GATE 2023 Aerospace Question Paper

Time Allowed :3 Hours	Maximum Marks :100	Total questions :65

General Instructions

GATE 2023 – Aerospace

GENERAL INSTRUCTIONS

1. The examination is of **3 hours (180 minutes)** duration.
2. The paper consists of **65 questions** carrying a total of **100 marks**.
3. Sections include: (i) General Aptitude (15 marks) and (ii) Aerospace Engineering subject section (85 marks).
4. Question Types:
   - **MCQs** – Multiple Choice Questions with one correct option.
   - **MSQs** – Multiple Select Questions with one or more correct options.
   - **NATs** – Numerical Answer Type, where a number is to be entered using the virtual keyboard.
5. Marking Scheme:
   - MCQs: +1 or +2 marks for correct; −1/3 or −2/3 negative for wrong.
   - MSQs: +1 or +2 marks for correct; no negative marking.
   - NATs: +1 or +2 marks for correct; no negative marking.
6. Only the on-screen virtual calculator is permitted; personal calculators are not allowed.
7. Use of mobile phones, smartwatches, or any electronic devices is strictly prohibited.

Q1. "You are delaying the completion of the task. Send .... contributions at the earliest."

(A) you are

(B) your

(C) you're

(D) yore

Q2. References : .... : : Guidelines : Implement (By word meaning)

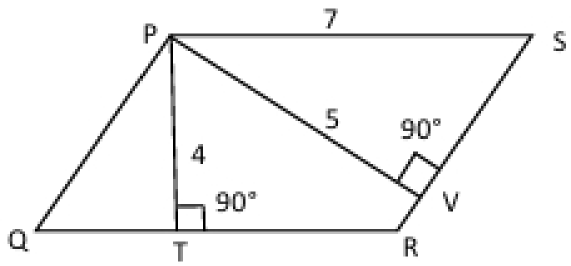
(A) Sight

(B) Site

(C) Cite

(D) Plagiarise

Q3. In the given figure, $PQRS$ is a parallelogram with $PS = 7$ cm, $PT = 4$ cm and $PV = 5$ cm. What is the length of RS (in cm)? (The diagram is representative.)



(A) $\frac{20}{7}$

(B) $\frac{28}{5}$

(C) $\frac{9}{2}$

(D) $\frac{35}{4}$

Q4. In 2022, June Huh was awarded the Fields medal (the highest prize in Mathematics). When he was younger, he was also a poet. He did not win any medals in the International Mathematics Olympiads. He dropped out of college.

Based only on the above information, which of the following statements can be logically inferred with *certainty*?

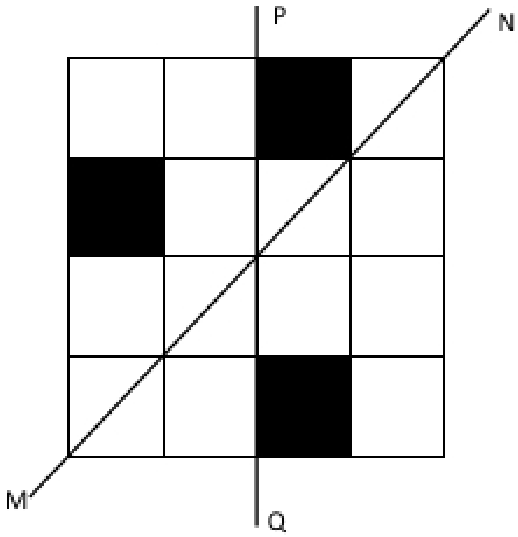
(A) Every Fields medalist has won a medal in an International Mathematics Olympiad.

(B) Everyone who has dropped out of college has won the Fields medal.

(C) All Fields medalists are part-time poets.

(D) Some Fields medalists have dropped out of college.

Q5. A line of symmetry divides a figure into two parts that are mirror images. The given figure consists of 16 unit squares. Three are already black. What is the *minimum* number of additional squares that must be coloured black so that both PQ (vertical midline) and MN (diagonal) are lines of symmetry?



(A) 3

(B) 4

(C) 5

(D) 6

Q6. In an imagined world: - Some creatures are cruel. - Humans are one kind of creature. - It is given that the statement "Some human beings are not cruel creatures" is FALSE. Which statements can be logically inferred with certainty?
(i) All human beings are cruel creatures. (ii) Some human beings are cruel creatures. (iii) Some creatures that are cruel are human beings. (iv) No human beings are cruel creatures.

