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# GATE 2024

## AEROSPACE ENGINEERING

EXAM HELD ON
10th Feb, 2024
(Afternoon Session)

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## QUESTIONS & SOLUTIONS

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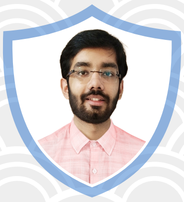
# OUR ACHIEVERS

## GATE-2024 AE



**K SUNIL**
IIST TRIVANDRUM
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ACHARYA INSTITUTE, B'LORE
**AIR - 6**

**HARIHARAN R**
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**AIR - 9**

**VIGNESH CG**
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**ADITYA ANIL KUMAR**
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**AIR - 17**

*And Many More ........*

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**AIR - 7**

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- ***Mr. Abhilash K*** *(Amrita Univ Coimbatore)*
- ***Ms. Ajitha Nishma V*** *(IIST Trivendrum)*
- ***Mr. Dheeraj Sappa*** *(IIEST Shibpur)*
- ***Ms. F Jahangir*** *(MIT Chennai)*
- ***Mr. Goutham*** *(KCG College Chennai)*
- ***Mr. M Kumar*** *(MVJ College Bangalore)*
- ***Mr. Mohit Kudal*** *(RTU Kota)*
- ***Mr. Niladhari Pahari*** *(IIEST Shibpur)*
- ***Mr. Nitesh Singh*** *(Sandip Univ Nashik)*
- ***Mr. Ramanathan A*** *(Amrita Univ Coimbatore)*
- ***Ms. Shruti S Rajpara*** *(IIEST Shibpur)*

## HAL DT ENGINEER

Job Position for Recruitment **(2023)**

- ***Mr. Anantha Krishan A.G*** *(Amrita Univ Coimbatore)*
- ***Mr. S.S Sanjay*** *(Amrita Univ Coimbatore)*
- ***Mr. Shashi Kanth M*** *(Sastra Univ Tanjore)*
- ***Mr. Vagicharla Dinesh*** *(Lovely Professional Univ Panjab)*

**FATHIMA J**
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**HAL DT ENGINEER** 2022

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**ARATHY ANILKUMAR NAIR**
(AMRITA UNIV, COIMBATORE)
**HAL DT ENGINEER** 2021

**SADSIVUNI TARUN**
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**HAL DT ENGINEER** 2021

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**RAM GOPAL SONI**
(GVIET, PUNJAB)
**CEMILAC LAB, DRDO**

# GATE 2024
# AEROSPACE ENGINEERING

## General Aptitude – GA

**Q. 1 – Q. 5 carry one mark each.**

1. If '→' denotes increasing order of intensity, then the meaning of the words [dry → arid → parched] is analogous to [diet → fast → _______ ]. Which one of the given options is appropriate to fill the blank?

(A) starve (C) feast
(B) reject (D) deny

2. If two distinct non-zero real variables $x$ and $y$ are such that $(x+y)$ is proportional to $(x-y)$ then the value of

(A) depends on xy
(B) depends only on x and not on y
(C) depends only on y and not on x
(D) is a constant

3. Consider the following sample of numbers:
9, 18, 11, 14, 15, 17, 10, 69, 11, 13
The median of the sample is

(A) 13.5 (C) 11
(B) 14 (D) 18.7

4. The number of coins of ₹1, ₹5, and ₹10 denominations that a person has are in the ratio 5:3:13. Of the total amount, the percentage of money in ₹5 coins is

(A) 21% (C) 10%
(B) $14\,{}^{2}/_{7}$% (D) 30%

5. For positive non-zero real variables p and q, if $\log(p^2+q^2) = \log p + \log q + 2\log 3$,
then, the value of $\dfrac{p^4+q^4}{p^2q^2}$ is

(A) 79 (C) 9
(B) 81 (D) 83

**Q. 6 – Q. 10 carry two marks each.**

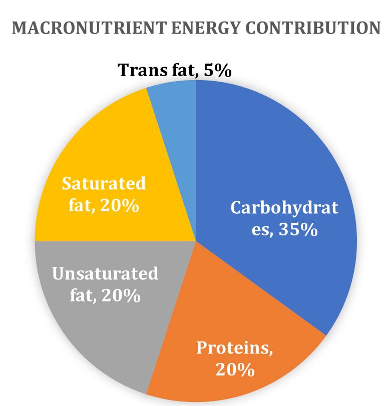
6. In the given text, the blanks are numbered (i)−(iv). Select the best match for all the blanks.
Steve was advised to keep his head ___(i)___ before heading ___(ii)___ to bat; for, while he had a head ___(iii)___ batting, he could only do so with a cool head s ___(iv)___ his shoulders.

(A) (i) down (ii) down (iii) on (iv) for
(B) (i) on (ii) down (iii) for (iv) on
(C) (i) down (ii) out (iii) for (iv) on
(D) (i) on (ii) out (iii) on (iv) for

7. A rectangular paper sheet of dimensions 54 cm × 4 cm is taken. The two longer edges of the sheet are joined together to create a cylindrical tube. A cube whose surface area is equal to the area of the sheet is also taken.
Then, the ratio of the volume of the cylindrical tube to the volume of the cube is

(A) $1/\pi$ (C) $3/\pi$
(B) $2/\pi$ (D) $4/\pi$

8. The pie chart presents the percentage contribution of different macronutrients to a typical 2,000 kcal diet of a person.



The typical energy density (kcal/g) of these macronutrients is given in the table.

| Macronutrient | Energy density (kcal/g) |
|---|---|
| Carbohydrates | 4 |
| Proteins | 4 |
| Unsaturated fat | 9 |
| Saturated fat | 9 |
| Trans fat | 9 |

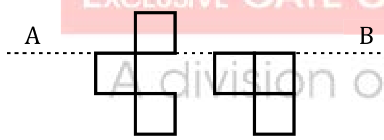
The total fat (all three types), in grams, this person consumes is

(A) 44.4
(B) 77.8
(C) 100
(D) 3,600

9. A rectangular paper of 20 cm × 8 cm is folded 3 times. Each fold is made along the line of symmetry, which is perpendicular to its long edge. The perimeter of the final folded sheet (in cm) is

(A) 18
(B) 24
(C) 20
(D) 21

10. The least number of squares to be added in the figure to make AB a line of symmetry is




(A) 6
(B) 4
(C) 5
(D) 7

## Aerospace Engineering – AE

**Q. 11 – Q. 35 carry one mark each.**

11. The following system of linear equations

$7x - 3y + z = 0$

$3x - y + z = 0$

$x - y - z = 0$

has:

(A) infinitely many solutions

(B) a unique solution

(C) no solution

(D) three solutions

12. The acceleration of a body travelling in a straight line is given by $a = -C_1 - C_2 v^2$ where $v$ is the velocity, and $C_1, C_2$ are positive constants. Starting with an initial positive velocity $v_o$, the distance travelled by the body before coming to rest for the first time is:

(A) $\frac{1}{2C_2} \ln\left(1 + \frac{C_2}{C_1} v_0^2\right)$

(B) $\frac{1}{2C_2} \ln\left(1 - \frac{C_2}{C_1} v_0^2\right)$

(C) $\frac{1}{2C_2} \ln(C_1 + C_2 v_0^2)$

(D) $\frac{1}{2C_2} \ln(1 + C_2 v_0^2)$

13. The three-dimensional stress-strain relationship for an isotropic material is given as

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \tau_{yz} \\ \tau_{xz} \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} P & Q & Q & 0 & 0 & 0 \\ Q & P & Q & 0 & 0 & 0 \\ Q & Q & P & 0 & 0 & 0 \\ 0 & 0 & 0 & R & 0 & 0 \\ 0 & 0 & 0 & 0 & R & 0 \\ 0 & 0 & 0 & 0 & 0 & R \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \gamma_{yz} \\ \gamma_{xz} \\ \gamma_{xy} \end{Bmatrix}$$

where, P, Q and R are the three elastic constants, $\sigma$ and $\tau$ represent normal and shear tresses and $\varepsilon$ and $\gamma$ represent normal and engineering shear strains. Which one of the following options is correct?

(A) $R = \frac{P-Q}{2}$

(C) $R = \frac{Q-P}{2}$

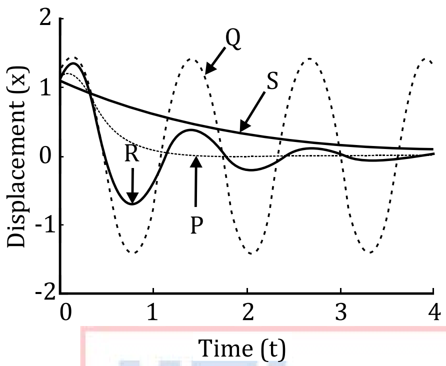
(C) $Q = \frac{P-R}{2}$

(D) $Q = \frac{R-P}{2}$

14. Consider the free vibration responses P, Q, R and S (shown in the figure) of a single degree of freedom spring-mass-damper system with the same initial conditions. For the different

damping cases listed below, which one of the following options is correct?

1. Overdamped
2. Underdamped
3. Critically damped
4. Undamped




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

15. For a single degree of freedom spring-mass-damper system subjected to harmonic forcing, the part of the motion (response) that decays due to damping is known as:
(A) transient response
(B) steady-state response
(C) harmonic response
(D) non-transient response

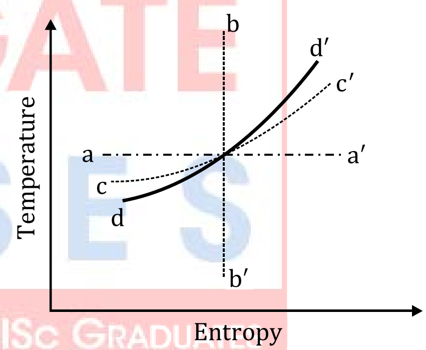
16. For an ideal gas, the specific heat at constant pressure is 1147 J/kg K and the ratio of specific heats is equal to 1.33. What is the value of the gas constant for this gas in J/kg K?

(A) 284.6 (C) 862.4
(B) 1005 (D) 8314

17. A surrogate liquid hydrocarbon fuel, approximated as C10H12, is being burned in a land-based gas turbine combustor with dry air (79% N2 and 21% O2 by volume).
How many moles of dry air are required for the stoichiometric combustion of the surrogate fuel with dry air at atmospheric temperature and pressure?

(A) 61.9 (C) 13
(B) 30.95 (D) 10

18. In the figure shown below, various thermodynamics processes for an ideal gas are represented. Match each curve with the process that it best represents.



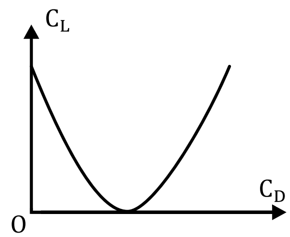

(A) aa’ – Isentropic; bb’ – Isothermal; cc’ – Isobaric; dd’ – Isochoric
(B) aa’ – Isothermal; bb’ – Isentropic; cc’ – Isochoric; dd’ – Isobaric
(C) aa’ – Isothermal; bb’ – Isentropic; cc’ – Isobaric; dd’ – Isochoric
(D) aa’ – Isothermal; bb’ – Isobaric; cc’ – Isentropic; dd’ – Isochoric

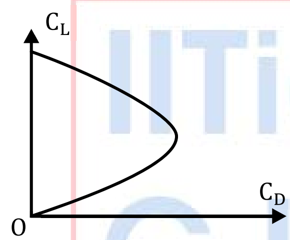
19. In an airbreathing gas turbine engine, the combustor inlet temperature is 600 K. The heating value of the fuel is $43.4 \times 10^{6}$ J/kg. Assume $C_p$ to be 1100 J/kg K for air and burned gases, and fuel-air ratio f << 1.0. Neglect kinetic energy at the inlet and exit of the combustor and

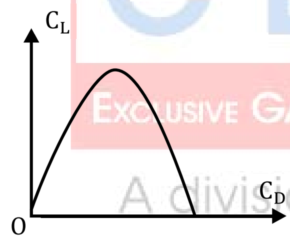
assume 100% burner efficiency. What is the fuel-air ratio required to achieve 1300 K temperature at the combustor exit?

