Q. 1 – Q. 25 carry one mark each.

Q.1 The partial differential equation $\frac{\partial u}{\partial t}+\frac{\partial\left(\frac{u^2}{2}\right)}{\partial x}=0$ is

(A) linear and first order
(B) linear and second order
(C) non-linear and first order
(D) non-linear and second order

Q.2 The system of equations for the variables x and y

$a\,x+b\,y=e$

$c\,x+d\,y=f$

has a unique solution only if

(A) $a\,d-b\,c\neq 0$ (B) $a\,c-b\,d\neq 0$ (C) $a+c\neq b+d$ (D) $a-c\neq b-d$

Q.3 A linear mass-spring-dashpot system is over-damped. In free vibration, this system undergoes

(A) non-oscillatory motion
(B) random motion
(C) oscillatory and periodic motion
(D) oscillatory and non-periodic motion

Q.4 A cantilever with thin-walled channel cross section is subjected to a lateral force at its shear center. The cantilever undergoes

(A) bending without twisting
(B) bending and twisting
(C) neither bending nor twisting
(D) twisting without bending

Q.5 The two non-zero principal stresses at a point in a thin plate are $\sigma_1 = 25\,MPa$ and $\sigma_2 = -25\,MPa$. The maximum shear stress (in MPa) at this point is ______.

Q.6 Consider the density and altitude at the base of an isothermal layer in the standard atmosphere to be ρ_1 and h_1, respectively. The density variation with altitude (ρ versus h) in that layer is governed by (R: specific gas constant, T: temperature, g_o: acceleration due to gravity at sea level)

(A) $\frac{\rho}{\rho_1}=e^{-\left[\frac{g_o}{RT}\right](h-h_1)}$
(B) $\frac{\rho}{\rho_1}=e^{-\left[\frac{g_o}{RT}\right](h_1-h)}$
(C) $\frac{\rho}{\rho_1}=e^{-\left[\frac{RT}{g_o}\right](h-h_1)}$
(D) $\frac{\rho}{\rho_1}=e^{-\left[\frac{RT}{g_o}\right](h_1-h)}$

Q.7 For constant free stream velocity and density, a change in lift for a large aspect ratio straight wing, with thin cambered airfoil section at small angles of attack, leads to

(A) a shift of the aerodynamic center and no shift of the center of pressure
(B) a shift of the center of pressure and no shift of the aerodynamic center
(C) shift of both the aerodynamic center and the center of pressure
(D) no shift either of the aerodynamic center or of the center of pressure

Q.8 Which one of the following modes of a stable aircraft has non-oscillatory response characteristics?

(A) Short period
(B) Phugoid
(C) Dutch roll
(D) Spiral

Q.9 As a candidate for a vertical tail, which one of the following airfoil sections is appropriate?

(A) NACA 0012 (B) NACA 2312 (C) NACA 23012 (D) Clarke Y profile

Q.10 The primary purpose of a trailing edge flap is to

(A) avoid flow separation
(B) increase $C_{l,\max}$
(C) reduce wave drag
(D) reduce induced drag

Q.11 Which one of the following aero engines has the highest propulsive efficiency?

(A) Turbojet engine without afterburner
(B) Turbojet engine with afterburner
(C) Turbofan engine
(D) Ramjet engine

Q.12 The stoichiometric fuel-to-air ratio in an aircraft engine combustor varies with the compressor pressure ratio as follows:

(A) increases linearly
(B) decreases linearly
(C) is independent
(D) increases nonlinearly

Q.13 A rocket engine produces a total impulse of 112 $kN.s$ in a burn time period of 3.5 minutes with a propellant mass flow rate of 0.25 kg/s. The effective exhaust velocity (in m/s) of gas ejecting from the engine is ______.

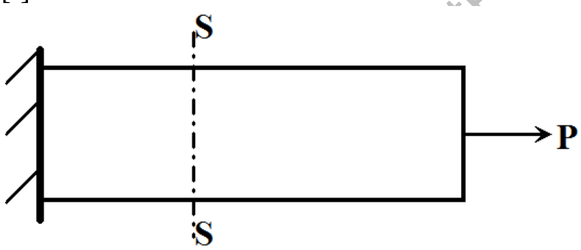
Q.14 The function $y = x^3 - x$ has

(A) no inflection point
(B) one inflection point
(C) two inflection points
(D) three inflection points

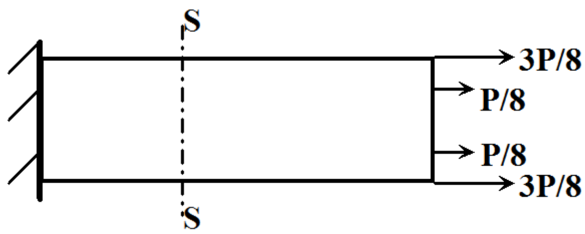
Q.15 A 0.5 kg mass is suspended vertically from a point fixed on the Earth by a spring having a stiffness of 5 N/mm. The static displacement (in mm) of the mass is ______.