(A) only (i)
(B) only (iii) and (iv)
(C) only (i) and (ii)
(D) (i), (ii) and (iii)

Q7. Sand and cement are mixed in the ratio $3 : 1$. Cost ratio of sand to cement is $1 : 2$. Total cost of sand and cement is 1000 rupees. Find the cost of cement used.

(A) 400
(B) 600
(C) 800
(D) 200

Q8. The World Bank has declared it will not offer *new* financing to Sri Lanka until an *adequate macroeconomic policy framework* is in place. It says Sri Lanka needs *structural reforms* focusing on economic stabilisation and tackling the root causes of its crisis. The crisis has starved the country of foreign exchange and led to shortages of food, fuel, and medicines. The Bank is *repurposing existing loans* to help with essentials.
Based only on this passage, which statement can be inferred with *certainty*?

(A) According to the World Bank, the root cause of Sri Lanka's crisis is lack of foreign exchange.
(B) The World Bank has stated it will advise Sri Lanka about how to tackle the root causes.
(C) According to the World Bank, Sri Lanka does not yet have an adequate macroeconomic policy framework.

(D) The World Bank has stated it will provide Sri Lanka with *additional* funds for essentials.

Q9. Find the coefficient of x^4 in $(x-1)^3(x-2)^3$.

(A) 33

(B) -3

(C) 30

(D) 21

Q10. Which of the following shapes can be used to tile (completely cover by repeating) a flat plane infinitely in all directions, without leaving gaps or overlaps?

(A) Circle

(B) Regular octagon

(C) Regular pentagon

(D) Rhombus

Q11. The direction in which a scalar field $\phi(x, y, z)$ has the largest rate of change is along:

(A) $\nabla\phi$

(B) $\nabla \times (\phi\vec{r})$

(C) $\phi\vec{r}$

(D) $(\nabla\phi \cdot d\vec{r})\vec{r}$

Q12. If a monotonic and continuous function $y = f(x)$ has exactly one root in the interval $x_1 < x < x_2$, then:

(A) $f(x_1)f(x_2) > 0$

(B) $f(x_1)f(x_2) = 0$

(C) $f(x_1)f(x_2) < 0$

(D) $f(x_1) - f(x_2) = 0$

Q13. Consider the one–dimensional wave (advection) equation

$$\frac{\partial u}{\partial t} + \frac{\partial u}{\partial x} = 0, \qquad -\infty < x < \infty,\ t \geq 0.$$

For the initial condition $u(x, 0) = e^{-x^2}$, the solution at $t = 1$ is:

(A) $u(x, 1) = e^{-(x-1)^2}$

(B) $u(x, 1) = e^{-1}$

(C) $u(x, 1) = e^{-x^2}$

(D) $u(x, 1) = e^{-(x+1)^2}$

Q14. A two–dimensional potential–flow solution for flow past an airfoil has the streamline pattern shown. Which additional condition is required to satisfy the Kutta condition?

(A) Addition of a source of strength $Q > 0$

(B) Addition of a source of strength $Q < 0$

(C) Addition of a circulation of strength $\Gamma > 0$ (counter–clockwise)

(D) Addition of a circulation of strength $\Gamma < 0$ (clockwise)

Q15. Consider the Blasius solution for the incompressible laminar flat–plate boundary layer. Among the options, select the correct relation for the development of the momentum thickness θ with distance x from the leading edge along the plate.

(A) $\theta \propto x^{2/3}$

(B) $\theta \propto x^{1/2}$

(C) $\theta \propto x^{1/7}$

(D) $\theta \propto x^{-2/3}$

Q16. In 2D potential flow, the doublet is the limit of the superposition of which two singularities?

(A) A uniform stream and a source

(B) A source and a sink of equal strength

(C) A uniform stream and a sink

(D) A source and a vortex

Q17. An ideal glider has drag characteristics given by

$$C_D = C_{D0} + C_{Di},$$

where $C_{Di} = KC_L^2$ is the induced drag coefficient, C_L is the lift coefficient, and K is a constant. For maximum range of the glider, the ratio $\frac{C_{D0}}{C_{Di}}$ is:

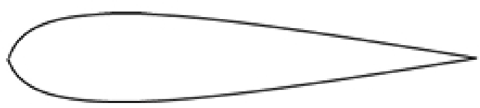
(A) 1

(B) $\frac{1}{3}$

(C) 3

(D) $\frac{3}{2}$

Q18. The figures shown in the options are schematics of airfoil shapes (not to scale). For a civilian transport aircraft designed for a cruise Mach number of 0.8, which among them is aerodynamically best suited as a wing section?