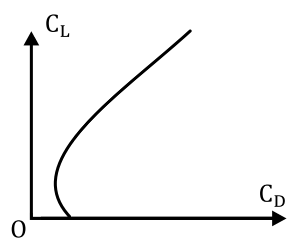
(A) 0.0177 (C) 0.0127
(B) 0.0215 (D) 0.0277

20. Which one of the following figures represents the drag polar of a general aviation aircraft?

(A)



(B)



(C)



(D)


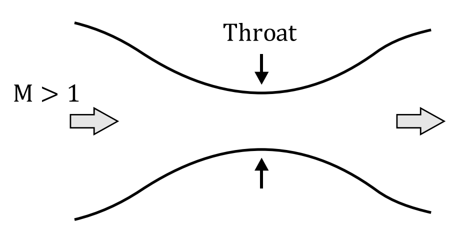

21. In the context of steady, inviscid, incompressible flows, consider the superposition of a uniform flow with speed U along the positive x-axis (from left to right), and a source of strength $\Lambda$ located at the origin. Which one of the following statements is NOT true regarding the location of the stagnation point of the resulting flow?

(A) It is located to the left of the origin
(B) It moves closer to the origin for increasing $\Lambda$, while U is held constant
(C) It moves closer to the origin for increasing U, while $\Lambda$ is held constant
(D) It is located along the x-axis

22. On Day 1, an aircraft flies with a speed of $V_1$ m/s at an altitude where the temperature is $T_1$ K. On Day 2, the same aircraft flies with a speed of $\sqrt{1.2}\,V_1$ m/s at an altitude where the temperature is 1.2 $T_1$ K. How does the Mach number $M_2$ on Day 2 compare with the Mach number $M_1$ on Day 1?
Assume ideal gas behavior for air. Also assume the ratio of specific heats and molecular weight of air to be the same on both the days.

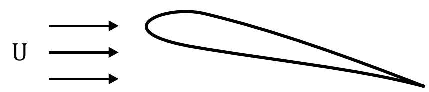
(A) $M_2 = 0.6M_1$ (C) $M_2 = 1/\sqrt{1.2}M_1$
(B) $M_2 = M_1$ (D) $M_2 = \sqrt{1.2}M_1$

23. Consider a steady, isentropic, supersonic flow (Mach number M > 1) entering a Convergent-Divergent (CD) duct as shown in the figure. Which one of the following options correctly describes the flow at the throat?

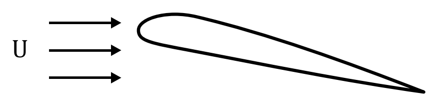



(A) Can only be supersonic
(B) Can only be sonic
(C) Can either be sonic or supersonic
(D) Can only be subsonic

24. Consider steady, incompressible, inviscid flow past two airfoils shown in the figure. The coefficient of pressure at the trailing edge of the airfoil with finite angle, shown in figure (I), is $C_{P_I}$ while that at the trailing edge of the airfoil with cusp, shown in figure (II), is $C_{P_{II}}$. Which one of the following options is TRUE?




(I) Training edge with finite angle

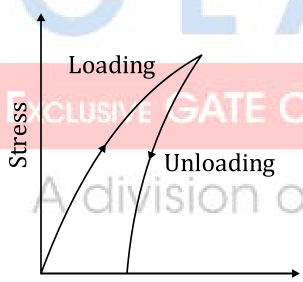



(II) Training edge with cusp

(A) $C_{P_I} < 1, C_{P_{II}} < 1$ (C) $C_{P_I} = 1, C_{P_{II}} < 1$
(B) $C_{P_I} = 1, C_{P_{II}} = 1$ (D) $C_{P_I} < 1, C_{P_{II}} = 1$

25. Which of the following options is/are correct?

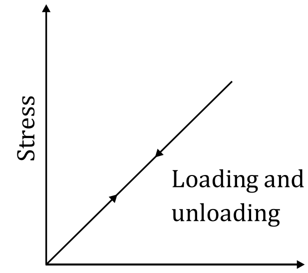
(A) The stress-strain graph for a nonlinear elastic material is as shown in the figure




(B) Material properties are independent of position in a homogeneous material

(C) An isotropic material has infinitely many planes of material symmetry

(D) The stress-strain graph for a linear elastic material is




26. Which of the following statements is/are correct about a satellite moving in a geostationary orbit?

(A) The orbit lies in the equatorial plane

(B) The orbit is circular about the center of the Earth

(C) The time period of motion is 90 minutes

(D) The satellite is visible from all parts of the Earth

27. In a conventional configuration airplane, the rudder can be used:

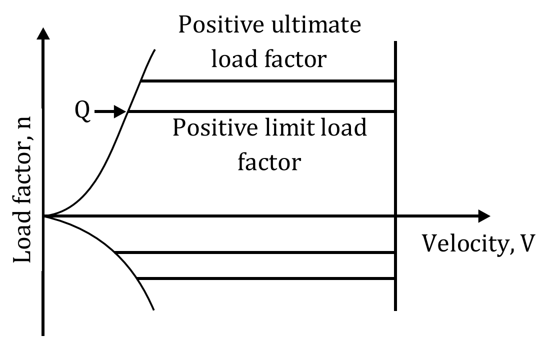
(A) to overcome adverse yaw during a turning maneuver

(B) to overcome yawing moment due to failure of one engine in a multi engine airplane

(C) for landing the airplane in crosswind conditions

(D) for enhancing longitudinal stability

28. Which of the following statements about a general aviation aircraft, while operating at point Q in the V-n diagram, is/are true?




(A) The aircraft has the highest turn rate

(B) The aircraft has the smallest turn radius

(C) The aircraft is flying with minimum drag

(D) The aircraft is operating at $C_{L,max}$

29. Two fair dice with numbered faces are rolled together. The faces are numbered from 1 to 6. The probability of getting odd numbers on both the dice is ____________ (rounded off to 2 decimal places).

30. A particle acted upon by a constant force $4\hat{i} + \hat{j} - 3\hat{k}$ N is displaced from point A with position vector $\hat{i} + 2\hat{j} + 3\hat{k}$ m to point B with position vector $5\hat{i} + 4\hat{j} + \hat{k}$ m. The work done by this force is ______ J (answer in integer).

31. Using Trapezoidal rule with one interval, the approximate value of the definite integral:

$$\int_1^2 \frac{dx}{1+x^2}$$

(rounded off to 2 decimal places).

32. A material has Poisson's ratio $\nu = 0.5$ and Young's modulus E=2500 MPa. The percentage change in its volume when subjected to a hydrostatic stress of magnitude 10 MPa is _____ (answer in integer).

33. An airplane experiences a net vertical ground reaction of 15000 N during landing. The weight of the airplane is 10000 N. The landing vertical load factor, defined as the ratio of inertial load to the weight of the aircraft, is ________ (rounded off to 1 decimal place).

34. An aircraft with a turbojet engine is flying with 250 m/s speed at an altitude, where the density of air is 1 kg/m$^3$. The inlet area of the engine is 1 m$^2$. The average velocity of the exhaust gases at the exit of the nozzle, with respect to aircraft, is 550 m/s. Assume the engine exit pressure is equal to the ambient pressure and the fuel-air ratio is negligible. The uninstalled thrust produced by the engine at these conditions is ________ N (rounded off to the nearest integer).

35. Using thin airfoil theory, the lift coefficient of a NACA 0012 airfoil placed at 5° angle of attack in a uniform flow is ___________ (rounded off to 2 decimal places).

**Q. 36 – Q. 65 carry two marks each.**

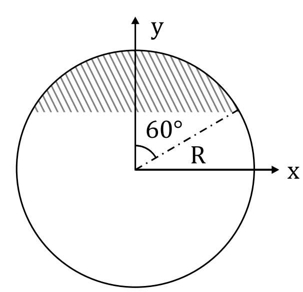
36. Given $y = e^{px} \sin qx$, where $p$ and $q$ are non-zero real numbers, the value of the differential expression

$$\frac{d^2y}{dx^2} - 2p\frac{dy}{dx} + (p^2+q^2)y$$

is

(A) 0
(B) 1
(C) $p^2 + q^2$
(D) pq

37. The volume of the solid formed by a complete rotation of the shaded portion of the circle of radius R about the y-axis is $k\pi R^3$. The value of $k$ is:




(A) 5/12
(B) 5/24
(C) 7/12
(D) 7/24

38. As per the International Standard Atmosphere model, which one of the following options about density variation with increase in altitude in the isothermal layer is correct?

(A) remains constant
(B) increases linearly
(C) decreases linearly
(D) decreases exponentially

39. At a point in the trajectory of an unpowered space vehicle moving about the Earth, the altitude above the mean sea level is 600 km, and the speed with reference to a coordinate system fixed to the center of mass of the Earth is 9 km/s. Assume that the Earth is a sphere with a radius 6400 km and $GM_{Earth} = 3.98 \times 10^{14}$ $m^3/s^2$, where, G is the universal gravitational constant and $M_{Earth}$ is mass of the Earth. The trajectory is:

(A) Circular (C) Parabolic
(B) Elliptic (D) Hyperbolic

40. A multistage axial compressor, with overall isentropic efficiency of 0.83, is used to compress air at a stagnation temperature of 300 K through a pressure ratio of 10:1. Each stage of the compressor is similar, and the stagnation temperature rise across each compressor stage is 20 K. Assume $C_p = 1005$ J/kg K and $\gamma = 1.4$ for air. How many stages are there in the compressor?

(A) 17 (C) 19
(B) 13 (D) 11

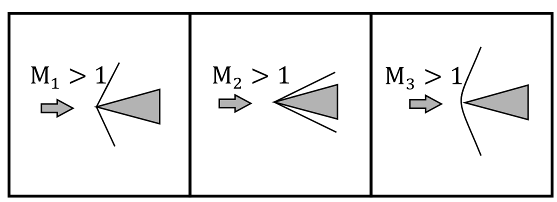
41. An aircraft with a turbojet engine is flying at 250 m/s. The uninstalled thrust produced by the engine is 60000 N. The heating value of the fuel is $44 \times 10^6$ J/kg. The engine has a thermal efficiency of 35% while burning the fuel at a rate of 3 kg/s. Assume the engine exit pressure to be equal to the ambient pressure. What is the propulsion efficiency of the engine under these conditions (in percentage)?

(A) 32.5 (C) 11.4
(B) 35.0 (D) 92.4

42. Consider a flat plate, with a sharp leading edge, placed in a uniform flow of speed U. The direction of the free-stream flow is aligned with the plate. Assume that the flow is steady, incompressible and laminar. The thickness of the boundary layer at a fixed stream-wise location L from the leading edge of the plate is δ. Which one of the following correctly describes the variation of δ with U?

