tau_r, \frac{T_0}{T_{t4}}=\frac{1}{\tau_\lambda}$

$$\frac{T_{t2}}{T_{t4}}=\frac{\tau_r}{\tau_\lambda}$$

Substituting in equation (1)

$$\frac{T_{t4.5}}{T_{t4}}=1-\frac{\tau_r}{\tau_\lambda}(\tau_c-1)$$

Q.29) An ideal rocket has characteristic exhaust velocity of 1200 m/s, mass flow rate of 75 kg/s, thrust coefficient of 1.5, and nozzle throat area of 0.025 m^2. The chamber pressure in kPa and the specific impulse due to gravity in seconds are ________, respectively. Assume that the acceleration due to gravity is 9.8 m/s^2.

(A) 3600 and 183.67 (B) 4600 and 190.51

(C) 3600 and 175.23 (D) 3500 and 183.67

Solution: (A)

$$\dot{m}=\frac{P_cA_t}{c^*}$$

$$75=\frac{P_c\times 0.025}{1200}$$

$$P_c=3600000\,Pa=3600\,kPa$$

$$I_{sp}g=C_F\times C^*$$

$$I_{sp}=\frac{1.5\times 1200}{9.8}=183.67\,s$$

Q.30) Consider a unit square body as shown in the figure below. The body is subjected to the deformation field u = –ay and v = ax, where 'a' is a constant. Due to the application of this deformation field, the body undergoes ________ in the x-y plane.

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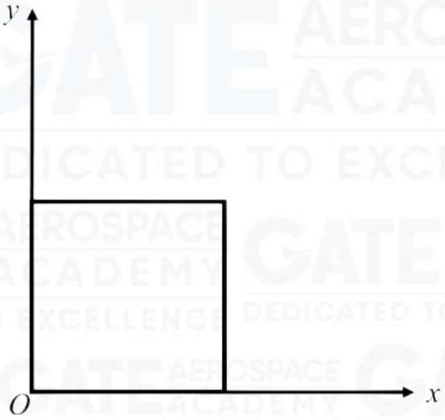


(A) biaxial deformation
(B) pure shear
(C) pure bending
(D) rigid body rotation

Solution: (D)

$u = -ay$, $v = ax$

Linear strain is given by

$$\varepsilon_x = \frac{\partial u}{\partial x} = 0, \quad \varepsilon_y = \frac{\partial v}{\partial x} = 0$$

Shear strain is given by

$$\Upsilon_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} = a + (-a) = 0$$

Rotational component

$$\omega_z = \frac{1}{2}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) = \frac{1}{2}(a + a) = a \neq 0$$

Hence its rigid body rotation

Q.31) Consider a launch vehicle of mass 10 tons being launched vertically. The vehicle has 8 tons of propellant, which burns completely at a constant rate over 50 s. If the engine specific impulse is 250 s, and the acceleration due to gravity at sea level is g_0, the acceleration experienced by the vehicle at lift-off is ________.

(A) g_0
(B) $2g_0$
(C) $3g_0$
(D) $4g_0$

Solution: (C)

$M_0 = 10000\, kg, M_P = 8000\, kg$

$I_{sp} = 250s$

$$V_e = I_{sp} \times g_0 = 160\, g_0$$

Mass flow rate of propellant

$$\dot{m}_e = \frac{8000}{50} = 160\, kg/s$$

Acceleration at lift off is given by

$$a = \frac{T - mg}{m}$$

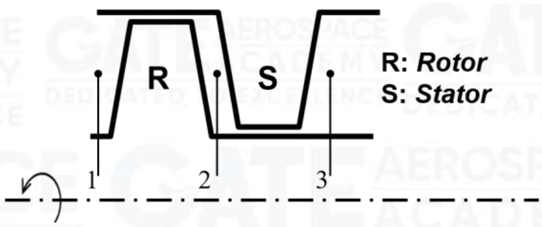
Thrust is given by

$$T = \dot{m}_e V_e$$

$$a = \frac{(160 \times 250\, g_0) - 10000 g_0}{10000}$$

$$a = \frac{40000 g_0 - 10000 g_0}{10000} = 3 g_0$$

Q.32) The figure below shows a compressor stage with station numbers 1, 2, and 3 as indicated. If p_{0i}, T_{0i}, and C_i refer to the average values of total pressure, total temperature, and absolute flow speed, respectively, at the i^{th} station, select the correct option considering losses.



(A) $p_{01} < p_{02}, p_{02} > p_{03}; T_{01} < T_{02}, T_{02} \approx T_{03}; C_1 < C_2, C_2 > C_3$
(B) $p_{01} < p_{02}, p_{02} = p_{03}; T_{01} < T_{02}, T_{02} \approx T_{03}; C_1 < C_2, C_2 = C_3$
(C) $p_{01} < p_{02}, p_{02} > p_{03}; T_{01} < T_{02}, T_{02} < T_{03}; C_1 > C_2, C_2 > C_3$
(D) $p_{01} < p_{02}, p_{02} < p_{03};\ T_{01} < T_{02}, T_{02} < T_{03};\ C_1 = C_2 = C_3$

Solution: (A)

Work is being done on air by rotor and absolute velocity across the rotor increases, hence across rotor stagnation temperature and pressure increases.

$$p_{01} < p_{02}\ , T_{01} < T_{02}, C_1 < C_2$$

Across stator, absolute velocity decreases and static pressure increases. No work is being done hence for ideal case both stagnation temperature and pressure remain constant. Considering losses, stagnation pressure will decrease across stator and stagnation temperature remains constant.

$$T_{02} \approx T_{03}, p_{02} > p_{03}, C_2 > C_3$$

Q.33) An experimental study is planned to map out the low-Reynolds number incompressible steady two-dimensional aerodynamic characteristics of a promising novel airfoil. The operational parameters of the problem are the speed, density and viscosity of the freestream, the chord of the airfoil and its angle of attack. If the objective is to achieve this with the minimum number of test runs N_{min} while taking 10 equally-spaced test values of each independent parameter of the problem in a suitable range, then $Nmin$ is ________.

(A) 10
(B) 100
(C) 10,000
(D) 1,00,000

Solution: (B)

Problem has total 5 parameters $(V, \rho, \mu, c, \alpha)$
According to bucking pi theorem it will be $m - n$ dimensionless terms
Where m is 5 and n is fundamental dimension
Hence $5 - 3 = 2$ (total 2 dimensionless group)
Those are Reynolds number and angle of attack

$$\left[\frac{\rho V c}{\mu}, \alpha\right]$$

For two dimensionless group and each having 10 readings, we need to take

$$= 10 \times 10 = 100\, readings$$

Q.34) Which of the following process(es) is/are involved in the compression of air in an ideal ramjet engine?