(A)	
(B)	
(C)	
(D)	

Q19. For a longitudinally statically stable aircraft, which one of the following represents the relationship between the coefficient of pitching moment about the center of gravity $C_{m_{cg}}$ and absolute angle of attack α_a?

(Note: nose–up moment is positive.)

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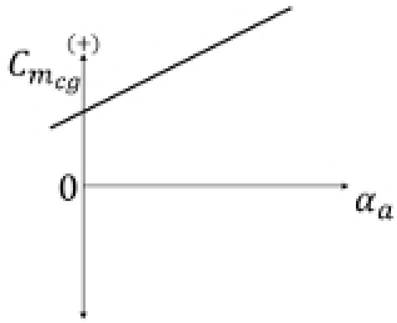
<tr><td>(A)</td><td>
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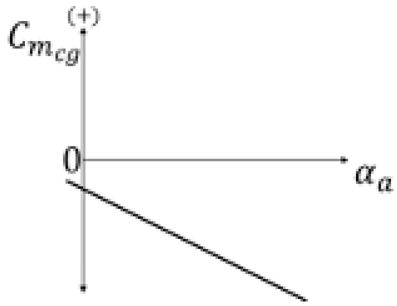
<tr><td>(B)</td><td>
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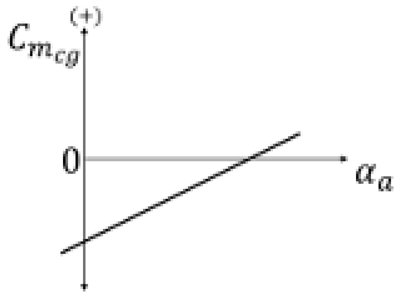
<tr><td>(C)</td><td>
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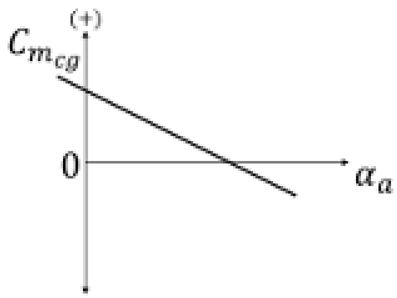
<tr><td>(D)</td><td>
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Q20. In a single–spool aviation turbojet engine, which of the following is the correct relationship between the *total* work output W_t of a 2-stage axial turbine and the *total* work required W_c by a 6-stage axial compressor, neglecting losses?

(A) $W_t = 2\,W_c$

(B) $W_t = 6\,W_c$

(C) $W_t = W_c$

(D) $W_t = 3\,W_c$

Q21. For a stage of a 50% reaction ideal axial-flow compressor (symmetrical blading), select the correct statement.

(A) The *stagnation* enthalpy rise across the rotor is 50% of the rise across the stage.

(B) The *static* enthalpy rise across the rotor is 50% of the rise across the stage.

(C) Axial velocity at rotor exit is 50% of that at rotor entry.

(D) The static pressure rise across the rotor is 50% of the rise across the stator.

Q22. An aircraft is cruising with a forward speed V_a and the jet exhaust speed relative to the engine at the exit is V_j. If $V_j/V_a = 2$, what is the propulsive efficiency?

(A) 0.50

(B) 1.00

(C) 0.33

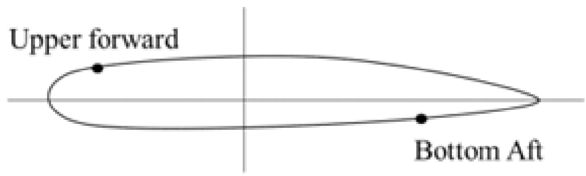
(D) 0.67

Q23. Consider the four basic symmetrical flight loading conditions corresponding to the corners of a typical $V\!-\!n$ diagram. For one condition it is observed that:

(i) the *compressive* bending stresses are maximum in the **bottom aft** region of the wing cross-section; and

(ii) the *tensile* bending stresses are maximum in the **upper forward** region of the wing cross-section (see figure).

Which flight loading condition corresponds to these observations?



(A) Positive high angle of attack

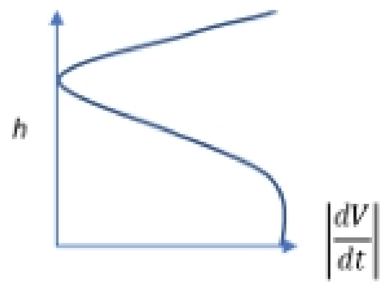
(B) Positive low angle of attack

(C) Negative high angle of attack

(D) Negative low angle of attack

Q24. Which one of the following figures represents the *qualitative* variation of absolute deceleration $\left|\dfrac{dV}{dt}\right|$ with altitude h (measured from mean sea level) for a space vehicle undergoing a **ballistic entry** into the Earth's atmosphere?