(A) $\delta \propto U$ (C) $\delta \propto U^{1/2}$
(B) $\delta \propto U^{3/2}$ (D) $\delta \propto U^{-1/2}$

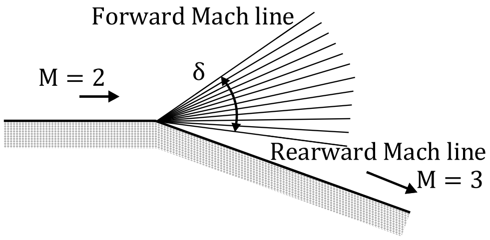
43. Shock structures for flow at three different Mach numbers over a given wedge are shown in the figure below. Assuming that only the weak shock solutions are possible for the attached oblique shocks, which one of the following options is TRUE?




(A) $M_1 < M_2 < M_3$ (C) $M_1 < M_3 < M_2$
(B) $M_1 > M_2 > M_3$ (D) $M_3 < M_1 < M_2$

44. Air flowing at Mach number M = 2 from left to right accelerates to M = 3 across an expansion corner as shown in the figure. What is the value of $\delta$ (the angle between the Forward and Rearward Mach lines) in degrees? The values of

the Prandtl-Meyer functions are $\nu(3) = 49.76°$ and $\nu(2) = 26.38°$.




(A) 23.38
(B) 19.47
(C) 53.38
(D) 33.91

45. Consider the function

$$f(x) = \begin{cases} x^2 & \text{for } x < 0 \\ x & \text{for } x \geq 0 \end{cases}$$

where x is real. Which of the following statements is/are correct?

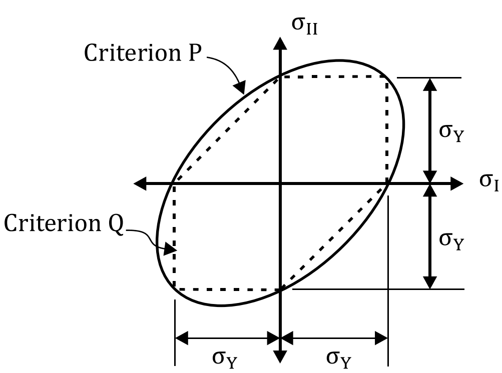
(A) The function is continuous for all x

(B) The derivative of the function is discontinuous at x = 0

(C) The derivative of the function is continuous at x = 1

(D) The function is discontinuous at x = 0

46. The figure shows plots of two yield loci for an isotropic material, where $\sigma_I$ and $\sigma_{II}$ are the principal stresses, and $\sigma_Y$ is the yield stress in uniaxial tension. Which of the following statements is/are correct?




(A) Criterion P represents the von Mises criterion

(B) Criterion Q represents the Tresca criterion

(C) Criterion P represents the Tresca criterion

(D) Criterion Q represents the von Mises criterion

47. Which of the following statements about absolute ceiling and service ceiling for a piston-propeller aircraft is/are correct?

(A) The altitude corresponding to absolute ceiling is higher than that for service ceiling

(B) At the absolute ceiling, the power required for cruise equals the maximum power available

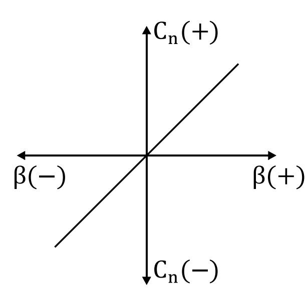
(C) The altitude corresponding to absolute ceiling is lower than that for service ceiling

(D) At the service ceiling, the maximum rate of climb is 50 ft/min

48. For an airplane having directional / weathercock static stability, which of the following options is/are correct?

(A) The airplane when disturbed in yaw, from an equilibrium state, will experience a restoring moment

(B) The variation of yawing moment coefficient ($C_n$) with sideslip angle ($\beta$) for the airplane will look like




(C) The airplane will always tend to point into the relative wind

(D) The airplane when disturbed in yaw will return to equilibrium state in a finite amount of time after removing the disturbance

49. Which of the following statements is/are TRUE for an axial turbine?

(A) For a fixed rotational speed, the mass flow rate increases with increase in the flow coefficient

(B) The absolute stagnation enthalpy of the flow decreases across the nozzle row

(C) The relative stagnation enthalpy remains unchanged through the rotor

(D) For a fixed rotational speed, the mass flow rate remains unchanged with a change in the flow coefficient

50. Which of the following statements is/are TRUE for a single stage axial compressor?

(A) Starting from design condition and keeping the mass flow rate constant, if the blade RPM is increased, the compressor rotor may experience positive incidence flow separation (actual relative flow angle greater than the design blade angle)

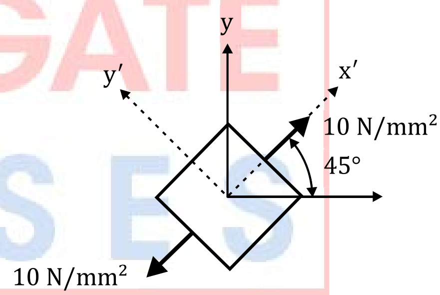
(B) Starting from design condition at the same blade RPM, if the mass flow rate is increased, the compressor rotor may experience positive incidence flow separation (actual relative flow angle greater than the design blade angle)

(C) Keeping the mass flow rate constant, if the blade RPM is increased, the compressor may experience surge

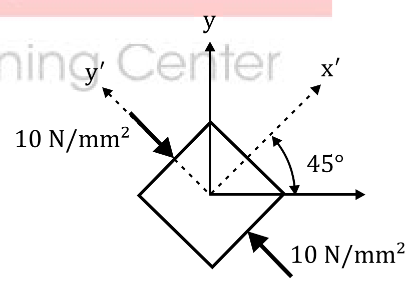
(D) At the same blade RPM, if the mass flow rate is increased, the compressor may experience surge

51. Consider the matrix $A = \begin{bmatrix} 5 & -4 \\ k & -1 \end{bmatrix}$, where k is a constant. If the determinant of A is 3, then the ratio of the largest eigenvalue of A to constant k is ________. (rounded off to 1 decimal place).

52. The state of stress at a point is caused by two separate loading cases. One of them produces a pure uniaxial tension along the $x'$ direction, and other one produces a pure uniaxial compression along the $y'$ direction, as shown in the figure. The sum of maximum and minimum principal stresses for the resultant state of stress caused by both loads acting simultaneously is _________ $N/mm^2$ (rounded off to 1 decimal place).

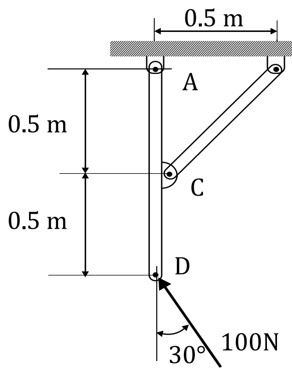



State of stress in case I

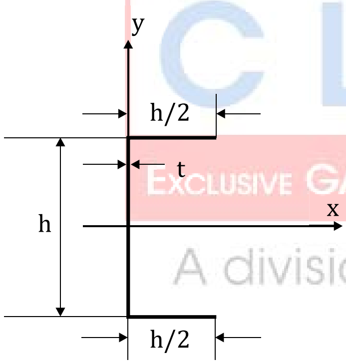



State of stress in case II

53. In the figure shown below, the magnitude of internal force in member BC is ________ N (rounded off to 1 decimal place).




54. The cross section of a thin-walled beam with uniform wall thickness t, shown in the figure, is subjected to a bending moment $M_x = 10$ Nm. If h=1m and t=0.001 m, the magnitude of maximum normal stress in the cross section is _______$N/m^2$ (answer in integer).




55. The equations of motion for a two degrees of freedom undamped spring-mass system are:

$m\ddot{x}_1 + 2kx_1 - kx_2 = 0$

$m\ddot{x}_2 - kx_1 + 2kx_2 = 0$

where m and k represent mass and stiffness respectively, in corresponding SI units, and $x_1$ and $x_2$ are the degrees of freedom. The larger of the two natural frequencies is given by: $\omega = \alpha\sqrt{k/m}$ rad/s. The value of $\alpha$ is _______ (rounded off to 2 decimal places).

56. Consider the plane strain field given by

$\varepsilon_{xx} = 10xy^2, \varepsilon_{yy} = -5x^2y$ and

$\gamma_{xy} = A\,xy\,(2x - y)$

where, A is a constant and $\gamma xy$ is the engineering shear strain. The value of the constant A for the strain field to be compatible is ___________ (rounded off to 1 decimal place).

57. A chemical rocket with an ideally expanded flow through the nozzle produces $5 \times 10^6$ N thrust at sea level. The specific impulse of the rocket is 200 s and acceleration due to gravity at the sea level is 9.8 $m/s^2$. The propellent mass flow rate out of the rocket nozzle is _______ kg/s (rounded off to the nearest integer).

58. A centrifugal compressor is designed to operate with air. At the leading edge of the tip of the inducer (eye of the impeller), the blade angle is 45°, and the relative Mach number is 1.0. The stagnation temperature of the incoming air is 300 K. Consider $\gamma = 1.4$. Neglect pre-whirl and slip. The inducer tip speed is _______ m/s (rounded off to the nearest integer).

59. Consider the following Fanno flow problem: Flow enters a constant area duct at a temperature of 273 K and a Mach number 0.2 and eventually reaches sonic condition (Mach number =1) due to friction.

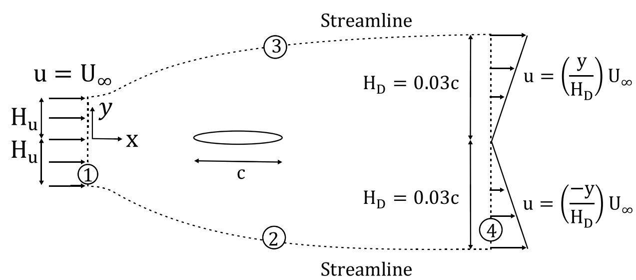
Assume $\gamma = 1.4$. The static temperature at the location where sonic condition is reached is___________ K (rounded off to 2 decimal places).

60. Consider an artificial satellite moving around the Moon in an elliptic orbit. The altitude of the satellite from the Moon's surface at the perigee is 25 km and that at the apogee is 134 km. Assume the Moon to be spherical with a radius of 1737 km. The trajectory is considered with reference to a coordinate system fixed to the center of mass of the Moon. The ratio of the speed of the satellite at the perigee to that at the apogee is _________ (rounded off to 2 decimal places).

61. For an aircraft moving at 4 km altitude above mean sea level at a Mach number of 0.2, the ratio of equivalent air speed to true air speed is ______ (rounded off to 2 decimal places).
The density of air at mean sea level is 1.225 $kg/m^3$ and at 4 km altitude is 0.819 $kg/m^3$.

62. For a general aviation airplane, one of the complex conjugate pair of eigenvalues for longitudinal dynamics is given by $-0.039 \pm 0.0567\ i$ (in SI units). If the system is disturbed to excite only this mode, the time taken for the amplitude of response to become half in magnitude is ______ s (rounded off to 1 decimal place).

63. The figure (not to scale) shows a control volume to estimate the forces on the airfoil with elliptic cross-section. Surfaces 2 and 3 are streamlines. Velocity profiles are measured at the upstream end (surface 1) and at the downstream end (surface 4) of the control volume. The drag coefficient for the airfoil is defined as $C_d = \frac{D}{\frac{1}{2}\rho U_\infty^2 c}$, where D is the drag force on the airfoil per unit span and ρ is the density of the air. The static pressure, $p_\infty$, is constant over the entire surface of the control volume.
Assuming the flow to be incompressible, two-dimensional and steady, the $C_d$ for the airfoil is ________ (rounded off to 3 decimal places).