(A) oblique shock (B) mechanical compression
(C) normal shock (D) subsonic diffusion

Solution: (A), (C), (D)

There is no rotating compressor in ideal ramjet engine hence there is no mechanical compression. Incoming supersonic flow gets slow down by oblique shock followed by normal shock and then flow becomes subsonic which then get diffused further in divergent portion of convergent divergent diffuser of ramjet engine.

Q.35) The deformation of an open-section bar subjected to pure torsion can be solved by choosing an appropriate Prandtl stress function. Which of the following statements is/are true about the Prandtl stress function?

(A) It satisfies the equilibrium equation
(B) It is zero on the lateral surfaces of the bar
(C) It satisfies the compatibility equation
(D) It does not satisfy the equilibrium equation

Solution: (A), (B), (C)

Prandtl stress function

$$\tau_{zy} = -\frac{\partial \phi}{\partial x}, \quad \tau_{zx} = \frac{\partial \phi}{\partial y}$$

Equilibrium equation in z direction is given by

$$\frac{\partial \sigma_{zz}}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} = 0$$

Substituting τ_{zy} and τ_{zx} and putting $\sigma_{zz} = 0$ in above equilibrium equation, we get that it satisfies the equilibrium equation.

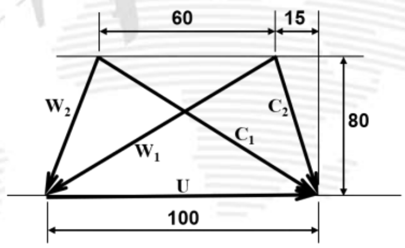
Compatibility equation

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} = -2G\frac{d\theta}{dz}$$

$$\nabla^2 \phi = -2G\frac{d\theta}{dz}$$

Prandtl function (ϕ) can be chosen to satisfy the compatibility equation.

Q.36) The figure below shows the velocity triangles at the inlet and outlet of the rotor of a low hub-to-tip ratio axial compressor at the mid-span of the blade. The absolute and relative velocities of the flow are denoted by C and W, respectively. The subscripts 1 and 2 refer to the locations before and after the rotor, respectively. The blade velocity is denoted by U. Select the CORRECT statement(s) for this device.



All values are in m/s.

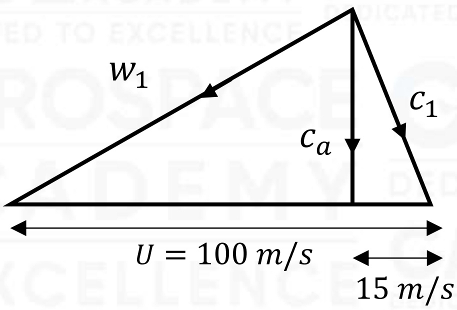
(A) The axial velocity is constant across the rotor
(B) The flow coefficient is 0.6
(C) The blade loading coefficient is 0.6
(D) If the acoustic velocity at the rotor inlet is 350 m/s, then the inlet relative Mach number is 0.333

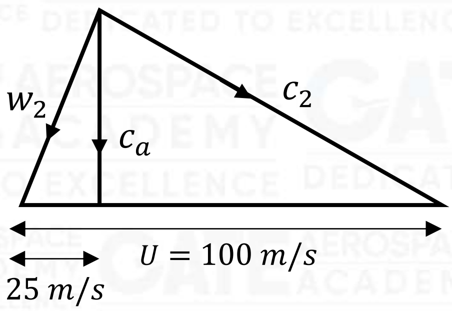
Solution: (A), (C), (D)

Flow coefficient (ϕ) is given by

$$\phi = \frac{c_a}{U} = \frac{80}{100} = 0.8$$

Inlet velocity triangle **Outlet velocity triangle**





From inlet velocity triangle

$$w_1^2 = c_a^2 + (100 - 15)^2$$

$$w_1^2 = 80^2 + 85^2$$

$$w_1 = 116.72\, m/s$$

$$c_1^2 = c_a^2 + 15^2 = 80^2 + 15^2$$

$$c_1 = 81.4\, m/s$$

From outlet velocity triangle

$$w_2^2 = c_a^2 + 25^2$$

$$w_2^2 = 80^2 + 25^2$$

$$w_2 = 83.815\, m/s$$

$$c_2^2 = c_a^2 + (100 - 25)^2 = 80^2 + 75^2$$

$$c_2 = 109.65\, m/s$$

$$workdone = \frac{1}{2}(c_2^2 - c_1^2) + \frac{1}{2}(w_1^2 - w_2^2)$$

$$= \frac{1}{2}(109.65^2 - 81.4^2) + \frac{1}{2}(116.72^2 - 83.815^2)$$

$$workdone = 5998\, J/kg$$

Blade loading coefficient (ψ) is given by

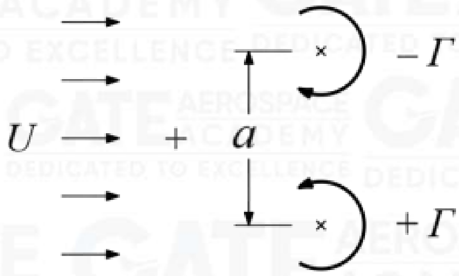
$$\psi = \frac{workdone}{U^2}$$

$$\psi = \frac{5998}{100^2} = 0.599 = 0.6$$

Inlet relative Mach number

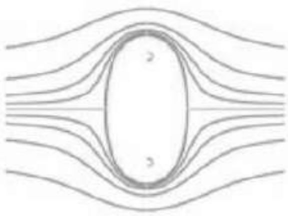
$$M_1 = \frac{w_1}{a} = \frac{116.72}{350} = 0.333$$

Q.37) Consider the flow over an oval modeled using the elementary potential flows as shown below. U represents uniform flow velocity and Γ represents circulation around an irrotational line vortex.