(A)



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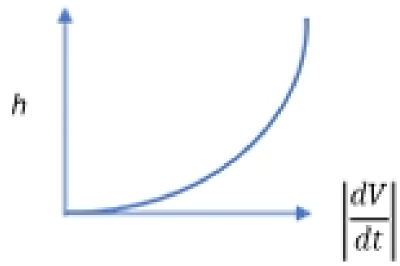
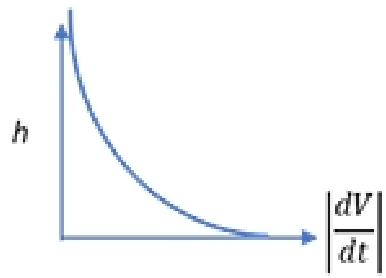
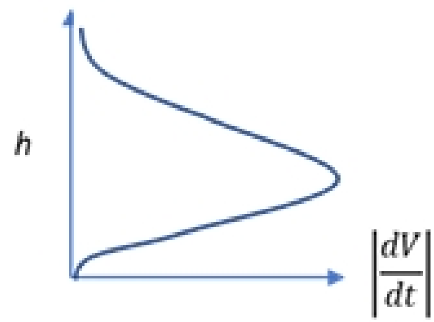


(C)



(D)



Q25. Which of the following statement(s) is/are true about harmonically excited *forced* vibration of a single degree–of–freedom linear spring–mass–damper system?

(A) The total response of the mass is a combination of free–vibration transient and steady–state response.

(B) The free–vibration transient dies out with time for each of the three possible conditions of damping (under–damped, critically damped, and over–damped).

(C) The steady–state periodic response is dependent on the initial conditions at the time of application of external forcing.

(D) The rate of decay of free–vibration transient response depends on the mass, spring stiffness and damping constant.

Q26. Which of the following statement(s) is/are true about the state of stress in a plane?

(A) Maximum or major principal stress is algebraically the largest direct stress at a point.

(B) The magnitude of minor principal stress cannot be greater than the magnitude of major principal stress.

(C) The planes of maximum shear stress are inclined at 90° to the principal axes.

(D) The normal stresses along the planes of maximum shear stress are equal.

Q27. Which of the following statement(s) is/are true about the ribs of an airplane wing with semi–monocoque construction?

(A) For a rectangular planform wing, the dimensions of the ribs DO NOT depend on their spanwise position in the wing.

(B) Ribs increase the column buckling stress of longitudinal stiffeners connected to them.

(C) Ribs increase plate buckling stress of the skin panels.

(D) Ribs help in maintaining aerodynamic shape of the wing.

Q28. From the options given, select all that are true for turbofan engines with afterburners.

(A) Turning afterburner ON increases specific fuel consumption.

(B) Turbofan engines with afterburners have variable area nozzles.

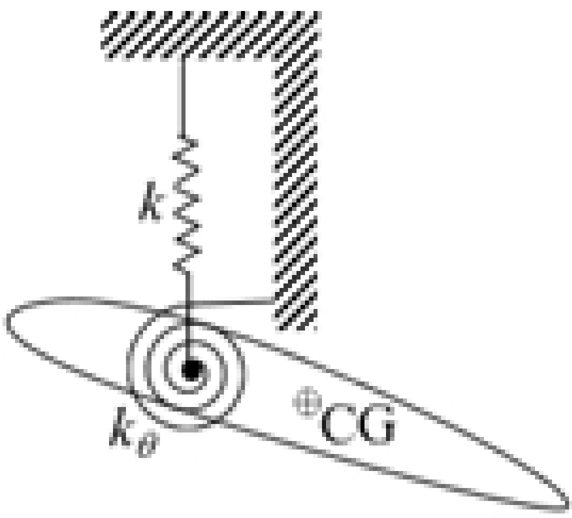
(C) Turning afterburner ON decreases specific fuel consumption.

(D) Turning afterburner ON increases stagnation pressure across the engine.

Q29. Which of the following statement(s) is/are true with respect to eigenvalues and eigenvectors of a matrix?