Q.16 A slender structure is subjected to four different loading cases (I, II, III and IV) as shown below (Figures not to scale). Which pair of cases results in identical stress distribution at section S – S located far away from both ends?

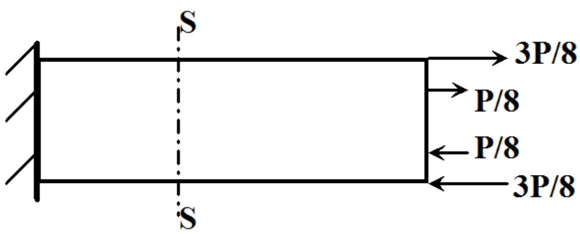
[I]



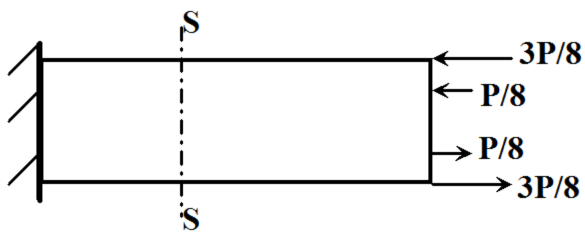
[II]



[III]



[IV]



(A) I and II
(B) II and III
(C) III and IV
(D) IV and I

Q.17 An aircraft in level and unaccelerated flight with a velocity of $v_\infty = 300\ m/s$ requires a power of $9 \times 10^6\ W$. If the aircraft weighs $1.5 \times 10^5\ N$, the lift-to-drag ratio $\frac{L}{D}$ is _____.

Q.18 The percentage change in the lift-off distance for a 20 % increase in aircraft weight is _____.

Q.19 Consider a monoplane wing and a biplane wing with identical airfoil sections, wingspans and incidence angles in identical conditions in a wind tunnel. As compared to the monoplane, the biplane experiences

(A) a higher lift and a higher drag
(B) a higher lift and a lower drag
(C) a lower lift and a lower drag
(D) a lower lift and a higher drag

Q.20 A statically stable trimmed aircraft experiences a gust and the angle of attack reduces momentarily. As a result, the center of pressure of the aircraft

(A) shifts forward
(B) shifts rearward
(C) does not shift
(D) coincides with the neutral point

Q.21 Consider a wing of elliptic planform, with its aspect ratio $AR \to \infty$. Its lift-curve slope, $\frac{dC_L}{d\alpha} =$ _____.

Q.22 An ideal gas in a reservoir has a specific stagnation enthalpy of h_0. The gas is isentropically expanded to a new specific stagnation enthalpy of $\frac{h_0}{2}$ and velocity u. The flow is one-dimensional and steady. Then $\frac{u^2}{h_0} =$ _____.

Q.23 The Reynolds number, Re is defined as $\frac{U_\infty L}{\nu}$ where L is the length scale for a flow, U_∞ is its reference velocity and ν is the coefficient of kinematic viscosity. In the laminar boundary layer approximation, comparison of the dimensions of the convection term $u\frac{\partial u}{\partial x}$ and the viscous term $\nu\frac{\partial^2 u}{\partial x^2}$ leads to the following relation between the boundary layer thickness δ and Re:

(A) $\delta \propto \sqrt{Re}$
(B) $\delta \propto 1/\sqrt{Re}$
(C) $\delta \propto Re$
(D) $\delta \propto 1/Re$

Q.24 Isentropic efficiencies of an aircraft engine operating at typical subsonic cruise conditions with the following components - intake, compressor, turbine and nozzle - are denoted by η_i, η_c, η_t and η_n, respectively. Which one of the following is correct?