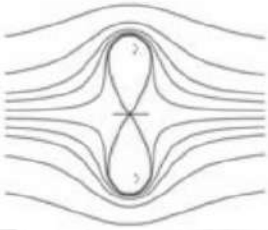


(A) Increasing U enlarges the oval
(B) Increasing Γ enlarges the oval
(C) Interchanging the sense of the two vortices does not alter the oval
(D) Moving the vortices too far apart causes the oval to break up

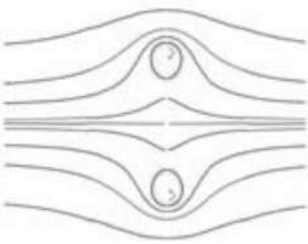
Solution: (B), (D)
Given combination will result in following shape



As uniform flow speed is increased, stagnation point will shift inward as shown in figure below



Hence increasing U doesn't enlarge the oval. If both vortices are moved away from each other then they will breakup as shown in figure below



Interchanging the sense of vortices will cause the stagnation location to change and flow pattern will alter.

Q.38) What is/are the use(s) of the single horseshoe vortex model of finite wing aerodynamic theory?
(A) It can approximate the wing pitching moment coefficient
(B) It can approximate the wing induced drag coefficient
(C) It can approximate the effect of the wing on the induced drag coefficient of a typical horizontal tail
(D) It can approximate the aerodynamic benefit/penalty of formation flight compared to isolated flight

Solution: (C), (D)

As per Prandtl lifting line theory, to model the wing, number of infinitesimal horse vortex are superimposed. In question single horse shoe vortex is mentioned. Hence option A and B are incorrect. Single horse shoe vortex can be used to find out the effect of formation flying and effect on wing on horizontal tail.

Q.39) Consider the differential equation with the initial conditions given below. If $y(x)$ is the solution of the equation, the value of the slope, $\frac{dy}{dx}$, at $x = \ln(2)$ is ________ (rounded off to three decimal places).

$$\frac{d^2y}{dx^2} + 2\frac{dy}{dx} + y = 0 \text{ with } y|_{x=0} = 0 \text{ and } \left.\frac{dy}{dx}\right|_{x=0} = 1$$

Solution:

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

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

Auxiliary equation

$$m^2 + 2m + 1 = 0$$
$$(m + 1)^2 = 0$$
$$m = -1$$

Repeated real roots

$$y(x) = (C_1 + C_2 x)e^{-x}$$

Given

$$y(0) = 0$$
$$y(0) = (C_1 + C_2 0)e^{-0}$$
$$y(0) = C_1$$
$$C_1 = 0$$
$$y(x) = C_2 x e^{-x}$$
$$\frac{dy}{dx} = C_2(1.e^{-x} + x.(-e^{-x}))$$
$$\frac{dy}{dx} = C_2(e^{-x} - x.e^{-x})$$

Given condition $\left.\frac{dy}{dx}\right|_{x=0} = 1$

$$\left.\frac{dy}{dx}\right|_{x=0} = C_2(e^{-0} - 0.e^{-0}) = 1$$
$$= C_2(1 - 0) = 1$$
$$y(x) = xe^{-x}$$

Slope at $x = \ln 2$

$$\frac{dy}{dx} = e^{-x} - x.e^{-x}$$

$$\left.\frac{dy}{dx}\right|_{\ln 2} = e^{-\ln 2} - \ln 2 . e^{-\ln 2}$$

$$\left.\frac{dy}{dx}\right|_{\ln 2} = \frac{1}{2} - (\ln 2).\frac{1}{2}$$

$$\left.\frac{dy}{dx}\right|_{\ln 2} = 0.153$$

Q.40) An object of mass 1 kg is launched with an initial speed of v_o into a large tank filled with a viscous liquid. The liquid exerts a resistive force (drag) of the form $D = \alpha v$ on any object that is moving inside it, where v is the instantaneous speed of the object and $= 1$ kg/s. If the effect of gravity is ignored, the time taken by the object to slow down to the speed $v_o/2$ is ___ s (rounded off to 2 decimal places).
Assume that the tank is sufficiently large for the above deceleration to happen inside the tank.

Solution:

$$F = Ma$$

$$F = M\frac{dv}{dt}$$

$$-D = M\frac{dv}{dt}$$

$$-\alpha v = M\frac{dv}{dt}$$

$$\frac{dv}{v} = \frac{-\alpha}{M}dt$$

$$\int_{v_0}^{\frac{v_0}{2}} \frac{dv}{v} = \int_0^t \frac{-\alpha}{M}dt$$

$$[\ln v]_{v_0}^{\frac{v_0}{2}} = \frac{-\alpha}{M}[t]_0^t$$

$$\ln\frac{\left(\frac{v_0}{2}\right)}{v_0} = \frac{-\alpha}{M}t$$

$$\ln\frac{1}{2} = \frac{-\alpha}{M}t$$

$$-\ln 2 = \frac{-\alpha}{M}t$$

$$t = \frac{M}{\alpha}.\ln 2$$

$$t = \frac{1}{1}.\ln 2$$

$$t = 0.69$$

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Q.41) The minimum value of the function $f(x) = |x| + |2x + 3|$ for real x is ___ (rounded off to 1 decimal place).

Solution:

$$f(x) = |x| + |2x + 3|$$

Critical point

$$x = 0$$
$$2x + 3 = 0$$
$$x = -1.5,0$$

$$f(x) = \begin{Bmatrix} (-x) + (-(2x+3)); x < -1.5 \\ (-x) + (2x+3); -1.5 \le x < 0 \\ (x) + (2x+3); x \ge 0 \end{Bmatrix}$$

$$f(x) = \begin{Bmatrix} (-3x - 3); x < -1.5 \\ (x + 3); -1.5 \le x < 0 \\ (3x + 3); x \ge 0 \end{Bmatrix}$$

At $x = 0$

$$f(0) = 3(0) + 3 = 3$$

$$f(0) = 3$$

At $x = 1.5$

$$f(-1.5) = x + 3$$

$$f(-1.5) = -1.5 + 3 = 1.5$$

Minimum value of the function is 1.5

Q.42) Isobutane (C_4H_{10}) is burnt completely in pure oxygen as per the reaction given below. Given that the standard heats of formation (in kcal/mole) of isobutane, carbon dioxide, and water vapour are $-31.489, -94.052$, and -60.150, respectively, the heat of reaction is ___ kcal (rounded off to 2 decimal places).

$$C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O$$

Solution:

$$C_4H_{10} + 6.5\ O_2 \rightarrow 4CO_2 + 5\ H_2O$$

heats of formation for C_4H_{10} is $-31.489\ kcal/mole$
heats of formation for CO_2 is $-94.052\ kcal/mole$
heats of formation for H_2O is $-60.150\ kcal/mole$
heat of reaction will be

$$\sum Heat_{products} - \sum Heat_{reactants}$$

$$(-94.052 \times 4) + (5 \times -60.150) + 31.489$$

$$-645.469\ kcal$$

Q.43) A furnace of 250 MW rating is used to melt and raise the temperature of aluminium from 25°C to 900°C. Aluminium has a solid-state specific heat, latent heat, and liquid-state specific heat of 0.9 kJ/kg – K, 390 kJ/kg, and 1.108 kJ/kg – K, respectively, and the furnace has 70% efficiency. The melting point of aluminium is 660°C. The amount of aluminium that can be processed per hour is ___ kg (rounded off to 1 decimal place).