(A) The sum of the eigenvalues of a matrix equals the sum of the elements of the principal diagonal.
(B) If λ is an eigenvalue of a matrix A, then $\frac{1}{\lambda}$ is always an eigenvalue of its transpose (A^{T}).
(C) If λ is an eigenvalue of an *orthogonal* matrix A, then $\frac{1}{\lambda}$ is also an eigenvalue of A.
(D) If a matrix has n distinct eigenvalues, it also has n independent eigenvectors.

Q30. For studying wing vibrations, a wing of mass M and finite dimensions has been idealized by assuming it to be supported using a linear spring of equivalent stiffness k and a torsional spring of equivalent stiffness k_θ as shown in the figure. The centre of gravity (CG) of the wing (idealized as an airfoil) is marked. The number of degree(s) of freedom for this idealized wing vibration model is ______. (*Answer in integer*)

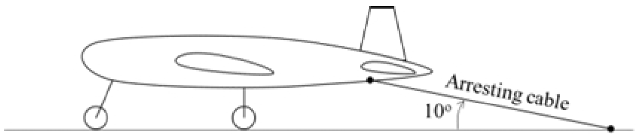


Q31. The system of equations

$$\begin{cases} x - 2y + \alpha z = 0, \\ 2x + y - 4z = 0, \\ x - y + z = 0 \end{cases}$$

has a non-trivial solution for $\alpha =$ ______. (*Answer in integer*)

Q32. An airplane weighing 40 kN is landing on a horizontal runway and is retarded by an arresting cable. The tension in the arresting cable at a given instant is 100 kN, and the cable makes $10°$ with the runway as shown. Assume engine thrust continues to balance airplane drag. The magnitude of the *horizontal load factor* is ______. (*round off to one decimal place*)



Q33. The ratio of the speed of sound in $\mathrm{H_2}$ (molecular weight 2 kg/kmol) to that in $\mathrm{N_2}$ (molecular weight 28 kg/kmol) at $T = 300$ K and $p = 2$ bar is ____. (*round off to two decimal places*)

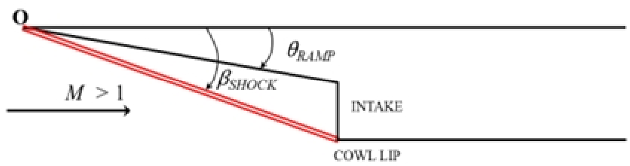
Q34. Airplane A and Airplane B are cruising at altitudes of 2 km and 4 km, respectively. The free–stream density and static pressure at 2 km are $1.01\ \mathrm{kg/m^3}$ and 79.50 kPa; at 4 km they are $0.82\ \mathrm{kg/m^3}$ and 61.70 kPa. The differential pressure reading from the pitot–static tubes is 3 kPa for both airplanes. Assuming incompressible flow, the ratio of cruise speeds V_A/V_B is ____. (*round off to two decimal places*)

Q35. A supersonic vehicle powered by a ramjet engine is cruising at 1000 m/s. The ramjet engine burns hydrogen in a subsonic combustor to produce thrust. The heat of combustion of hydrogen is 120 MJ/kg. The overall efficiency of the engine η_0, defined as the ratio of propulsive power to the total heat release in the combustor, is 40%. Taking $g_0 = 10\ \mathrm{m/s^2}$, the specific impulse of the engine is ____ seconds. (*round off to nearest integer*)

Q36. Given the function $y(x) = (x+3)(x-2)$, for $-4 < x < 4$. What is the value of x at which the function has a minimum?

(A) $-\frac{3}{2}$
(B) $-\frac{1}{2}$
(C) $\frac{1}{2}$
(D) $\frac{3}{2}$

Q37. A supersonic aircraft has an air intake ramp that can be rotated about the leading edge O such that the shock from the leading edge meets the cowl lip as shown. Select all the correct statement(s) as per oblique shock theory when flight Mach number M increases.



(A) It is always possible to find a ramp setting θ_{RAMP} such that the shock still meets the cowl lip (β_{SHOCK} remains the same).
(B) If θ_{RAMP} is held fixed, the shock angle β_{SHOCK} will increase.
(C) If M exceeds a critical value, it would NOT be possible to find a ramp setting θ_{RAMP} such that the shock still meets the cowl lip (β_{SHOCK} remains the same).
(D) Shock angle $\beta_{\text{SHOCK}} < \sin^{-1}\left(\frac{1}{M}\right)$.