(A) $\eta_i < \eta_c < \eta_t < \eta_n$
(B) $\eta_t < \eta_i < \eta_c < \eta_n$
(C) $\eta_c < \eta_t < \eta_i < \eta_n$
(D) $\eta_c < \eta_i < \eta_t < \eta_n$

Q.25 A rocket nozzle is designed to produce maximum thrust at an altitude, $H = 8\ km$ from the sea level. The nozzle operates in

(A) under-expanded condition for $H > 8\ km$
(B) under-expanded condition for $H < 8\ km$
(C) sonic exit condition for $H > 8\ km$
(D) unchoked condition for $H < 8\ km$

Q. 26 – Q. 55 carry two marks each.

Q.26 In the solution of $\frac{d^2y}{dx^2} - 2\frac{dy}{dx} + y = 0$, if the values of the integration constants are identical and one of the initial conditions is specified as $y(0) = 1$, the other initial condition $y'(0) =$ _____.

Q.27 For $x > 0$, the general solution of the differential equation $\frac{dy}{dx} = 1 - 2y$ asymptotically approaches _______.

Q.28 For a parabola defined by $y = ax^2 + bx + c,\ a \neq 0,$ the coordinates (x, y) of the extremum are

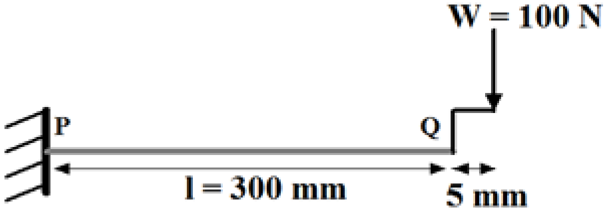
(A) $\left(\frac{-b}{2a} + \frac{\sqrt{b^2 - 4ac}}{2a}, 0\right)$ (B) $\left(\frac{-b}{2a}, \frac{-b^2 + 4ac}{2a}\right)$

(C) $\left(\frac{-b}{2a}, \frac{-b^2 + 4ac}{4a}\right)$ (D) $(0, c)$

Q.29 The 2-D stress state at a point P in the x-y coordinate system is $\begin{bmatrix} 60 & 50 \\ 50 & -40 \end{bmatrix}$ MPa. The magnitude of the tangential stress (in MPa) on a surface normal to the x-axis at P is _____.

Q.30 A cube made of a linear elastic isotropic material is subjected to a uniform hydrostatic pressure of $100\ N/\text{mm}^2$. Under this load, the volume of the cube shrinks by 0.05%. The Young's modulus of the material, $E = 300\ GPa$. The Poisson's ratio of the material is _____.

Q.31 A massless cantilever beam PQ has a solid square cross section ($10\ mm \times 10\ mm$). This beam is subjected to a load W through a rigid massless link at the point Q, as shown below (figure not to scale). If the Young's modulus of the material $E = 200\ GPa$, the deflection (in mm) at point Q is _____.



Q.32 An aircraft, with a wing loading $\frac{W}{S} = 500\ N/m^2$, is gliding at $\left(\frac{L}{D}\right)_{max} = 10$ and $C_L = 0.69$. Considering the free stream density $\rho_\infty = 0.9\ kg/m^3$, the equilibrium glide speed (in m/s) is _____.

Q.33 For a thin flat plate at 2 degrees angle of attack, the pitching moment coefficient about the trailing edge is _____.

Q.34 A satellite is to be transferred from its geostationary orbit to a circular polar orbit of the same radius through a single impulse out-of-plane maneuver. The magnitude of the change in velocity required is __________ times the magnitude of the escape velocity.

Q.35 A planetary probe is launched at a speed of 200 km/s and at a distance of 71,400 km from the mass center of its nearest planet of mass $1.9 \times 10^{28}\,kg$. The universal gravitational constant, $G = 6.67 \times 10^{-11} \frac{m^3}{kg\ s^2}$. The ensuing path of the probe would be

(A) elliptic (B) hyperbolic (C) parabolic (D) circular

Q.36 The velocity profile of an incompressible laminar boundary layer over a flat plate developing under constant pressure is given by $\frac{u(y)}{U_\infty} = \frac{3y}{2\delta} - \frac{1}{2}\left(\frac{y}{\delta}\right)^3$. The freestream velocity $U_\infty = 10\ m/s$ and the dynamic viscosity of the fluid $\mu = 1.8 \times 10^{-5} \frac{kg}{m\,s}$. At a streamwise station where the boundary layer thickness $\delta = 5mm$, the wall shear stress is ________$\times 10^{-3}\,Pa$.