Solution:

Heat is required to raise the temperature of aluminum up to melting point that is from 25°C to 660°C, then heat is required to change the phase from solid phase to liquid phase known as latent heat. Then in liquid state aluminium will be heated from 660°C to 900°C.

Heating solid AI from 25°C to 660°C

$$q_1 = c_{p_s}(T_m - T_i) = 0.9 \cdot (660 - 25) = 571.5 \text{ kJ/kg}$$

Melting Al at 660°C

$$q_2 = L = 390 \text{ kJ/kg}$$

Heating liquid AI from 660°C to 900°C

$$q_3 = c_{p_l}(T_f - T_m) = 1.108 \cdot (900 - 660) = 265.92 \text{ kJ/kg}$$

Total specific heat

$$q_1 + q_2 + q_3 = 571.5 + 390 + 265.92 = 1227.42\ kJ/kg$$

$$power = \dot{m} \times 1227.42$$

$$250 \times 0.7 \times 10^3 = \dot{m} \times 1227.42$$

$$\dot{m} = \frac{250 \times 0.7 \times 10^3}{1227.42} = 142.575\ kg/s$$

$$\dot{m} = 142.575 \times 3600 = 513270\ kg/h$$

Q.44) For an airfoil section the pitching moment coefficient is determined about a reference point that is 0.3 times the chord behind the leading edge. It varies with the lift coefficient as shown in the table below. The distance of the aerodynamic center from the leading edge of the airfoil as a fraction of the chord is ___ (rounded off to one decimal place).

c_l	0.2	0.4	0.6	0.8
c_m	-0.02	0	0.02	0.04

Solution: Relationship between moment coefficient at two points x and a is given by

$$C_{m_a} = C_{m_x} + C_l\left(\frac{x}{c} - \frac{a}{c}\right)$$

Point a corresponds to location of aerodynamics centre

Point x corresponds to given location of 0.3c from leading edge

$$C_{m_{ac}} = C_{m_x} + C_l\left(\frac{x}{c} - \frac{a}{c}\right)$$

Differentiating with respect to C_l

$$\frac{dC_{m_{ac}}}{dC_l} = \frac{dC_{m_x}}{dC_l} + \left(\frac{x}{c} - \frac{a}{c}\right)$$

As per definition moment coefficient about aerodynamic centre remains constant. Hence

$$\frac{dC_{m_{ac}}}{dC_l} = 0$$

$$0 = \frac{dC_{m_x}}{dC_l} + \left(\frac{x}{c} - \frac{a}{c}\right)$$

$$\frac{a}{c} = -\frac{dC_{m_x}}{dC_l} + \frac{x}{c}$$

$$x = 0.3c$$

$$\frac{dC_{m_x}}{dC_l} = \frac{0.04 - (-0.02)}{0.8 - 0.2} = 0.1$$

$$\frac{a}{c} = -0.1 + \frac{0.3c}{c}$$

$$\frac{a}{c} = 0.2$$

Q.45) An earth satellite moves in an elliptical orbit with a perigee altitude of 300 km and an apogee altitude of 3000 km. Assume that the radius of the earth is 6378 km. The eccentricity of the orbit is ________ (rounded off to three decimal places).

Solution:

Perigee altitude $h_p = 300\ km$, Apogee altitude $h_a = 3000\ km$, Radius of earth 6378 km

Eccentricity of the orbit $e = \frac{r_a - r_p}{r_a + r_p}$

$$e = \frac{r_a - r_p}{r_a + r_p}$$

$$r_a = 6378 + 3000 = 9378\ km$$

$$r_p = 6378 + 300 = 6678\ km$$

$$e = \frac{9378 - 6678}{9378 + 6678}$$

$$e = 0.168$$

Q.46) Consider a finite wing of aspect ratio 10 with span effectiveness factor 0.95. Its airfoil section has a lift slope of 0.106 per degree and a zero-lift angle of attack of −1.5°. The lift coefficient of the wing at an angle of attack of 3.5° is __________ (rounded off to 2 decimal places).

Solution:

$$AR = 10, e = 0.95, a_o = 0.106/deg$$

$$a = \frac{a_o}{1 + \frac{57.3a_o}{\pi eAR}}$$

$$a = \frac{0.106}{1 + \frac{57.3 \times 0.106}{3.14 \times 0.95 \times 10}} = 0.088/deg$$

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

$$C_l = 0.088\,[3.5 - (-1.5)] = 0.44$$

Q.47) W_A and W_B are the respective maximum take-off weights of an aircraft for two ambient air conditions given below.

Condition A: $p = 1$ bar, $T = 50°C$; Condition B: $p = 0.66$ bar, $T = -30°C$

If all other parameters relevant for take-off are kept the same in these two conditions, the ratio W_B/W_A is ___ (rounded off to 3 decimal places).

Solution:

At condition A: $p = 1\ bar, T = 50^{\circ}\ C$

At condition B: $p = 0.66\ bar, T = -30^{\circ}\ C$

$$S_{Takeoff} = \frac{1.44\ W^2}{g\rho S C_{L_{max}} T}$$

$$T \alpha\ \rho$$

Taking all other parameters as same

$$\rho^2\ \alpha\ 1.44\ W^2$$

$$\frac{1.44\ {W_B}^2}{1.44\ {W_A}^2} = \frac{{\rho_B}^2}{{\rho_A}^2} \dots\dots\dots (1)$$

By using equation of state $p_A = \rho_A R T_A$

$$\frac{p_A}{RT_A} = \rho_A \dots\dots\dots (2)$$

Similarly at condition B

$$\frac{p_B}{RT_B} = \rho_B \dots\dots\dots (3)$$

Substituting 2 and 3 questions in equation 1 we get

$$\frac{W_B}{W_A} = \frac{p_B}{T_B} \times \frac{T_A}{p_A} \dots\dots\dots (4)$$

At condition A: $p = 1\ bar, T = 50 + 273 = 323\ k$

At condition B: $p = 0.66\ bar, T = -30 + 273 = 243\ k$

$$\frac{W_B}{W_A} = \frac{0.66}{243} \times \frac{323}{1} = 0.877$$

Q.48) A thin-walled circular tube is made of a material whose magnitude of the ultimate strength, both in tension and compression, is 200 MPa. The mean radius of the tube is 0.2 m and the wall thickness is 0.004 m. Based on the maximum stress criteria, the maximum torque that the tube can sustain is ________ kNm (round off to the nearest integer).