Q38. Two missiles A and B powered by solid rocket motors have identical specific impulse, liftoff mass of 5600 kg each, and burn durations of $t_A = 30$ s and $t_B = 70$ s, respectively. The propellant mass flow rates $\dot{m}_A$ and $\dot{m}_B$ are given as:

$$\dot{m}_A = 120\,\text{kg/s},\ 0 \le t \le 30, \quad \dot{m}_B = 70\,\text{kg/s},\ 0 \le t \le 70$$

Neglecting gravity and aerodynamic forces, the relation between final velocities V_A and V_B is:

(A) $V_A = 4.1V_B$

(B) $V_A = V_B$

(C) $V_A = 0.5V_B$

(D) $V_A = 0.7V_B$

Q39. A perfect gas stored in a reservoir exhausts through a convergent nozzle. The jet emerges at choked conditions with average velocity u. If reservoir pressure p_0 increases while T_0 remains constant, determine effect on M, u, T, p, ρ.

(A) u, M, p, T, ρ increase

(B) u, p, T, ρ increase, M same

(C) u, M, T same, p, ρ increase

(D) u, M, T same, only p increases

Q40. A general aviation airplane has $W = 10\,\text{kN}$, $S = 15\,\text{m}^2$, $\rho = 0.60\,\text{kg/m}^3$, $C_{D0} = 0.025$, $K = 0.05$, thrust $T = 1\,\text{kN}$. Find the maximum cruise speed.

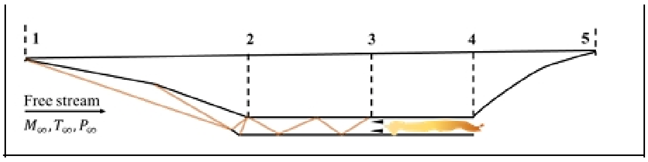
(A) 87 m/s

(B) 30 m/s

(C) 36 m/s

(D) 101 m/s

Q41. A scramjet engine features an intake, isolator, combustor, and a nozzle, as shown. Station 3 indicates the combustor entry point. Assume stagnation enthalpy is constant between Stations 1 and 3, and air is a calorically perfect gas with specific heat ratio γ. Select the correct expression for Mach number M_3 at the inlet to the combustor from the options given.



(A) $M_3 = M_\infty \sqrt{\frac{2}{\gamma - 1}\left(\frac{T_0}{T_3} - 1\right)}$

(B) $M_3 = \sqrt{\frac{2}{\gamma - 1}\left[\frac{T_0}{T_3}\left(1 + \frac{\gamma - 1}{2} M_\infty^2\right) - 1\right]}$

(C) $M_3 = M_\infty \sqrt{\frac{T_\infty}{T_3}}$

(D) $M_3 = \sqrt{\frac{\gamma + 1}{2}\left(\frac{T_0}{T_3} - 1\right) M_\infty^2}$

Q42. Consider the equation $\frac{dy}{dx} + ay = \sin(\omega x)$, where a and ω are constants. Given $y = 1$ at $x = 0$, select all correct statements as $x \to \infty$.

(A) $y \to 0$ if $a \neq 0$

(B) $y \to 1$ if $a = 0$

(C) $y \to A \exp(|a|x)$ if $a < 0$; A is a constant

(D) $y \to B \sin(\omega x + C)$ if $a > 0$; B, C are constants

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Q43. Given vectors

$$\vec{A} = 9\hat{\imath} - 5\hat{\jmath} + 2\hat{k}, \quad \vec{B} = 11\hat{\imath} + 4\hat{\jmath} + \hat{k}, \quad \vec{C} = -7\hat{\imath} + 14\hat{\jmath} - 3\hat{k}$$

which of the following statements are TRUE?

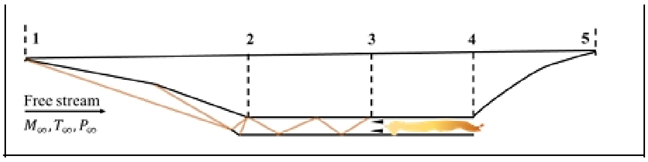
(A) Vectors $\vec{A}, \vec{B}, \vec{C}$ are coplanar

(B) The scalar triple product of $\vec{A}, \vec{B}, \vec{C}$ is zero

(C) $\vec{A}$ and $\vec{B}$ are perpendicular

(D) $\vec{C}$ is parallel to $\vec{A} \times \vec{B}$

Q44. Consider a one-dimensional inviscid supersonic flow in a diverging duct with heat addition (Q_{in}). Which of the following statement(s) is/are always TRUE?