64. An airplane of mass 1000 kg is in a steady level flight with a speed of 50 m/s. The wing has an elliptic planform with a span of 20 m and planform area 31.4 $m^2$.
Assuming the density of air at that altitude to be 1 $kg/m^3$ and acceleration due to gravity to be 10 $m/s^2$, the induced drag on the wing is _______ N (rounded off to 1 decimal place)

65. It is desired to estimate the aerodynamic drag, D, on a car traveling at a speed of 30 m/s. A one-third scale model of the car is tested in a wind-tunnel following the principles of dynamic similarity. The drag on the scaled model is measured to be $D_m$. The ratio $D/D_m$ is _______ (rounded off to 1 decimal place).

# Answer Keys GATE 2024 - Aerospace Engineering

## GENERAL APTITUDE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | A | 3 | A | 5 | A | 7 | A | 9 | A |
| 2 | D | 4 | C | 6 | C | 8 | C | 10 | A |

## TECHNICAL

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 11 | A | | 31 | 0.35 to 0.35 | | 51 | 1.4 to 1.6 |
| 12 | A | | 32 | 0 to 0 | | 52 | 0 to 0 |
| 13 | A | | 33 | 1.5 to 1.5 | | 53 | 141.0 to 141.5 |
| 14 | C | | 34 | 75000 to 75000 | | 54 | 14900 to 15100 |
| 15 | A | | 35 | 0.54 to 0.56 | | 55 | 1.72 to 1.74 |
| 16 | A | | 36 | A | | 56 | 4.9 to 5.1 |
| 17 | A | | 37 | B | | 57 | 2500 to 2600 |
| 18 | C | | 38 | D | | 58 | 230 to 240 |
| 19 | A | | 39 | B | | 59 | 227.0 to 231.0 |
| 20 | D | | 40 | A | | 60 | 1.05 to 1.07 |
| 21 | B | | 41 | A | | 61 | 0.80 to 0.84 |
| 22 | B | | 42 | D | | 62 | 17.7 to 17.9 |
| 23 | C | | 43 | D | | 63 | 0.018 to 0.022 |
| 24 | C | | 44 | D | | 64 | 63.0 to 64.5 |
| 25 | B;C;D | | 45 | A;B;C | | 65 | 1.0 to 1.0 |
| 26 | A;B | | 46 | A;B | | | |
| 27 | A;B;C | | 47 | A;B | | | |
| 28 | A;B;D | | 48 | A;B;C | | | |
| 29 | 0.24 to 0.26 | | 49 | A;C | | | |
| 30 | 24 to 24 | | 50 | A;C | | | |

# Explanations GATE 2024 - Aerospace Engineering

## General Aptitude – GA

1. **[Ans. A]**

[dry → arid → parched]

[diet → fast → starve]

2. **[Ans. D]**

$(x+y) \propto (x-y)$

$(x+y) = k(x-y)$

$x + y = kx - ky$

$x - kx = -y - ky$

$x(1-k) = y(-1-k)$

$\frac{x}{y} = \frac{-(1+k)}{1-k} = \frac{-(k+1)}{-(k-1)}$

$\frac{x}{y} = \frac{k+1}{k-1}$, where k is a constant

$\frac{x}{y}$ is constant

3. **[Ans. A]**

Given, 9, 18, 11, 14, 15, 17, 10, 69, 11, 13

First arrange these number either in ascending or descending order.

9, 10, 11, 11, **13, 14** ,15, 17, 18, 69

$\text{Median} = \frac{13+14}{2} = 13.5$

4. **[Ans. C]**

| | | | | | |
|---|---|---|---|---|---|
| Given values of coin | → | ₹1, | ₹5, | ₹10 | |
| | | × | × | × | |
| ratio | → | 5 : | 3 : | 13 | |
| Total Value | | 5 + | 15 + | 130 | = 150 |

$\because$ % of money in ₹ 5 coins $= \frac{₹5 \times 3}{150} \times 100$

$= \frac{15}{150} \times 100$

$= 10\%$

5. **[Ans. A]**

Given, $\log(p^2+q^2) = \log p + \log q + 2\log 3$

$\log(p^2+q^2) = \log p + \log q + \log 3^2$

$\log(p^2+q^2) = \log(p \times q \times 3^2)$

Taking exponential on b.s

$p^2 + q^2 = 9pq$

$\frac{p^2+q^2}{pq} = 9 \Rightarrow \frac{p}{q} + \frac{q}{p} = 9$

Squaring on b.s

$\frac{p^2}{q^2} + \frac{q^2}{p^2} + 2 \times \frac{p}{q} \times \frac{q}{p} = 81$

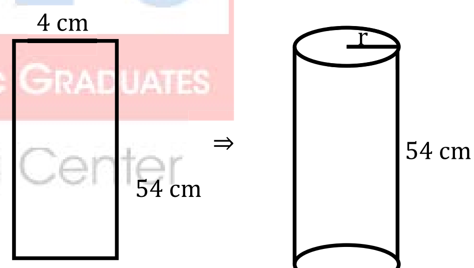
$\frac{p^4+q^4}{p^2q^2} = 81 - 2$

$\frac{p^4+q^4}{p^2q^2} = 79$

6. **[Ans. C]**

Steve was advised to keep his head <u>down</u> before heading <u>out</u> to bat; for while he had a head <u>for</u> batting, he could only do so with a cool head <u>on</u> his shoulders.

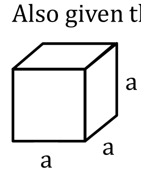
7. **[Ans. A]**




Rectangular paper

Cylindrical tube

Also given that




$2\pi r = 4$

$r = \frac{2}{\pi}$

Surface area of cube = Area of rectangular paper

$6a^2 = 4 \times 54$

$a^2 = 4 \times 9$

$a = 2 \times 3 \Rightarrow a = 6 \text{ cm}$

$$\therefore \frac{\text{Volume of cylinder}}{\text{Volume of cube}} = \frac{\pi r^2 h}{a^3} = \frac{\pi \times \left(\frac{2}{\pi}\right)^2 \times 54}{6^3}$$

$$= \frac{\pi \times \frac{4}{\pi^2} \times 54}{6^3} = \frac{1}{\pi}$$

8. **[Ans. C]**

From the pie chart

(unsat fat +sat fat + trans fat) of 2000 kCal

$$\left(\frac{20\%}{9} + \frac{20\%}{9} + \frac{5\%}{9}\right) \times 2000 \text{ kCal}$$

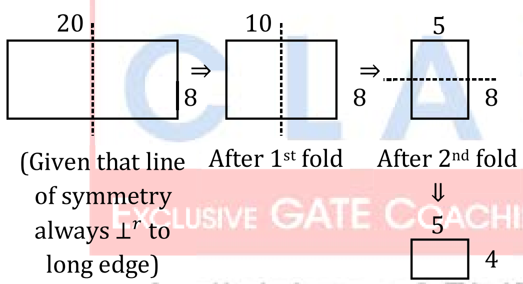
$\therefore$ Total fat in grams

$$= \left(\frac{20 \times 2000}{100 \times 9} + \frac{20 \times 2000}{100 \times 9} + \frac{5 \times 2000}{100 \times 9}\right) \frac{\text{kCal}}{\text{kCal/g}}$$

$$= \frac{400}{9} + \frac{400}{9} + \frac{100}{9} = \frac{900}{9} \text{grams}$$

$= 100$ grams

9. **[Ans. A]**

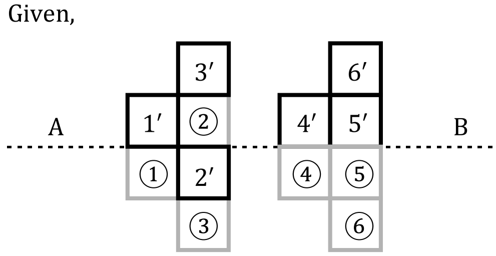



$\therefore$ Perimeter of final folded sheet $= 2(5 + 4)$

$= 2(9) = 18$

10. **[Ans. A]**

Given,




$\because$ Least number of squares added is 6.

## Aerospace Engineering – AE

11. **[Ans. A]**

Given, $\left.\begin{aligned} 7x - 3y + z = 0 \\ 3x - y + z = 0 \\ x - y - z = 0 \end{aligned}\right\}$ Homogenous set of linear equation

Now writing in matrix form

$$A = \begin{bmatrix} 7 & -3 & 1 \\ 3 & -1 & 1 \\ 1 & -1 & -1 \end{bmatrix}$$

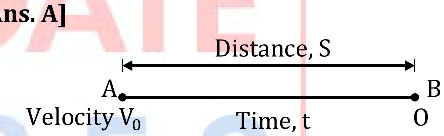
$|A| = 7(1 + 1) + 3(-3 - 1) + 1(-3 + 1)$

$= 14 - 12 - 2$

$|A| = 0$

We know that for a homogeneous set of linear equations when $|A| = 0$ it have infinity many solutions.

12. **[Ans. A]**




Given, acceleration, $a = -C_1 - C_2V^2$

$$\frac{dv}{dt} = -C_1 - C_2V^2$$

Now separate variables and integrate both side wrt time and velocity

$$\int_{v_o}^{v} \frac{dv}{-C_1 - C_2v^2} = \int_0^t dt$$

Now using partial fractions to simplify LHS

$$\frac{-1}{C_2} \int_{v_o}^{v} \left(\frac{1}{v} + \frac{C_2 v}{C_1 + C_2v^2}\right) dv = t$$

$$\frac{-1}{C_2}\left[\ln(V) + \frac{1}{2}\ln(C_1 + C_2v^2)\right]_{v_o}^{v} = t$$

Now solve for v in terms of t and use the condition that the body comes to rest when V = 0

$$\frac{-1}{C_2}\left[\ln(0) + \frac{1}{2}\ln(C_1)\right] + \frac{1}{C_2}\left[\ln(V_o) + \frac{1}{2}\ln(C_1 + C_2V_o^2)\right]$$

$$= t$$

$$\ln\left(\frac{C_1 + C_2V_0^2}{C_1}\right) = 2C_2t$$

$$\frac{C_1 + C_2 V_0^2}{C_1} = e^{2C_2 t}$$

$$V_0^2 = \frac{C_1}{C_2}\left(e^{2C_2 t} - 1\right)$$

Since the distance travelled by the body is the integral of its velocity we can write,

$$S = \int_0^t V dt = \int_0^t \sqrt{\frac{C_1}{C_2}\left(e^{2C_2 t} - 1\right)} dt$$

On Simplifying the above equation, we get

$$S = \frac{1}{2C_2}\ln\left(1 + \frac{C_2}{C_1}V_0^2\right)$$

13. **[Ans. A]**

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{zx} \end{Bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0 \\ \nu & 1-\nu & \nu & 0 & 0 & 0 \\ \nu & \nu & 1-\nu & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{Bmatrix}$$

Comparing this with the given question we get,

$$P = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)}$$

$$Q = \frac{E\nu}{(1+\nu)(1-2\nu)}$$

$$R = \frac{E}{2(1+\nu)} = G$$

Now

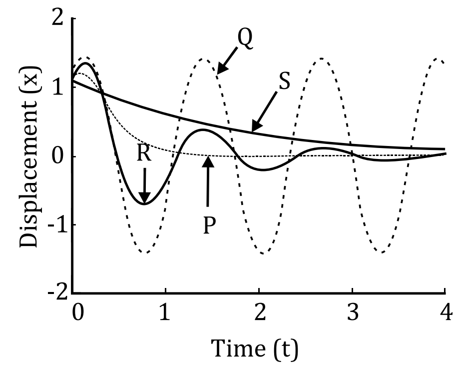
$$P - Q = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)} - \frac{E\nu}{(1+\nu)(1-2\nu)}$$

$$= \frac{E(1-2\nu)}{(1+\nu)(1-2\nu)} = \frac{E}{(1+\nu)}$$

Dividing by 2 on bs

$$\frac{P-Q}{2} = \frac{E}{2(1+\nu)} \Rightarrow R = \frac{P-Q}{2}$$

14. **[Ans. C]**




From the diagram

Q → no change in amplitude → undamped

R → oscillatory motion coming back to initial portion→ underdamped

P → Takes minimum time to come back to initial portion → Critically damped

S → Overdamped.