Solution: $r_m = 0.2\ m\ , t = 0.04m$

$$\tau_{max} = \frac{T}{I_P} r_m$$

$$I_P = 2\pi r_m^3 t$$

$$\tau_{max} = \frac{T}{2\pi r_m^3 t} r_m = \frac{T}{2\pi r_m^2 t}$$

For pure shear maximum principal stress is equal to shear stress

$$\sigma_1 = \tau$$

$$\sigma_1 = \frac{T}{2\pi r_m^2 t}$$

According to maximum principal stress criteria

$$\sigma_1 = \sigma_y = 200 \times 10^6$$

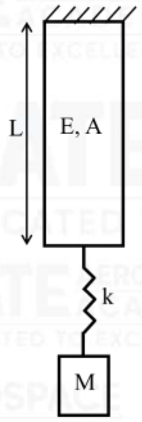
$$\frac{T}{2\pi r_m^2 t} = 200 \times 10^6$$

$$T = 2\pi r_m^2 t \times 200 \times 10^6$$

$$T = 2\pi \times 0.2^2 \times 0.004 \times 200 \times 10^6$$

$$T = 201\ kNm$$

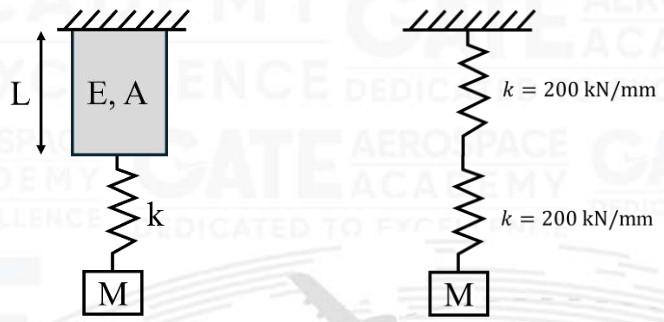
Q.49) A system comprising a bar, spring and mass is shown in the figure below. The bar, having negligible mass, is made of a material having Young's modulus E = 200GPa, cross-sectional area A = 100 mm^2, and length L = 100 mm. The spring stiffness k = 200kN/mm and the mass M = 100 kg. The natural frequency of free vibration of the system is ________ rad/s (rounded off to the nearest integer).



Solution: Stiffness of bar is given by

$$k = \frac{AE}{L} = \frac{100 \times 200 \times 10^3}{100} = 200 \times 10^3\ N/mm$$

$$k = 200\ kN/mm$$



Equivalent stiffness of system is given by

$$\frac{1}{k_{eq}} = \frac{1}{k_1} + \frac{1}{k_2}$$

$$\frac{1}{k_{eq}} = \frac{1}{200} + \frac{1}{200}$$

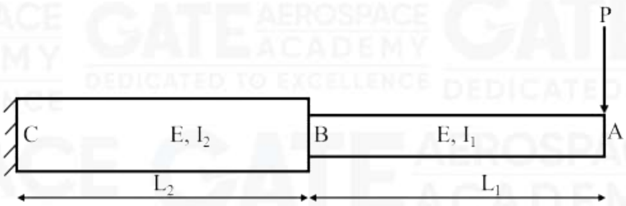
$$k_{eq} = 100\ kN/mm$$

Natural frequency will be

$$\omega_n = \sqrt{\frac{k_{eq}}{m}} = \sqrt{\frac{100 \times 10^6}{100}}$$

$$\omega_n = 1000\, rad/s$$

Q.50) A stepped cantilever beam, made of a material having Young's modulus E = 200GPa, is shown in the figure below. The length and the moment of inertia of the beam from point A to B are $L_1 = 100$ mm and $I_1 = 100\ \text{mm}^4$, respectively. The length and the moment of inertia of the beam from point B to C are $L_2 = 100$ mm and $I_2 = 700\ \text{mm}^4$, respectively. A shear force P = 30 N is applied at point A of the beam. The magnitude of the deflection of the beam at point A is __________ mm (rounded off to 1 decimal place).



Solution: Strain energy stored by beam due to bending is given by

$$U = \int_0^l \frac{M^2 dx}{2EI}$$

$$U = \int_0^l \frac{(-Px)^2 dx}{2EI_1} + \int_l^{2l} \frac{(-Px)^2 dx}{2EI_2}$$

$$U = \frac{P^2}{2EI_1}\left[\frac{x^3}{3}\right]_0^l + \frac{P^2}{2EI_2}\left[\frac{x^3}{3}\right]_l^{2l}$$

$$U = \frac{P^2 l^3}{6EI_1} + \frac{7P^2 l^3}{6EI_2}$$

Deflection under the load is given by

$$\delta = \frac{\partial U}{\partial P} = \frac{Pl^3}{3EI_1} + \frac{7Pl^3}{3EI_2}$$

$$\delta = \frac{30 \times 100^3}{3 \times 200 \times 10^3 \times 100} + \frac{7 \times 30 \times 100^3}{3 \times 200 \times 10^3 \times 700}$$

$$\delta = \frac{1}{2} + \frac{1}{2} = 1\ mm$$

Q.51) A centrifugal compressor has a constant-width radial diffuser. The diameters at the diffuser inlet and outlet are 0.2 m and 0.3 m, respectively. The flow at the diffuser inlet and outlet is assumed to be steady and uniform. The average velocity at the diffuser inlet and outlet are ($60\hat{\mathbf{e}}_r + 75\hat{\mathbf{e}}_\theta$) m/s and ($u\hat{\mathbf{e}}_r + 50\hat{\mathbf{e}}_\theta$) m/s, respectively. If the flow through the diffuser is treated as steady and incompressible, the value of u is ___ (rounded off to the nearest integer).