(A) Mach number, $M_2 > M_1$

(B) Stagnation pressure, $P_1^0 > P_2^0$

(C) Static pressure, $P_2 > P_1$

(D) Stagnation temperature, $T_1^0 < T_2^0$

Q45. Consider the International Standard Atmosphere (ISA) with h being the geopotential altitude (in km) and $\frac{dT}{dh}$ being the temperature gradient (in K/m). Which of the following combination(s) of $\left(h, \frac{dT}{dh}\right)$ is/are correct as per ISA?

(A) $(7, -6.5 \times 10^{-3})$

(B) $(9, 4 \times 10^{-3})$

(C) $(15, 0)$

(D) $(35, 3 \times 10^{-3})$

Q46. For an airfoil, which of the relations about the critical Mach number M_{cr} and drag divergence Mach number M_{dd} are correct?

(A) $M_{cr} < M_{dd}$

(B) $M_{cr} < 1.0$

(C) $M_{dd} < 1.0$

(D) $M_{cr} > 1.0$

Q47. Which of the following statement(s) about the elastic flexural buckling load of columns is/are correct?

(A) The buckling load increases with increase in flexural rigidity of the column.

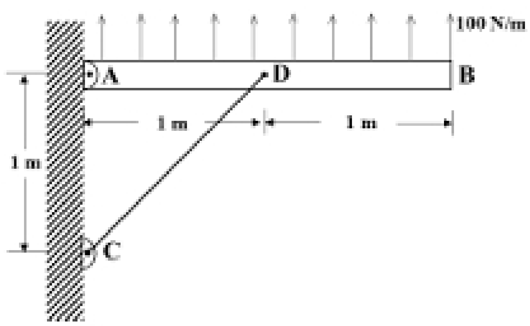
(B) The buckling load increases with increase in the length of the column.

(C) The boundary conditions of the column affect the buckling load.

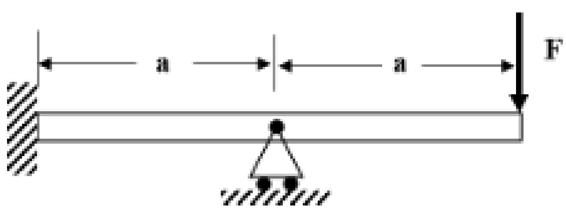
(D) The buckling load is NOT directly dependent on the density of the material used for the column.

Q48. The thickness of a uniform hollow circular shaft is equal to the difference between the outer radius and the inner radius. The ratio of the inner diameter to outer diameter of the shaft is 0.5. For the shaft reacting to an applied torque, the ratio of the maximum shear stress τ to the maximum shear stress $\tau_{\text{thin-wall}}$ obtained using the thin-wall approximation is .... (round off to one decimal place)

Q49. A rigid bar AB of length 3 m is subjected to a uniformly distributed load of 100 N/m. The bar is supported at A (pin) and by rod CD connected at D. The rod CD has axial stiffness 40 N/mm, and C is pinned. Find the vertical deflection at point D (in mm).

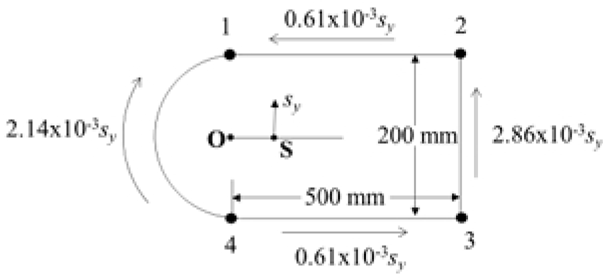


Q50. A cantilever beam of length $2a$ is loaded at the tip with force F. The beam is supported in the middle by a roller (pin). Find the reaction moment at the built-in end of the beam as $\alpha F a$, where $\alpha =$ .... (round off to one decimal place).



Q51. A single degree-of-freedom spring–mass–damper system has viscous damping ratio $\zeta = 0.1$. The mass has initial displacement of 10 cm without velocity. After exactly two complete cycles of damped oscillation, find amplitude of displacement (in cm, round off to two decimals).