Q.37 The Pitot tube of an aircraft registers a pressure $p_0 = 54051\ N/m^2$. The static pressure, density and the ratio of specific heats of the freestream are $p_\infty = 45565\ N/m^2$, $\rho_\infty = 0.6417\ kg/m^3$ and $\gamma = 1.4$, respectively. The indicated airspeed (in m/s) is

(A) 157.6 (B) 162.6 (C) 172.0 (D) 182.3

Q.38 Consider a NACA 0012 aerofoil of chord c in a freestream with velocity V_∞ at a non-zero positive angle of attack α. The average time-of-flight for a particle to move from the leading edge to the trailing edge on the suction and pressure sides are t_1 and t_2, respectively. Thin aerofoil theory yields the velocity perturbation to the freestream as $V_\infty \frac{(1+\cos\theta)\alpha}{\sin\theta}$ on the suction side and as $-V_\infty \frac{(1+\cos\theta)\alpha}{\sin\theta}$ on the pressure side, where θ corresponds to the chordwise position, $x = \frac{c}{2}(1-\cos\theta)$. Then $t_2 - t_1$ is

(A) $-\frac{8\pi\alpha c}{V_\infty\left(4-\pi^2\alpha^2\right)}$ (B) 0 (C) $\frac{4\pi\alpha c}{V_\infty\left(4-\pi^2\alpha^2\right)}$ (D) $\frac{8\pi\alpha c}{V_\infty\left(4-\pi^2\alpha^2\right)}$

Q.39 Air enters an aircraft engine at a velocity of 180 m/s with a flow rate of 94 kg/s. The engine combustor requires 9.2 kg/s of air to burn 1 kg/s of fuel. The velocity of gas exiting from the engine is 640 m/s. The momentum thrust (in N) developed by the engine is

(A) 43241 (B) 45594 (C) 47940 (D) 49779

Q.40 A solid rocket motor is designed with a cylindrical end-burning propellant grain of length 1 m and diameter 32 cm. The density of the propellant grain is 1750 kg/m^3. The specific impulse of the motor is 190 s and the acceleration due to gravity is 9.8 m/s^2. If the propellant burns for a period of 150 s, then the thrust (in N) produced by the rocket motor is ________.

Q.41 A liquid propellant rocket has the following component masses:

Mass of payload	$= 180\ kg$
Mass of fuel	$= 470\ kg$
Mass of oxidizer	$= 1170\ kg$
Mass of structures	$= 150\ kg$
Mass of guidance systems	$= 20\ kg$

The effective exhaust velocity is 3136 m/s. The velocity increment (in km/s) of the rocket at burnout, while operating in outer space, is ________.

Q.42 If all the eigenvalues of a matrix are real and equal, then

(A) the matrix is diagonalizable
(B) its eigenvectors are not necessarily linearly independent
(C) its eigenvectors are linearly independent
(D) its determinant is necessarily zero

Q.43 The value of the integral $\int_1^2 \left(4x^3 + 3x^2 + 2x + 1\right) dx$ evaluated numerically using Simpson's rule with one step is

(A) 26.5 (B) 26 (C) 25.5 (D) 25.3

Q.44 The following data is for a single degree of freedom system with viscous damping:
mass, $m = 10\ kg$; spring stiffness, $k = 2.25\ N/mm$;
damping coefficient, $c = 0.0125\ N\ s/mm$.
The ratio of any two successive amplitudes is _____.

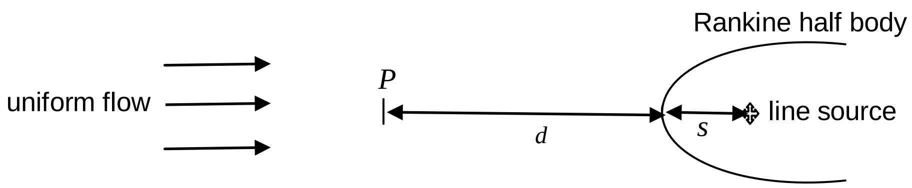
Q.45 Determine the correctness or otherwise of the following assertion [a] and reason [r]:

Assertion [a]: Aircraft directional static stability can be improved by moving the vertical tail rearward.

Reason [r]: Moving the vertical tail rearward increases the moment arm from the tail aerodynamic center to the aircraft center of gravity.