Solution:

$d_i = 0.2m$, $d_o = 0.3m$, width = b

Area $A = \pi d b$

Radial and tangential velocities at inlet are

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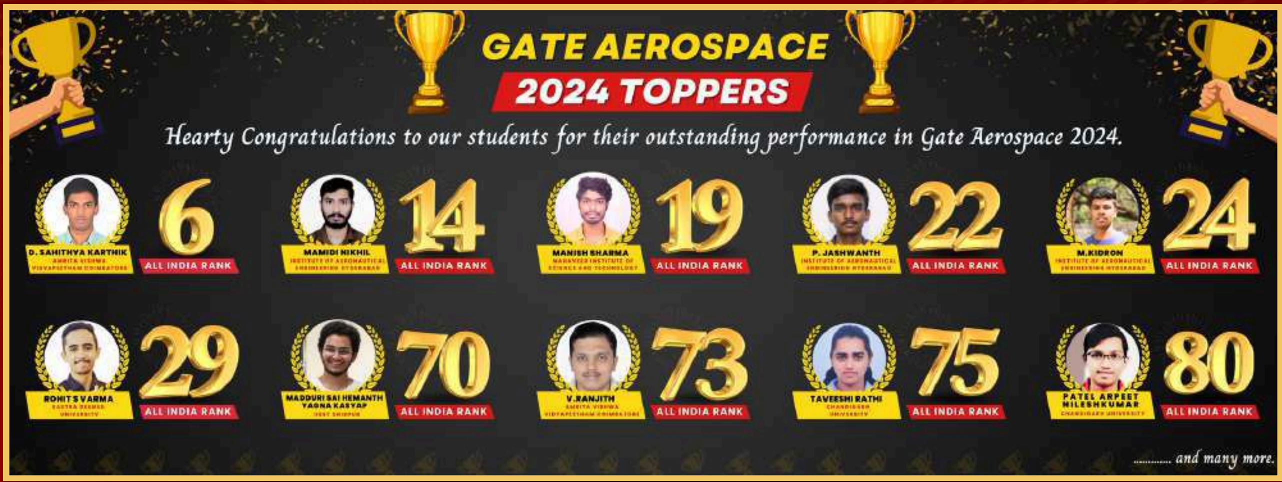

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$c_{r_i} = 60\ m/s,\ c_{\theta_i} = 75\ m/s$

Radial and tangential velocities at outlet are

$c_{r_o} = u\ m/s,\ c_{\theta_o} = 50\ m/s$

For steady and incompressible flow, using mass conservation we get

$$\rho_i c_{r_i} A_i = \rho_o c_{r_o} A_o$$
$$c_{r_i} A_i = c_{r_o} A_o$$
$$c_{r_i} \pi d_i b = c_{r_o} \pi d_o b$$
$$c_{r_i} d_i = c_{r_o} d_o$$
$$60 \times 0.2 = u \times 0.3$$
$$u = \frac{60 \times 0.2}{0.3} = 40\ m/s$$

Q.52) A gas mixture at a pressure of 800 kPa and a density of 5 kg/m^3 enters a turbine stage. The temperature of the gas at the nozzle exit and the stage exit are 790 K and 750 K, respectively. Assume the specific heats are constant for the gas mixture in the range of temperatures considered. The specific heat at constant pressure is 0.72 kJ/kg − K and the ratio of specific heats is 1.33. The value of the degree of reaction of the turbine stage is ___ (rounded off to 2 decimal places).

Solution: Degree of reaction of turbine is given by

$$R = \frac{h_2 - h_3}{h_1 - h_3} = \frac{T_2 - T_3}{T_1 - T_3}$$

$T_2 = 790\ K, T_3 = 750\ K, p_1 = 800\ kPa, \rho_1 = 5\ kg/m^3, c_p = 0.72\ kJ/kgK, \gamma = 1.33$

$$c_p = \frac{\gamma R}{\gamma - 1}$$
$$0.72 \times 1000 = \frac{1.33\ R}{1.33 - 1}$$
$$R = 178.646\ J/kgK$$
$$p_1 = \rho_1 R\ T_1$$
$$T_1 = \frac{p_1}{R\rho_1} = \frac{800 \times 1000}{178.646 \times 5}$$
$$T_1 = 895.625\ K$$
$$R = \frac{T_2 - T_3}{T_1 - T_3} = \frac{790 - 750}{895.625 - 750} = 0.27$$

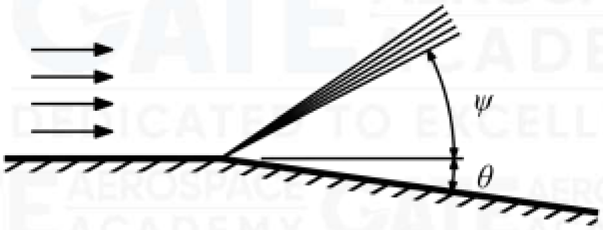
Q.53) Thin airfoil theory predicts the zero-lift angle of attack $\alpha_{L=0}$ of NACA 2412 airfoil as −2.1°. The corresponding prediction of $\alpha_{L=0}$ for NACA 5410 airfoil is ________ degrees (rounded off to 1 decimal place).

Solution: NACA 2412 airfoil has 2% camber whereas NACA 5410 airfoil has 5% camber

$$(\alpha_{L=0})_{\text{NACA 5410}} = -\frac{2.1 \times 5}{2} = -5.25°$$

Q.54) Consider a centered Prandtl-Meyer expansion fan at a $\theta = 4°$ corner in a Mach 1.78 air flow, as shown in the figure below. The angle ψ (see figure) made by the ending wave of the fan with respect to the incoming stream is ___________ degrees (rounded off to 1 decimal place).

An excerpt from the table of Prandtl-Meyer function for air is provided below.



M	*ν* [deg]	*M*	*ν* [deg]	*M*	*ν* [deg]
1.72	18.40	1.82	21.30	1.92	24.15
1.74	18.98	1.84	21.88	1.94	24.71
1.76	19.56	1.86	22.45	1.96	25.27
1.78	20.15	1.88	23.02	1.98	25.83
1.80	20.73	1.90	23.59	2.00	26.38