15. **[Ans. A]**

Equation of motion with forced vibration

$m\ddot{x} + c\dot{x} + kx = F_o \sin\omega t$

Solution for this DE is

$x = x_c + x_p$

$x_c$ = transient response;

$x_p$ = Steady state response

The complimentary function part can be written as,

$m\ddot{x} + kx + c\dot{x} = 0 \rightarrow$ This equation stands for damped free vibration or transient response part of forced vibration.

16. **[Ans. A]**

Given, $C_p = 1147$ J/kgK

$\gamma = 1.33$

WKT

$$C_p - C_v = R, \quad \gamma = \frac{C_p}{C_v}$$

$$C_p - \frac{C_p}{\gamma} = R$$

$$1 - \frac{1}{\gamma} = \frac{R}{C_p}$$

$$\Rightarrow R = C_p \frac{(\gamma - 1)}{\gamma}$$

$$= \frac{1147(1.33 - 1)}{1.33}$$

$$R = 284.6$$

17. **[Ans. A]**

For stochiometric combustion of hydrocarbon fuel with air,

$C_{10}H_{12} + n_x Air \rightarrow 10CO_2 + 6H_2O$

Here,

Air = 79% of $N_2$ + 21% of $O_2$ by volume

$\therefore C_{10}H_{12} + n\,(0.79N_2 + 0.21O_2)$

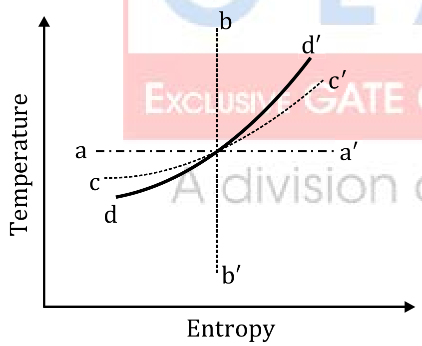
$\rightarrow 10CO_2 + 6H_2O$

From RHS we need 26 oxygen atoms (or) 13 $O_2$

$\therefore n \times 0.21 = 13$

$n = 61.9$

18. **[Ans. C]**




aa′ → Constant temp → Isothermal

bb′ → Constant entropy → Isentropic

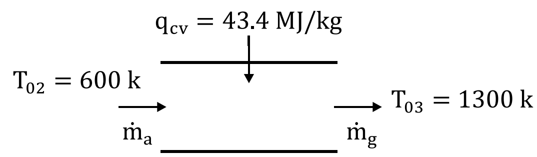
Slope of constant volume process in T-S diagram > Slope of constant pressure process in T-S diagram

cc′ → constant press → Isobaric

dd′ → constant volume → Isochoric

19. **[Ans. A]**

Given,




$C_{p_a} = C_{p_g} = 1100$ J/kgK

By energy balance

$$\dot{m}_g C_{p_g} T_{03} = m_a C_{p_a} T_{02} + \eta_b \dot{m}_f q_{cv}$$

$$\dot{m}_a (1 + f)\, C_{p_g} T_{03} = \dot{m}_a \left[C_{p_a} T_{02} + \eta_b f q_{cv}\right]$$

$$(1 + f) C_{p_g} T_{03} = C_{p_a} T_{02} + \eta_b f q_{cv}$$

$$f C_{p_g} T_{03} - \eta_b f q_{cv} = C_{p_a} T_{02} - C_{p_g} T_{03}$$

$$f = \frac{C_{p_g} T_{03} - C_{p_a} T_{02}}{\eta_b q_{cv} - C_{p_g} T_{03}}$$

Given that

$C_{p_g} = C_{p_a} = C_p = 1100$ J/kgK

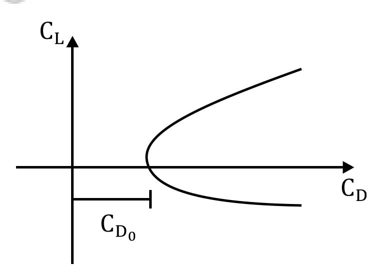
$$f = \frac{C_p T_{03} - C_p T_{02}}{q_{cv} - C_p T_{03}}$$

$$= \frac{1100(1300 - 600)}{43.4 \times 10^6 - (1100 \times 1300)}$$

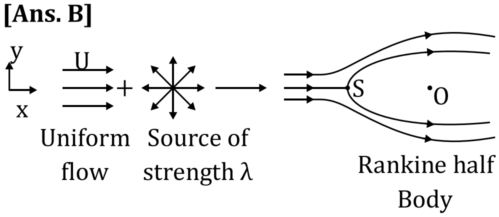
$$f = 0.0177$$

20. **[Ans. D]**

WKT the general drag polar.



21. **[Ans. B]**




WKT,

Distance of stagnation point from origin

$= \frac{\lambda}{2\pi U} \begin{pmatrix}\text{Obtained from equating the} \\ \text{velocity components to zero}\end{pmatrix}$

$\because$ it is clearly seen that the stagnation point is located upstream of the source.

Therefore

$\Rightarrow$ If $\lambda \uparrow$, $U$ = constant, distance $\uparrow \rightarrow$ point S will shift in farther away from origin

$\Rightarrow$ If $\lambda$ = constant, $U \uparrow$, distance $\downarrow \rightarrow$ point S will shift in towards the origin

22. **[Ans. B]**

Given, Day 1 $\rightarrow V_1, T_1, M_1$

Day 2 $\rightarrow \sqrt{1.2}\, V_1, 1.2T_1, M_2$

WKT,

$$M = \frac{V}{\sqrt{\gamma RT}}, M_1 = \frac{V_1}{\sqrt{\gamma RT_1}}, M_2 = \frac{V_2}{\sqrt{\gamma RT_2}}$$

Now,

$$\frac{M_2}{M_1} = \frac{V_2}{V_1} \times \sqrt{\frac{\gamma RT_1}{\gamma RT_2}} = \frac{\sqrt{1.2}V_1}{V_1} \times \sqrt{\frac{T_1}{1.2\ T_1}}$$

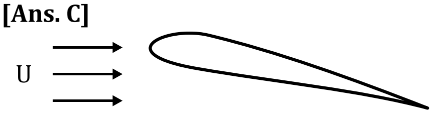
$$\frac{M_2}{M_1} = 1 \ \rightarrow \ M_2 = M_1$$

23. **[Ans. C]**

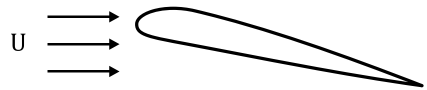
The given throat area is not necessarily a critical area for a given supersonic flow. So the flow decelerates but still remain supersonic at the throat. If the area is less than or equal to critical area then it will be sonic. Area here refers to the are ratio (A/A*).

Therefore, at the throat flow can be either sonic or supersonic.

24. **[Ans. C]**



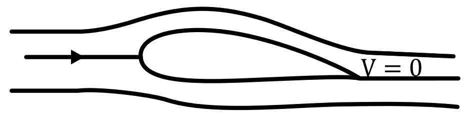

(I) Trailing edge with finite angle




(II) Trailing edge with cusp

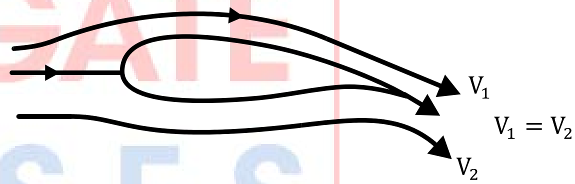
Now,

For finite angle TE




Here trailing edge is stagnation point ($V_{TE} = 0$)

For cusped TE




Here trailing edge is not a stagnation point

Now, as we know

$$C_{p_{TE}} = 1 - \left(\frac{V_{TE}}{V_\infty}\right)^2$$

Therefore,

For finite angle TE, $V_{TE} = 0 \Rightarrow C_{p_I} = 1$

For cusped TE, $V_{TE} \neq 0 \Rightarrow C_{p_{II}} < 1$

25. **[Ans. B, C, D]**

For an elastic material, there will no permanent deformation during loading and unloading. So Option A is wrong.

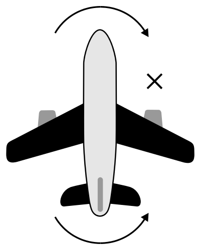
26. **[Ans. A, B]**

Geostationary orbits lies in equational plane at a very high altitude and it has a time period of 24 hours and the orbit is circular about the centre of earth.

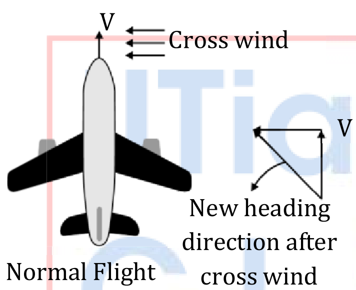
27. **[Ans. A, B, C]**

$\Rightarrow$ We need rudder to counteract adverse yaw.

$\Rightarrow$ In longitudinal stability, only elevator play a role.




$\Rightarrow$ we need rudder to counteract the moment generated by failure of engine in a multi engine a/c.




$\Rightarrow$ we need rudder to counteract this crosswind conditions.