(A) Both [a] and [r] are true and [r] is the correct reason for [a]
(B) Both [a] and [r] are true but [r] is not the correct reason for [a]
(C) Both [a] and [r] are false
(D) [a] is true and [r] is false

Q.46 Consider a 2-D blunt body in an incompressible fluid stream. The flow is irrotational and can be modeled as a linear combination of a uniform flow and a line source (Rankine half body) as shown below. Let s be the distance of the line source from the front stagnation point. Let d be the upstream distance from the stagnation point to the streamwise location (labeled below as P) where the oncoming stream reaches 90% of its undisturbed velocity. Then $d/s =$ _____.

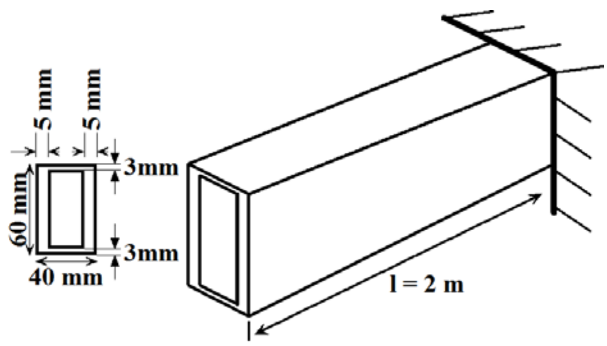


Q.47 Following are the operational parameters of an axial compressor stage:

Air mass flow rate	= 24 kg/s
Static temperature of air at the rotor inlet	= 278 K
Velocity of air at the rotor inlet (zero whirl velocity)	= 140 m/s
Work done on the compressor rotor	= 734 kJ
Isentropic efficiency of the compressor stage	= 0.86
Ratio of specific heats	= 1.4
Specific heat at constant pressure	= 1.005 kJ/kgK

The stagnation pressure ratio across the axial compressor stage is ________.

Q.48 The thin rectangular tube shown below is made of a material with shear modulus, $G = 80\ GPa$. The shear flow is calculated based on the mid-thickness dimensions. If the free end is allowed to twist no more than 0.0727 rad, then the maximum torque (in Nm) which the tube can be subjected to at its free end is _______.



Q.49 A 200 mm long simply-supported column has a $5\ mm \times 10\ mm$ rectangular cross section. The Young's modulus of the material, $E = 200\ GPa$. Assuming a factor of safety of 2.5 corresponding to the buckling load, the maximum load (in N) the column can support in compression is _______.

Q.50 For a level flight at cruise altitude, $C_D = 0.018$ with drag coefficient at zero lift, $C_{D,0} = 0.015$. For a 30° climb at the same altitude and speed, C_D = _____ $\times 10^{-3}$.

Q.51 An aircraft is flying with inertial ground and wind speeds of $\vec{v}_g^{\,b} = (100,\ 5,\ 5)\ m/s$ and $\vec{v}_w^{\,b} = (0, -5, -10)\ m/s$, respectively, as expressed in the body frame. The corresponding sideslip angle (in degrees) is

(A) 0 (B) 5.65 (C) 8.49 (D) 9.54

Q.52 The elliptical area swept by a satellite is $5.6 \times 10^9 km^2$ in one full orbit. Its angular speed is observed to be $0.00125\ rad/s$ when it is at a distance of $7{,}200\ km$ from the center of mass of its primary. Its orbital period (in Earth days) is _______.

Q.53 For a normal shock, the relation between the upstream Mach number (M_1) and the downstream Mach number (M_2) is given by $M_2^{\,2} = \dfrac{(\gamma-1)M_1^{\,2}+2}{2\gamma M_1^{\,2}+1-\gamma}$. For an ideal gas with $\gamma = 1.4$, the asymptotic value of the downstream Mach number is _______.

Q.54 A centrifugal air compressor is operating at the following conditions:

Inlet stagnation temperature	$= 288\ K$
Inlet stagnation pressure	$= 1.15\ bar$
Exit stagnation temperature	$= 454\ K$
Exit stagnation pressure	$= 4.8\ bar$

The energy loss due to non-isentropic compression per unit mass of flowing air (ratio of specific heats, $\gamma = 1.4$ and specific heat at constant pressure, $C_p = 1.005\ kJ/kgK$) is ______ kJ/kg.

Q.55 Hot gas (ratio of specific heats, $\gamma = 1.33$) at a temperature of $1450\ K$ enters into an axial turbine and expands isentropically. Assume that the kinetic energy of the gas across the turbine is negligible. If the ratio of inlet to outlet pressures of the turbine is 9.5, then the temperature (in K) of gas exiting the turbine is _______.