Solution: $\theta = 4°, M_1 = 1.78$

From table at $M_1 = 1.78$

$$v_1 = 20.15$$

$$v_2 = v_1 + \theta = 20.15 + 4 = 24.15$$

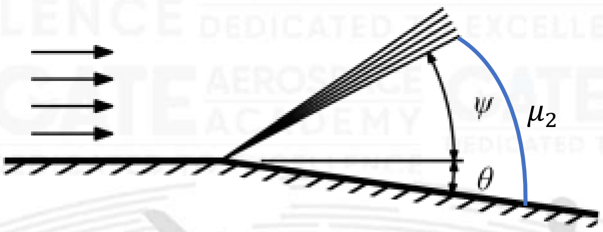
From table at $v_2 = 24.15$

$$M_2 = 1.92$$

Mach wave angle at $M_2 = 1.92$

$$\mu_2 = \sin^{-1}\left(\frac{1}{M_2}\right)$$

$$\mu_2 = \sin^{-1}\left(\frac{1}{1.92}\right) = 31.388°$$



Angle ψ is given by

$$\psi = \mu_2 - \theta$$

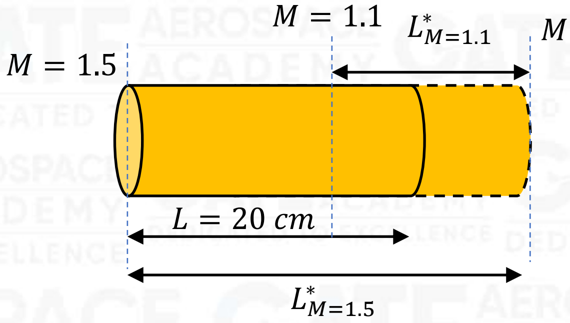
$$\psi = 31.388 - 4 = 27.4°$$

Q.55) A Mach 1.5 air flow enters a round duct of length 20 cm and diameter 3 cm. If the flow exits with Mach number 1.1, the average Fanning friction factor f of the duct is ___ $\times 10^{-3}$ (rounded off to 1 decimal place).

An excerpt from the Fanno flow table for air is given below.

M	1.1	1.2	1.3	1.4	1.5	1.6
$\frac{4fL^*}{D}\times 10^4$	99.35	336.4	648.3	997.4	1361	1724

Solution:



From Table

$\frac{4fL^*_{M=1.5}}{D}\times 10^4 = 1361,\ \frac{4fL^*_{M=1.1}}{D} = 99.35$

$$\frac{4fL^*_{M=1.5}}{D}\times 10^4 - \frac{4fL^*_{M=1.1}}{D}\times 10^4 = \frac{4fL}{D}\times 10^4$$

$$\frac{4fL}{D}\times 10^4 = 1361 - 99.35 = 1261.65$$

$$\frac{4f\times 0.2}{0.03}\times 10^4 = 1261.65$$

$$f = 4.73\times 10^{-3}$$

$$= 4.7\ answer$$

General Aptitude (GA)

Q.1 – Q.5 Carry ONE mark Each

Q.1) Which "He often _____ the numbers. False claims are not going to help. Honesty _________trust", said the manager.

Choose the option with the correct order of words to fill the blanks.

(A) exaggerates; engenders

(B) excels; encourages

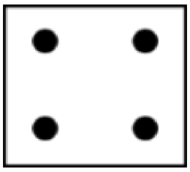
(C) aggravates; alleviates

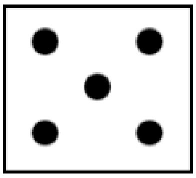
(D) diminishes; eliminates

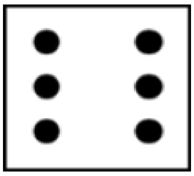
Solution: (A)

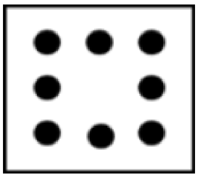
"He often **exaggerates** the numbers. False claims are not going to help. Honesty **engenders** trust", said the manager.

Q.2) In the sequence of tiles shown below, the missing tile indicated by the question mark should be

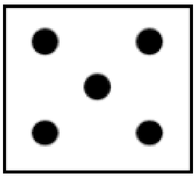
(A) 

(B) 

(C) 

(D) 

Solution: (B)
The pattern increases step by step.
The number of dots is not random — it increases by adding one more each time.
It follows this rule: +1, then +2, then +3, then +4
So, each new box adds one extra dot more than the previous increase.



Q.3) A school has 100 students distributed among 1st to 10th standards. Based on this, which one of the following statements is always correct?
(A) There are at least 10 students who belong to the same standard.
(B) There is at least one student in each standard.
(C) There are at most 10 students in 10th standard.
(D) The total number of students from 1st to 5th standards is at least 50.

Solution: (A)
Since no condition is given that there must be one student in each standard,
the correct statement is: There are at least 10 students who belong to the same standard.

Q.4) How many 3-digit numbers can be formed using three distinct single digit prime numbers?
(A) 64 (B) 24
(C) 12 (D) 4
Solution: (B)
Single-digit prime numbers are: 2, 3, 5, 7
We are selecting 3 different digits out of 4 primes and arranging them.
Number of ways is ${}^4p_3 = 4 \times 3 \times 2 = 24$

Q.5) In a group of students, 10 students like Mathematics, 12 students like English, 4 students like both Mathematics and English, and 6 students like neither Mathematics nor English. The number of students in the group is _____

(A) 18 (B) 20
(C) 24 (D) 32

Solution: (C)

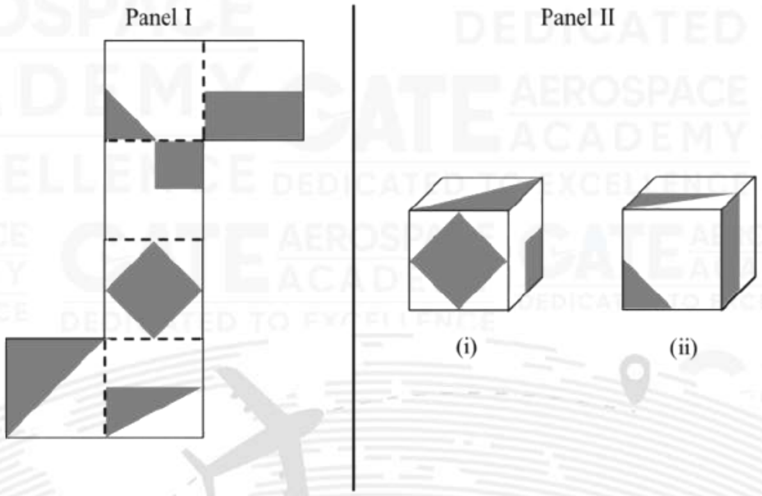
Students who like:
Mathematics (M) = 10, English (E) = 12, Both (M ∩ E) = 4, Neither = 6
Total who likes at least one = M + E – Both = 10 + 12 – 4 = 18
Total students = 18 + 6 = 24

Q.6 – Q.10 Carry TWO marks Each

Q.6) Charity : P :: Retaliation : Q
Choose the appropriate pair of words P and Q that fit the analogy.
(A) P = Parsimonious; Q = Vengeful
(B) P = Altruistic; Q = Amicable
(C) P = Resentful; Q = Spiteful
(D) P = Magnanimous; Q = Vindictive

Solution: (D)
Charity: Magnanimous :: Retaliation: Vindictive
Charity is an act that shows a person is magnanimous, Retaliation is an act that shows a person is vindictive.