28. **[Ans. A, B, D]**

From the V-n diagram, we know

Q $\rightarrow$ Maneuvering point

$\rightarrow$ At Q, $C_L$ & n at their absolute peak values

$\rightarrow$ Turn radius R and turn rate ($\omega$) are at their both min and max values respectively.

$$R \propto \frac{1}{\sqrt{n^2-1}}, \qquad \omega \propto \sqrt{n}$$

29. **[Ans. *] Range: 0.24 to 0.26**

Number of sample space in rolling a two fair dice $= 6^2 = 36$

Favourable outcomes are

$$\left.\begin{matrix} (1,1), & (1,3), & (1,5) \\ (3,1), & (3,3), & (3,5) \\ (5,1), & (5,3), & (5,5) \end{matrix}\right\} \rightarrow \text{total} = 9$$

$\therefore$ Probability of getting odd numbers on both the dice.

$$= \frac{\text{No. of favourable outcomes}}{\text{No. of sample space}}$$

$$= \frac{9}{36}$$

$$= \frac{1}{4} = 0.25$$

30. **[Ans. *] Range: 24 to 24**

Given, $\vec{F} = 4\hat{\imath} + \hat{\jmath} - 3\hat{k}\ \text{N}$

$$\underset{\hat{\imath}+2\hat{\jmath}+3\hat{k}\ \text{m}}{A} \bullet\!\!-\!\!-\!\!-\!\!-\!\!\bullet \underset{5\hat{\imath}+4\hat{\jmath}+\hat{k}\ \text{m}}{B}$$

$$\vec{r} = \overrightarrow{AB} = \overrightarrow{OB} - \overrightarrow{OA}$$

$$\vec{r} = \overrightarrow{AB} = 4\hat{\imath} + 2\hat{\jmath} - 2\hat{k}\ \text{m}$$

$\because$ Work done, $W.D = \vec{F} \cdot \vec{r}$

$$= (4\hat{\imath} + \hat{\jmath} - 3\hat{k}) \cdot (4\hat{\imath} + 2\hat{\jmath} - 2\hat{k}\text{m})$$

$$WD = 16 + 2 + 6 = 24$$

31. **[Ans. *] Range: 0.35 to 0.35**

Given that one interval,

$$h = 1$$

$$x_0 = 1 \quad\quad x_1 = 2 = x_n$$

By trapezoidal rule,

$$y = \frac{h}{2}(y_0 + y_n + 2(y_1 + y_2 + \cdots + y_{n-1}))$$

here,

$$y = f(x) = \frac{1}{1+x^2} \Rightarrow f(x_0) = y_o = \frac{1}{1+1} = \frac{1}{2}$$

$$f(x_n) = y_n = \frac{1}{1+4} = \frac{1}{5}$$

$$\therefore y = \frac{1}{2}\left(\frac{1}{2} + \frac{1}{5}\right) = \frac{1}{2} \times \frac{7}{10} = \frac{7}{20}$$

$$y = 0.35$$

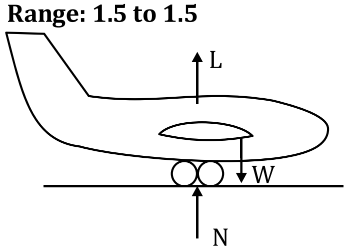
32. **[Ans. *] Range: 0 to 0**

Given that $\nu = 0.5$

WKT, $K = \dfrac{E}{3(1-2\nu)} \Rightarrow$ when $\nu = 0.5$ , $K \rightarrow \infty$

When bulk modulus tends to infinity, the material is highly incompressible. So, change in volume will be 0.

33. **[Ans. *] Range: 1.5 to 1.5**




Given, $N = 15000N$

$W = 10000N$

$\eta_{land} = \frac{\text{Reaction force}}{\text{weight}} = \frac{15000}{10000}$

$= 1.5$

34. **[Ans. *] Range: 75000 to 75000**


$F = \dot{m}_g C_j - \dot{m}_a C_i + \cancelto{0}{(P_e - P_a)}Ae$

$= \dot{m}_a[(1 + \underbrace{f}_{\text{negligible}})C_j - C_i]$ , $\dot{m}_a = \rho_{in} A_{in} C_i$

$F = \dot{m}_a[C_j - C_i]$

$= \rho_i C_i^2 A_{in}\left(\frac{C_j}{C_i} - 1\right) = 1 \times 250^2 \times 1\left(\frac{550}{250} - 1\right)$

$F = 75000N$

35. **[Ans. *] Range: 0.54 to 0.56**

Given, NACA $\underline{0012}$, $\alpha = 5°$

$\downarrow$

Symmetric a/f

From thin a/f theory

$C_l = 2\pi\alpha, \alpha$ in radian

$= 2 \times \pi \times 5 \times \frac{\pi}{180}$

$C_l = 0.55$

36. **[Ans. A]**

Given, $y = e^{px} \sin qx$

To find $\frac{d^2y}{dx^2} - 2p\left(\frac{dy}{dx}\right) + (p^2 + q^2)y$

Now,

$\frac{dy}{dx} = e^{px}.p.\sin qx + e^{px}\,q\cos qx$

$-2p\left(\frac{dy}{dx}\right) = -2p^2e^{px}\sin qx - 2pq\cos qx\, e^{px}$

$\frac{d^2y}{dx^2} = p^2e^{px}\sin qx + pqe^{px}\cos qx + pqe^{px}\cos qx$
$\quad - q^2e^{px}\sin qx$

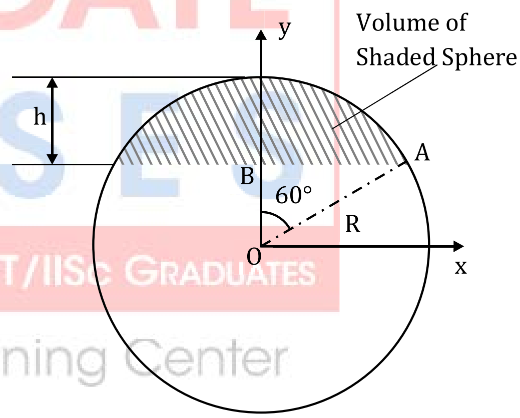
$(p^2 + q^2)y = p^2e^{px}\sin qx + q^2e^{px}\sin qx$

Now,

$\frac{d^2y}{dx^2} - 2p\left(\frac{dy}{dx}\right) + (p^2 + q^2)y = 0$

37. **[Ans. B]**

Given,




Volume of shaded sphere $= \frac{\pi}{3}h^2(3R - h)$ ... (1)

Now, from $\Delta OAB$

$\cos 60° = \frac{OB}{R}$

$OB = \frac{R}{2} = h$

Now,

$(V_{shaded})_{sphere} = \frac{\pi}{3}\left(\frac{R}{2}\right)^2\left(3R - \frac{R}{2}\right)$

$= \frac{\pi}{3}\left(\frac{R^2}{4}\right)\left(\frac{5R}{2}\right)$

$= \frac{5}{24}\pi R^3$

Comparing this with given volume $= k\pi R^3$

$\therefore k = \dfrac{5}{24}$

38. **[Ans. D]**

WKT

In isothermal layer (stratosphere)

$$\frac{\rho}{\rho_{11\,km}} = e^{\frac{-g}{RT_{11km}}(h-h_{11})}$$

From the above relation we can say that the density decreases exponentially with increase in altitude in isothermal layer.

39. **[Ans. B]**

Given, $h = 600$ km, $R_E = 6400$ km

$GM_E = 3.98 \times 10^{14}\ m^3/s^2$, velocity $V = 9$ km/s

We know that,

$$V_{circular} = \sqrt{\frac{GM_E}{R_E + h}}, V_{Parabolic} = \sqrt{\frac{2GM_E}{R_E + h}}$$

If any velocity between $V_{circular}$ & $V_{parabolic} \rightarrow$ elliptical trajectory

If given $V > V_{parabolic} \rightarrow$ hyperbolic

Now,

$$V_{circular} = \sqrt{\frac{3.98 \times 10^{14}}{7000 \times 10^3}} = 7650\ m/s = 7.65\ km/s$$

$V_{parabolic} = \sqrt{2}, V_{circular} = \sqrt{2} \times 7.65 = 10.8193$ km/s

$\because$ Given velocity of 9 km/s lies between $V_{circular}$ and $V_{parabolic}$

Therefore, the trajectory is elliptical.

40. **[Ans. A]**

Given, $\eta_c = 0.83, T_{01} = 300K,\ \pi_C = 10 : 1$

$(\Delta T_0)_{stage} = 20$ K

Now,

$$\eta_c = \frac{T'_{02} - T_{01}}{T_{02} - T_{01}} = \frac{T_{01}\left(\pi_C^{\frac{\gamma-1}{\gamma}} - 1\right)}{(\Delta T_0)_{overall}}$$

$$(\Delta T_0)_{overall} = \frac{T_{01}\left(\pi_C^{\frac{\gamma-1}{\gamma}} - 1\right)}{\eta_c}$$

$$= \frac{300\left(10^{\frac{1.4-1}{1.4}} - 1\right)}{0.83}$$

$$= 336.3737$$

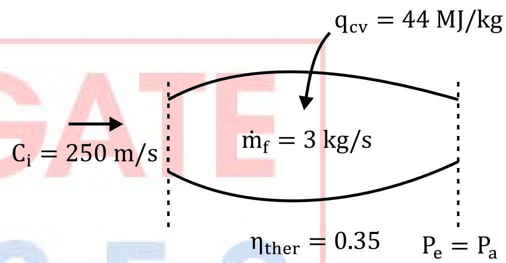
No. of stages,

$$n = \frac{(\Delta T_0)_{overall}}{(\Delta T_0)_{stage}} = \frac{336 - 3737}{20}$$

$n = 16.81 \approx 17$

41. **[Ans. A]**

Given,




$$\eta_{Prop} = \frac{\text{Thrust power}}{\text{Propulsive power}},$$

$$\eta_{thermal} = \frac{\text{Propulsive power}}{\text{Heat input power}}$$

Propulsive power $= \eta_{therm} \times \eta_b \times \dot{m}_f \times q_{CV}$

Now,

$$\eta_{prop} = \frac{F \times Ci}{\eta_{therm} \times \eta_b \times \dot{m}_f \times q_{CV}}$$

$$= \frac{6000 \times 250}{0.35 \times 3 \times 44 \times 10^6}$$

$$= 0.325$$

$$= 32.5\%$$

42. **[Ans. D]**

From Blasius solution

For flat plate,

$$\frac{\delta}{x} \propto \frac{1}{\sqrt{Re_x}}$$

$$\delta \propto \frac{x}{\sqrt{\frac{U_\infty x}{\nu}}}$$

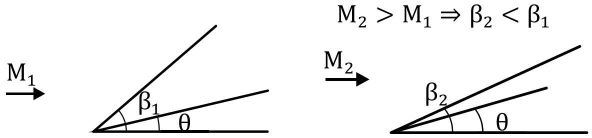
$$\delta|_{x=L} \propto \frac{L}{\sqrt{\frac{U_\infty L}{\nu}}}$$

$$\delta \propto U_\infty^{-1/2}$$

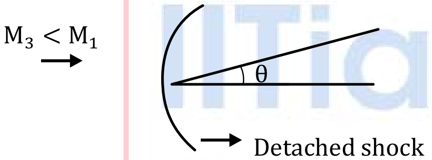
43. **[Ans. D]**

According to $\theta - \beta - M$ relations for oblique shock, As M increase (with $\theta$ constant), $\beta$ decreases shock moves closer to the body.

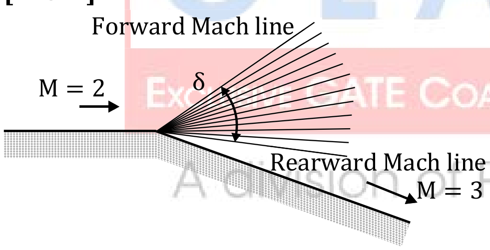
$$M_2 > M_1 \Rightarrow \beta_2 < \beta_1$$




Less than certain value of M, for a given $\theta$, shock detaches from the surface.