Q52. The shear flow distribution in a single cell, thin-walled beam under a shear load S_y is shown in the figure. The cell has horizontal symmetry with booms marked 1 to 4. The shear modulus G is same for all walls, and the area of the cell is $135000\,\text{mm}^2$. With respect to point O, find the distance of shear centre S (in mm). (round off to nearest integer)



Q53. A thin-walled cylindrical pressure vessel of yield strength 300 MPa has radius-to-thickness ratio $R/t = 100$. Using von Mises yield criterion, find internal pressure at failure. (round off to two decimals)

Q54. Solve differential equation:

$$x^2\frac{d^2y}{dx^2} + 4x\frac{dy}{dx} + 2y = 0, \quad x \geq 1$$

with initial conditions $y = 0,\ y'(1) = 1$ at $x = 1$. Find y at $x = 2$. (round off to two decimals)

Q55. The operating characteristics of a pump are measured as $C_p = a\Phi^2$, where

$$C_p = \frac{P}{\rho\omega^3 D^5}, \quad \Phi = \text{flow coefficient}, \quad a = \text{constant}.$$

If ω increases by 25% (i.e. $\omega \to 1.25\omega$) and the flow coefficient Φ is constant, determine α such that P becomes αP. (round off to two decimal places)

Q56. A thin cambered airfoil has lift coefficient $C_l = 0$ at angle of attack $\alpha = -1°$. Estimate C_l at $\alpha = 4°$, assuming stall occurs at much higher α. (round off to two decimal places)

Q57. In potential flow, a uniform stream of strength U flows along x-axis. Line sources of strength $\pi/2, -\pi/3, \pi/4, -\pi/5$ are placed at $x = 0, 1, 2, 3$ respectively. Find strength of an additional line source at $x = 4$ such that a closed streamline encircles all five sources. (round off to two decimal places)

Q58. Enstrophy is defined as square of magnitude of vorticity. For velocity field

$$\vec{V} = (4x - 1.5y + 2.5z)\hat{\imath} + (1.5x - 1.5y)\hat{\jmath} + (0.7xy)\hat{k},$$

find enstrophy at $(1, 1, 1)$. (round off to two decimal places)

Q59. An airplane with wing planform area $S = 20\,\text{m}^2$ and weight $W = 8\,\text{kN}$ is flying straight and level with a speed of $V = 100\,\text{m/s}$. The total drag coefficient is $C_D = 0.026$ and the air density is $\rho = 0.7\,\text{kg/m}^3$. The total thrust required to introduce a steady climb at angle $\gamma = 0.1$ radians is .... N. (round off to the nearest integer)

Q60. The maximum permissible load factor and the maximum lift coefficient for an airplane are $n_{\max} = 7$ and $C_{L,\max} = 2$, respectively. For a wing loading $W/S = 6500$ N/m^2 and air density $\rho = 1.23$ kg/m^3, the speed yielding the highest possible turn rate in the vertical plane is .... m/s. (round off to the nearest integer)

Q61. A gas turbine combustor burns methane with air at equivalence ratio $\phi = 0.5$, where $\phi = \dfrac{(F/A)}{(F/A)_{\text{st}}}$. If the air mass-flow rate is $\dot{m}_{\text{air}} = 20$ kg/s, find the methane mass-flow rate (kg/s). (round off to two decimal places)

Q62. Given $G = 6.67 \times 10^{-11}$ N m^2/kg^2, planet mass $M = 6.4169 \times 10^{23}$ kg and radius $R = 3390$ km, find the escape velocity (km/s). (round off to one decimal place)

Q63. A satellite is in a circular orbit around Earth with period $T = 90$ minutes. Take Earth's radius $R_E = 6370$ km, Earth's mass $M_E = 5.98 \times 10^{24}$ kg, and $G = 6.67 \times 10^{-11}$ N m^2/kg^2. Find the altitude above mean sea level (km).

Q64. A centrifugal air compressor has inlet root diameter $D_1 = 0.25\,$m and outlet impeller diameter $D_2 = 0.6\,$m. Pressure ratio $\pi_c = p_{02}/p_{01} = 5.0$. Air at rotor inlet: $p_{01} = 1\,$atm, $T_{01} = 25$°C $= 298\,$K. Polytropic efficiency $\eta_p = 0.8$, slip factor $\sigma = 0.92$. Take $C_p = 1.004\,$kJ/kg-K and $\gamma = 1.4$. Find the impeller speed (RPM). (round off to the nearest integer)

Q65. A cryogenic liquid rocket engine (expander cycle) burns liquid hydrogen and liquid oxygen at stoichiometry. The hydrogen mass-flow rate is $\dot{m}_{H_2} = 32\,$kg/s, and the oxygen mass-flow rate satisfies $\dot{m}_{O_2}/\dot{m}_{H_2} = 8$. Assuming the forward reaction dominates, find the rate of formation of H_2O (kmol/s). (round off to the nearest integer)