Q.7) A paper shown in Panel I is folded along the dashed lines (- - -) to construct a cube. The shaded regions shown in Panel I appear on the outer surface of the cube. Referring to cubes shown in Panel II, which one of the options is correct?

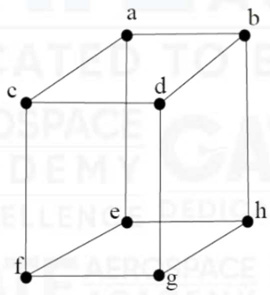


(A) Only (i) can correspond to the unfolded cube in Panel I.
(B) Only (ii) can correspond to the unfolded cube in Panel I.
(C) Both (i) and (ii) can correspond to the unfolded cube in Panel I.
(D) Neither (i) nor (ii) can correspond to the unfolded cube in Panel I.

Solution: (A)

Only (i) can correspond to the unfolded cube in Panel I.

Q.8) Consider the cube shown below with its 8 corners labelled a, b, c, d, e, f, g, and h. The figure is representative. All corners are to be colored such that any two corners that are connected by an edge must be of different colors. The minimum number of colors required to achieve this is ________



(A) 8 (B) 4
(C) 3 (D) 2

Solution: (D)

A cube has: 8 vertices,12 edges, each vertex is connected to 3 other vertices
Given condition Any two vertices connected by an edge have different colors
Minimum number of colors required is 2

Q.9) Four hills H1, H2, H3, and H4 are present in an area. The following observations are made about them:
i. Neither H2 nor H3 is the easternmost hill.
ii. Neither H2 nor H3 is the westernmost hill.
iii. Neither the easternmost hill nor the westernmost hill is the southernmost hill.
iv. Two hills are located to the west of H2.
v. The southernmost hill has at least two hills to its east.
The southernmost hill is ________.

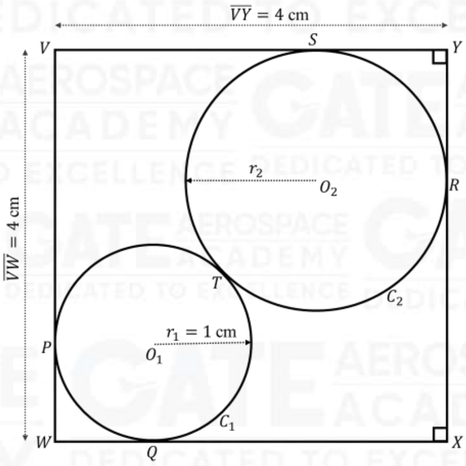
(A) H1 (B) H2
(C) H3 (D) H4

Solution: (C)

The southernmost hill is H3
From (i) and (ii):
H2 and H3 are neither easternmost nor westernmost.
So, the easternmost and westernmost must be H1 and H4.
From (iv):
Two hills are to the west of H2.
So, H2 must be third from the west (only one hill to its east).
Possible west → east order:
H1 – H3 – H2 – H4
(or)
H4 – H3 – H2 – H1
From (v):
The southernmost hill has at least two hills to its east.
So, it must be either the westernmost or the second from west.
From (iii):
The southernmost hill cannot be easternmost or westernmost.
So, it must be second from west.
Second from west = H3

Q.10) As shown in the figure, circle C_1 with center O_1 and radius r_1 touches the square $VWXY$ at points P and Q while circle C_2 with center O_2 and radius r_2 touches the square $VWXY$ at points R and S. The two circles touch each other at T.

Given $r_1 = 1$ cm and $\overline{VY} = \overline{VW} = 4$ cm, $r_2 =$ ___ cm.



(A) $4 - 3\sqrt{2}$ (B) $1 + 2\sqrt{2}$

(C) $7 - 4\sqrt{2}$ (D) $5 + 3\sqrt{2}$

Solution: (C)

When two circles touch externally, the distance between their centers is equal to the sum of their radii

$$O_1O_2 = r_1 + r_2 = 1 + r_2$$

Using the distance formula between O_1 (1, 1) and O_2 $(4 - r_2, 4 - r_2)$

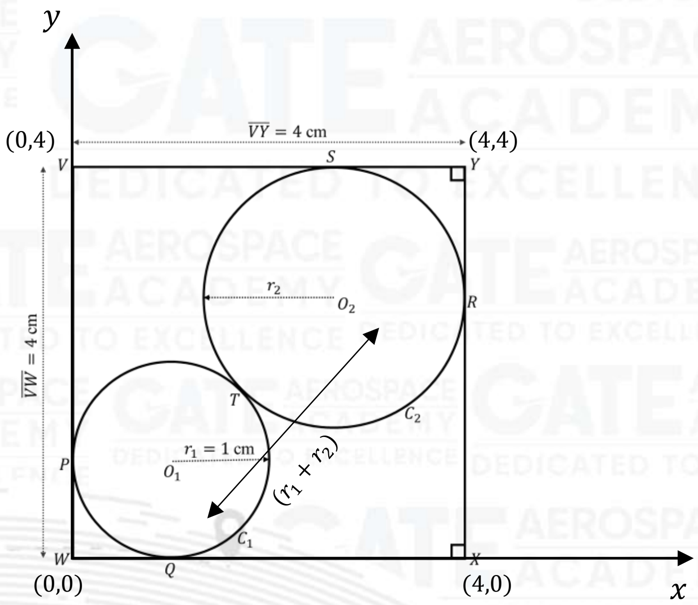
$$(4 - r_2 - 1)^2 + (4 - r_2 - 1)^2 = (1 + r_2)^2$$
$$2(3 - r_2)^2 = (1 + r_2)^2$$

Solving for r_2

$$3\sqrt{2} - 1 = r_2(1 + \sqrt{2})$$
$$r_2 = \frac{3\sqrt{2} - 1}{(1 + \sqrt{2})}$$

Rationalizing, we get

$$r_2 = \frac{3\sqrt{2} - 1}{(1 + \sqrt{2})} \times \frac{(1 - \sqrt{2})}{(1 - \sqrt{2})}$$
$$r_2 = \frac{6 - 4\sqrt{2} + 1}{1}$$
$$r_2 = 7 - 4\sqrt{2}$$



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