44. **[Ans. D]**




Given, $\nu(3) = 49.76°$

$\nu(2) = 26.38°$

Now,

$$\mu(2) = \sin^{-1}\left(\frac{1}{2}\right) = 30°$$

$$\mu(3) = \sin^{-1}\left(\frac{1}{3}\right) = 19.47°$$

WKT,

$$\theta = \nu(3) - \nu(2) = 49.76° - 26.38°$$

$$\theta = 23.38$$

WKT,

$$\delta = \mu(2) - \mu(3) + \theta$$

$$= 30° - 19.47° + 23.38 = 33.91°$$

45. **[Ans. A, B, C]**

Given,

$$f(x) = \begin{cases} x^2 & \text{for } x < 0 \\ x & \text{for } x \geq 0 \end{cases}$$

From the plot f(x) is continuous for all x

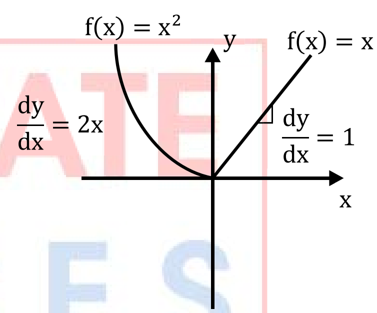
For $x = 0$

$$\text{LHD} = \lim_{x\to 0^-} \frac{f(x) - f(0)}{x - 0} = \lim_{x\to 0^-} \frac{x^2 - 0}{0} = x = 0$$

$$\text{RHD} = \lim_{x\to 0^+} \frac{f(x) - f(0)}{x - 0} = \lim_{x\to 0^+} \frac{x - 0}{0} = 1$$

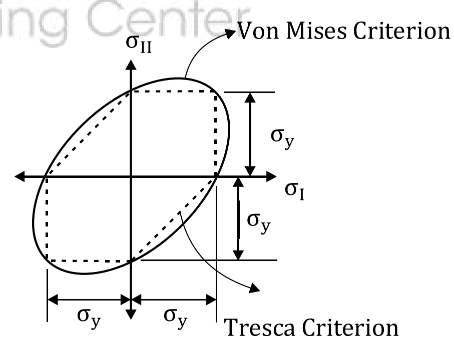
LHD $\neq$ RHD $\Rightarrow \because$ the derivative of the function is discontinuous at $x = 0$

From the plot, it is clearly seen that the derivative of the function is continuous at $x = 1$.




46. **[Ans. A, B]**

From theories of failure, the graphical representation are,




47. **[Ans. A, B]**

Absolute ceiling is altitude at which

→ Power available ($P_A$) Power required ($P_R$)

→ Rate if climb (ROC) is zero

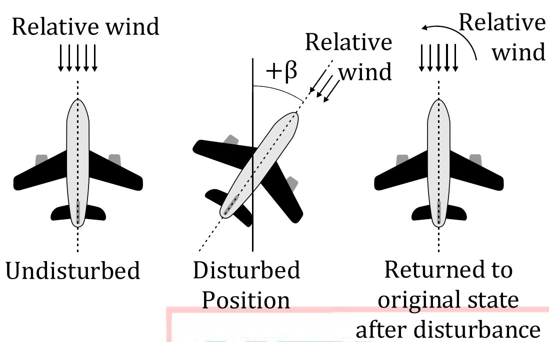
For service ceiling

→ Altitude at which $(ROC)_{max}$ for piston engine aircraft = 100 ft/min (or) 0.5 m/s

$(ROC)_{max}$ for jet engine aircraft = 500 ft/min (or) 2.5 m/s

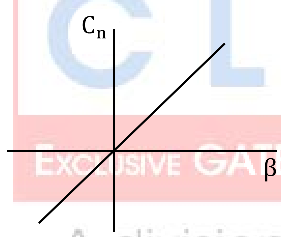
48. **[Ans. A, B, C]**

Weathercock/ directional static stability




In weathercock static stability aircraft tend to return to its equilibrium position by a restoring moment.

Plot of $C_n$ vs $\beta$




From the three-diagram drawn above, the airplane will always tend to point in relative wind direction.

49. **[Ans. A, C]**

In the nozzle row of the turbine, only energy transformation occurs, and no energy transfer takes place. Therefore, the absolute stagnation enthalpy remains constant across the nozzle row.

→ From the Rothalpy (Rotational enthalpy) concept of turbine we know that,

$$ho_{relative} = h_1 + \frac{w_1^2}{2} = h_2 + \frac{w_2^2}{2} = \text{constant.}$$

Here $w_1, w_2$ are relative velocities. Therefore, the relative stagnation enthalpy remains unchanged through the rotor.

→ For a fixed rotational speed (N → Constant)

$$U = \frac{\pi DN}{60}$$

As D,N are constant

U also constant

Now,

$\dot{m} = \rho CaA \rightarrow (*)$

WKT,

$\phi(\text{Flow coefficient}) = \frac{Ca}{U}$,

Where U is constant when $\phi$ increases, Ca also increases

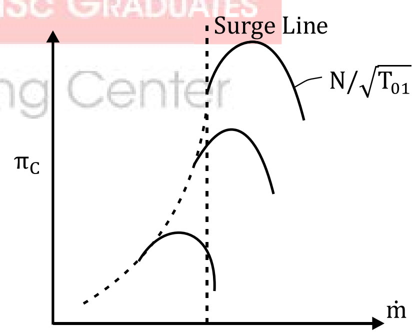
Thus, from (*),

When Ca increase ⇒ $\dot{m}$ also increases

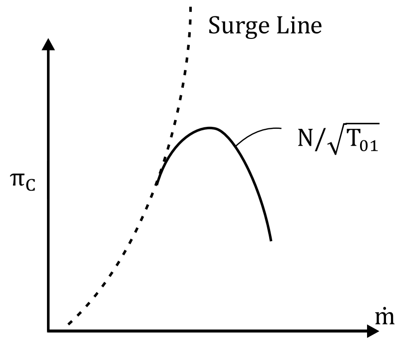
Therefore, for a fixed rotational speed, mass flow rate increases with increase in flow coefficient.

50. **[Ans. A, C]**

From compressor characteristics,




Keeping $\dot{m}$ constant

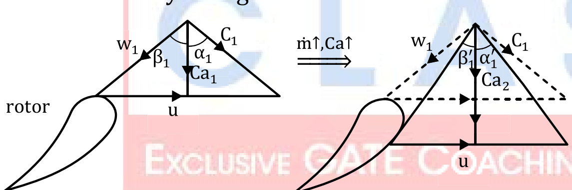



Keeping Constant RPM

When keeping mass flow rate constat, if we increase blade RPM at same point, the constant $\dot{m}$ line will cross the surge line and the compressor may surge.

When keeping blade RPM constant, if we increase $\dot{m}$, it will tend to move away from the surge line towards the right and the compressor will not surge.

→ From velocity triangle




N→ fixed ⇒ U is fixed

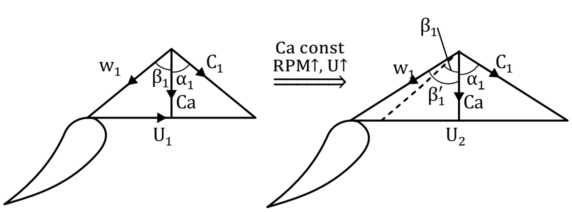
WKT,

$\dot{m} = \rho Ca\, U$, where U is fixed

$\therefore \dot{m}\uparrow, Ca\uparrow$

From the two velocity triangles, $\beta_1' < \beta_1$(actual relative flow angle is less than design blade angle).

→ From the velocity triangle,




$\dot{m}$ →constant ⇒ Ca → Constant

When blade RPM increased → U increases

From the two velocity $\Delta^{real}$. $\beta_1' > \beta_1$ (Actual relative flow angle greater than design blade angle).

51. **[Ans. *] Range: 1.4 to 1.6**

Given, $A = \begin{bmatrix} 5 & -4 \\ k & -1 \end{bmatrix}, |A| = 3$

$$\begin{vmatrix} 5 & -4 \\ k & -1 \end{vmatrix} = 3 \Rightarrow -5 + 4k = 3$$

$4k = 8$

$k = 2$

Now,

$$\begin{vmatrix} 5-\lambda & -4 \\ 2 & (-1-\lambda) \end{vmatrix} = 0 \Rightarrow (5-\lambda)(-1-\lambda) + 8 = 0$$

$-5 - 5\lambda + \lambda + \lambda^2 + 8 = 0$

$\lambda^2 - 4\lambda + 3 = 0$

$\lambda = 3, 1$

$\because \lambda_{max} = 3$

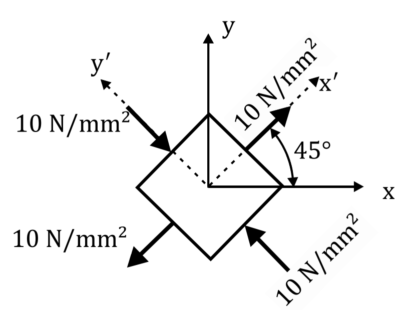
$k = 2$

Now,

$$\frac{\lambda_{max}}{k} = \frac{3}{2} = 1.5$$

52. **[Ans. *] Range: 0 to 0**

Combined load diagram



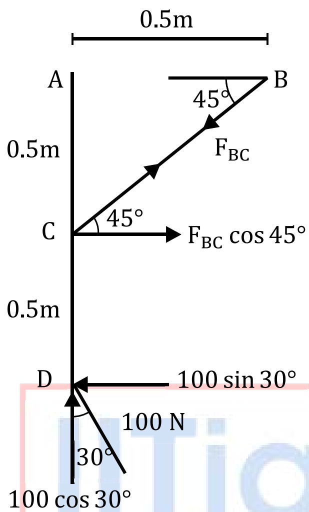

Since no shear stress are acting, therefore the acting stress are principle stresses,

$\sigma_I = 10\ N/mm^2$

$\sigma_{II} = -10\ \text{N/mm}^2$

$\because$ Sum of maximum and minimum principle stress $= \sigma_I + \sigma_{II} = 10 - 10 = 0$

53. **[Ans. *] Range: 141.0 to 141.5**




Now,

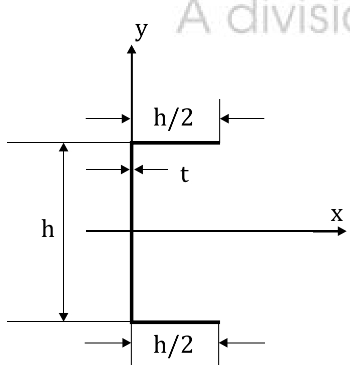
$\sum M_A = 0$

$(100 \sin 30° \times 1) = F_{BC} \cos 45° \times 0.5$

$F_{BC} = 141.4\ \text{N}$

54. **[Ans. *] Range: 14900 to 15100**

Given ,




$M_x = 10\ \text{Nm}$

$h = 1\text{m}$

$t = 0.001\ \text{m}$

From the diagram

$I_{xy} = 0$

$M_y = 0$

Now,

$\sigma_z = \dfrac{M_X}{I_{xx}} y, \qquad \text{at } y = \dfrac{h}{2}, \sigma_z = \sigma_{z_{max}}$

Now,

$I_{xx} = \dfrac{th^3}{12} + 2\left(t \times \dfrac{h}{2}\left(\pm\dfrac{h}{2}\right)^2\right)$

[here neglecting higher order thickness terms]

$= \dfrac{th^3}{12} + \dfrac{th^3}{4} = \dfrac{th^3}{3}$

$\sigma_{z_{max}} = \dfrac{10}{\dfrac{0.001 \times 1^3}{3}} \times \dfrac{1}{2} = \dfrac{15}{0.001}$

$= 15 \times 10^3\ \text{N/m}^2$

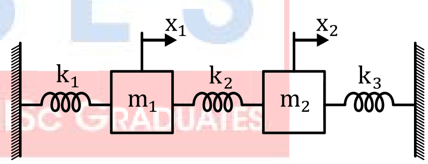
$= 15000\ \text{N/m}^2$

55. **[Ans. *] Range: 1.72 to 1.74**

Given, $m\dot{x}_1 + 2kx_1 - kx_2 = 0$

$m\ddot{x}_2 - kx_1 + 2kx_2 = 0$

We know, the 2-DOF spring mass system




From the given equation we can say

$k_1 = k_2 = k_3 = k$

$m_1 = m_2 = m$

The above can be arrived by comparing the given equation with the 2-DOF spring mass system equation of motion.

$m_1\ddot{x}_1 + (k_1 + k_2)x_1 - k_2x_2 = 0$

$m_2\ddot{x}_2 - k_2x_1 + (k_2 + k_3)x_2 = 0$

Now substituting $m_1 = m_2 = m$ and $k_1 = k_2 = k_3 = k$ in natural frequency equation.

$$m_1m_2\omega^4 - \big(m_1(k_2 + k_3) + m_2(k_1 + k_2)\big)\omega^2 + k_1k_2 + k_2k_3 + k_3k_1 = 0$$

$m^2\omega^4 - 4km\,\omega^2 + 3k^2 = 0$

Let $\omega^2 = x$

$$m^2x^2 - 4kmx + 3k^2 = 0$$

$$x = \frac{4km \pm \sqrt{16k^2m^2 - 12k^2m^2}}{2m^2}$$

$$= \frac{4\,km \pm 2\,km}{2m^2}$$

$$= \frac{6\,km}{2m^2} \left(\begin{array}{c}\text{Taking highest}\\ \text{natural frequency}\end{array}\right)$$

$$x = \omega^2 = \frac{3k}{m}$$

$$\omega_{highest} = \sqrt{\frac{3k}{m}}$$

Comparing this with given

$$\omega_{high} = \alpha\sqrt{\frac{k}{m}}$$

$$\alpha = \sqrt{3} = 1.73$$

56. **[Ans. *] Range: 4.9 to 5.1**

Given,

$\varepsilon_{xx} = 10\,xy^2, \varepsilon_{yy} = -5x^2y,$

$\gamma_{xy} = Axy\,(2x - y)$

$\gamma_{xy} = 2Ax^2y - Axy^2$

WKT,

2-D compatibility equation

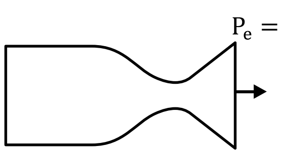
$$\frac{\partial^2\gamma_{xy}}{\partial x\,\partial y} = \frac{\partial^2\varepsilon_{xx}}{\partial y^2} + \frac{\partial^2\varepsilon_{yy}}{\partial x^2}$$

$$4Ax - 2Ay = 20x - 10y$$

$$A(4x - y) = 5(4x - y) \Rightarrow A = 5.0$$

57. **[Ans. *] Range: 2500 to 2600**

Given,




$F = 5\,MN$

$I_S = 200s$

$g = 9.8\,m/s^2$

$$F = \dot{m}_pC_j + (P_e - P_a)Ae$$

$$F = \dot{m}_pC_j = \dot{m}_gI_sg_0$$

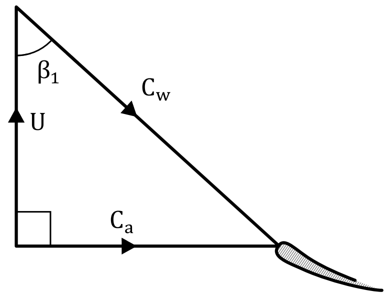
$$\dot{m}_p = \frac{F}{I_{sp} \times g_0} = \frac{5 \times 10^6}{200 \times 9.8}$$

$$\dot{m}_p = 2551\,kg/s$$

**[Ans. *] Range: 230 to 240**

Given, $T_0 = 300k, M_{relat} = 1, \beta_1 = 45°, \alpha_1 = 0°$

First, we draw velocity triangle.




$C_a = C_w \sin\beta_1 \quad \ldots.(1)$

Divide (1) by speed of sound.

$$\frac{C_a}{\sqrt{\gamma RT}} = \frac{C_w}{\sqrt{\gamma RT}}\sin\beta_1$$

$$\therefore Ma = M_{relat}\sin\beta_1 = 1 \times \frac{1}{\sqrt{2}} = \frac{1}{\sqrt{2}}$$

Now,

$$\text{Static temp}, T = \frac{T_0}{1 + \frac{\gamma - 1}{2}M_a^2}$$

$$= \frac{300}{1 + (0.2)\left(\frac{1}{\sqrt{2}}\right)^2}$$

$$= 272.72k$$

Now,

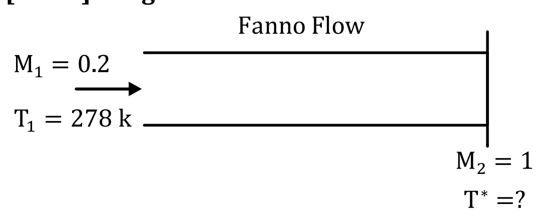
$$u = C_w\cos\beta_1$$

$$= M_{relat}\sqrt{\gamma RT}\cos\beta_1$$

$$= 1 \times \sqrt{1.4 \times 287 \times 272.72} \times \frac{1}{\sqrt{2}}$$

$$u = 234.074\,m/s \approx 234\,m/s$$

58. **[Ans. *] Range: 227.0 to 231.0**




As there is no heat transfer, $T_o$ remains constant along the duct.

$$T_{01} = T_{02} = T_0^*$$

$$T_1\left(1+\frac{\gamma-1}{2}M_1^2\right)=T^*\left(1+\frac{\gamma-1}{2}\right)$$

$\gamma = 1.4$, Find $T^*$

$T^* = 229.32$ k

59. **[Ans. *] Range: 1.05 to 1.07**

Given, $r_p = 25 + 1737$

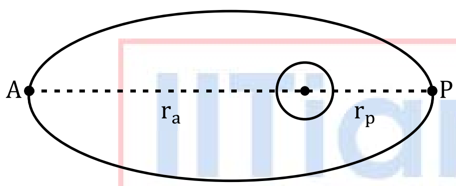
$r_a = 134 + 1737$

$$e = \frac{r_a - r_p}{r_a + r_p} = 0.030$$

Now,

$$\frac{V_p}{V_a} = \frac{1+e}{1-e} = \frac{1+0.03}{1-0.03}$$

$$\frac{V_p}{V_a} = 1.0618 \approx 1.06$$




60. **[Ans. *] Range: 0.80 to 0.84**

Given, $\rho_{sea} = 1.225\ kg/m^3$

$\rho_{4km} = 0.819\ kg/m^3$

WKT,

$$\left(\frac{V_{EAS}}{V_{TAS}}\right)^2 = \frac{\rho_{alt}}{\rho_{sea}} \Rightarrow \frac{V_{EAS}}{V_{TAS}} = \sqrt{\frac{\rho_{4km}}{\rho_{sea}}} = \sqrt{\frac{0.819}{1.225}}$$

$$\frac{V_{EAS}}{V_{TAS}} = 0.8176 \approx 0.82$$

61. **[Ans. *] Range: 17.7 to 17.9**

Given, $\lambda_{1,2} = -0.039 \pm 0.0567i$

WKT, in general

$$\lambda_{1,2} = -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2 - 1}$$

$$= -\zeta\omega_n \pm \omega_n\sqrt{1-\zeta^2}\, i$$

Comparing the above two equations

$\zeta\omega_n = 0.039, \omega_n\sqrt{1-\zeta^2} = 0.0567$

We also know,

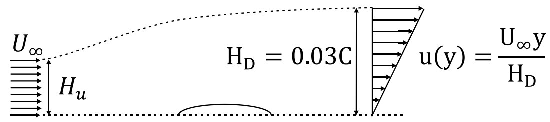
$\lambda = \eta \pm i\omega$

$$\therefore t_{1/2} = \frac{0.693}{|\eta|} = \frac{0.693}{0.039}$$

$$= 17.769 \approx 17.8$$

62. **[Ans. *] Range: 0.018 to 0.022**

Now considering the above half of the elliptic cross section,




By mass conservation

$$\rho U_\infty H_u = \rho\int_0^{H_D} u(y)dy$$

$$\Rightarrow U_{\infty H_U} = \frac{U_\infty}{H_D}\int_0^{H_D} y\, dy$$

$$= \frac{U_\infty}{H_D}\left[\frac{y^2}{2}\right]_0^{H_D}$$

$$U_\infty H_U = \frac{U_\infty}{H_D}\times\frac{H_D^2}{2}$$

$$H_U = \frac{H_D}{2}$$

By Momentum conservation

$$-\rho U_\infty^2 H_U + \rho\int_0^{H_D} u^2(y)dy = Drag$$

$$-\rho U_\infty^2\frac{H_D}{2} + \frac{\rho U_\infty^2}{H_D^2}\left(\frac{y^3}{3}\right)_0^{H_D} = D$$

$$\frac{-\rho U_\infty^2 H_D}{2} + \frac{\rho U_\infty^2}{H_D^2}\left(\frac{H_D^3}{3}\right) = D$$

$$-D = \frac{-\rho U_\infty^2 H}{6}$$

$$D = \frac{\rho U_\infty^2 H_D}{6}\times 2$$

(Multiply by 2 because initially we considered only upper half)

$$= \frac{\rho U_\infty^2 H_D}{3}$$

$$D = \frac{\rho U_\infty^2(0.03C)}{3} = \rho U_\infty^2(0.01)C$$

Now,

Given, that $C_D = \dfrac{D}{\frac{1}{2}\rho U_\infty^2 C}$

$= \dfrac{\rho U_\infty^2 C\,(0.01)}{\frac{1}{2}\rho U_\infty^2 C}$

$C_D = 0.020$

63. **[Ans. *] Range: 63.0 to 64.5**

Given, $m = 1000\text{kg}, V_\infty = 50\text{ m/s}, b = 20\text{m}$

$S = 31.4\text{ m}^2, \rho_{alt} = 1\text{ kg/m}^2, g = 10\text{ m/s}^2$

Now,

$D_i = \dfrac{1}{2}\rho\, V_\infty^2 S C_{D_i}$

$C_{D_i} = kC_L^2, \quad k = \dfrac{1}{\pi e AR}$

$e = 1, AR = \dfrac{b^2}{S} = \dfrac{20^2}{31.4}, AR = 12.738$

Given that steady and level flight,

$L = W$

$\dfrac{1}{2}\rho V^2 S C_L = 1000 \times 10$

$C_L = \dfrac{2\times 10^4}{\rho V_\infty^2 S}$

Now,

$C_{D_i} = \dfrac{1}{\pi \times 12.738} \times \dfrac{4\times 10^8}{\rho^2 V_\infty^4 S^2}$

$\therefore D = \dfrac{1}{2}\rho V_\infty^2 S \times \dfrac{1}{\pi\times 12.738} \times \dfrac{4\times 10^8}{\rho^2 V_\infty^4 S^2}$

$= \dfrac{4\times 10^8}{2\times\pi\times 12.738\times 1\times 50^2\times 31.4}$

$= 63.6\text{N}$

64. **[Ans. *] Range: 1.0 to 1.0**

By Dynamic similarity

$Re)_{prototype} = Re)_{modal}$

Given that,

$\dfrac{L_p}{L_m} = 3$

Now,

$\dfrac{\rho_p U_p L_p}{\mu} = \dfrac{\rho_m U_m L_m}{\mu}$

$U_p = \dfrac{L_m}{L_p} U_m \Rightarrow U_m = 3\,Up$

$\therefore \dfrac{D_P}{D_m} = \dfrac{C_D \times \frac{1}{2}\rho U_p^2 S_p}{C_D \times \frac{1}{2}\rho U_m^2 S_m}$

$= \dfrac{U_p^2}{(3U_p)^2} \times \left(\dfrac{L_p}{L_m}\right)^2 \quad \begin{pmatrix} S_p = L_p^2 \\ S_m = L_m^2 \end{pmatrix}$

$= \dfrac{1}{9}\times 9$

$\dfrac{D_p}{D_m} = 1$

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