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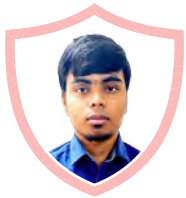

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Shashi Kanth M
Sastra Univ - Tanjore

Vagicharla Dinesh
Lovely Professional Univ - Punjab

Anantha Krishan A.G
Amrita Univ - Coimbatore

HAL DT ENGINEER 2022

Fathima J
MIT - Chennai

Mohan Kumar H
MVJCE - Bangalore

HAL DT ENGINEER 2021

Arathy Anilkumar Nair
Amrita Univ - Coimbatore

Sadsivuni Tarun
Sastra Univ - Tanjore

DRDO & ADA Scientist B

Job Position for Recruitment (2021-24) Based on GATE AE score

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Amrita Univ - Coimbatore

Ajitha Nishma V
IIST - Trivendrum

Dheeraj Sappa
IIEST - Shibpur

Govarthan K
RVCE - Bangalore

F Jahangir
MIT - Chennai

Goutham
KCG College - Chennai

M Kumar
MVJ College - Bangalore

Sanjay S
Amrita Univ - Coimbatore

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Nitesh Singh
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Snehasis C
IIEST - Shibpur

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Amrita Univ - Coimbatore

Shruti S Rajpara
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GVIET - PUNJAB

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MIT - Chennai

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DGCA Air Safety & Worthiness Officer

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FGIET - Raebareli

Aishwarya PS
BMS College - Bangalore

Anil Kumar Nakkala
Malla Reddy College - Hyderabad

Ayush Boral
KIIT - Bhubaneswar

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PEC - Chandigarh

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IOCL & NPCIL

Nitish Patnaik
(Vivekanand ESIT- Mumbai)
Graduate Engineer- Instrumentation

NTPC

Milton Ghosh
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Sathyabama University - Chennai

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IIEST - Shibpur

Ankur Vats
School Of Aeronautics - Neemrana

8. Propulsion

GATE AE - 2007

One Mark Questions.

1. Which one of the following engines should be used by a subsonic passenger transport airplane for minimum specific fuel consumption?
   (A) Turbojet engine with afterburner
   (B) Turbofan engine
   (C) Ramjet engine
   (D) Scramjet engine

2. On which one of the following thermodynamic cycles does an ideal ramjet operate?
   (A) The Rankine cycle
   (B) The Brayton cycle
   (C) The Carnot cycle
   (D) The Otto cycle

Two Marks Questions.

3. Air enters through the eye of a centrifugal compressor with a stagnation temperature 300 K and exits the compressor with a stagnation temperature 424 K. If the isentropic efficiency of the compressor is 0.81 and the ratio of specific heats of the flowing gas (assumed as constant) is 1.4, then the pressure ratio across the compressor is
   (A) 2.75 (C) 65.00
   (B) 5.60 (D) 228.00

4. For an impulse turbine with identical stages, the hot gas exits from the stator blades at the mean blade height at an absolute angle of 70 degrees with the axis of the turbine. If the absolute inlet blade angle with the axis of the turbine at the mean blade height for the rotor blades is 37 degrees, then the absolute exit blade angle with the axis of the turbine at the mean blade height of the rotor blades is
   (A) 33 degrees (C) 53 degrees
   (B) 37 degrees (D) 53.5 degrees

5. Which one of the following materials should be selected to design an axial flow turbine operating at high temperatures?
   (A) Steel alloy (C) Nickel alloy
   (B) Titanium alloy (D) Aluminum alloy

6. Which one of the following statements is true?
   (A) The isentropic efficiency of a compressor is constant throughout the compressor
   (B) Flow separation problems are more critical for the axial compressors than for the centrifugal compressors
   (C) The pressure ratio of a centrifugal compressor approaches zero as the compressor mass flow rate approaches zero
   (D) Centrifugal compressors are always designed with multiple stages

7. The on-board rocket motor of a satellite of initial mass 2000 kg provides a specific impulse of 280 seconds. If this motor is fired to give a speed increment of 500 m/s along the direction of motion, the mass of propellant consumed is:

(A) 685 kg (C) 1666 kg
(B) 333 kg (D) 167 kg

8. Combustion between fuel (octane) and oxidizer (air) occurs inside a combustor with the following stoichiometric chemical reaction:
$2C_8H_{18} + (25O_2 + 94N_2) \rightarrow 16CO_2 + 18H_2O + 94N_2$
The atomic weights of carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) are 12, 1, 16, and 14, respectively. If the combustion takes place with the fuel to air ratio 0.028, then the equivalence ratio of the fuel-oxidizer mixture is
(A) 0.094 (C) 0.721
(B) 0.422 (D) 2.371

9. In a rocket engine, the hot gas generated in the combustion chamber exits the nozzle with a mass flow rate 719 kg/sec and velocity 1794 m/s. The area of the nozzle exit section is 0.635 m^2. If the nozzle expansion is optimum, then the thrust produced by the engine is
(A) 811 kN (C) 1354 kN
(B) 1290 kN (D) 2172 kN

10. A gas turbine engine operates with a constant area duct combustor with inlet and outlet stagnation temperatures 540 K and 1104 K. respectively. Assume that the flow is one dimensional, incompressible and frictionless and that the heat addition is driving the flow inside the combustor. The pressure loss factor (stagnation pressure loss non-dimensionalized by the inlet dynamic pressure) of the combustor is
(A) 0 (C) 1.044
(B) 0.489 (D) 2.044

11. The diffuser of an airplane engine decelerates the airflow from the flight Mach number 0.85 to the compressor inlet Mach number 0.38. Assume that the ratio of the specific heats is constant and equal to 1.4. If the diffuser pressure recovery ratio is 0.92, then the isentropic efficiency of the diffuser is
(A) 0.631 (C) 0.892
(B) 0.814 (D) 1.343

12. The purpose of a fuel injection system in the combustor is
(A) to accelerate the flow in the combustor
(B) to increase the stagnation pressure of the fuel-air mixture
(C) to ignite the fuel-air mixture
(D) to convert the bulk fuel into tiny droplets

13. Which one of the following values is nearer to the vacuum specific impulse of a rocket engine using liquid hydrogen and liquid oxygen as propellants?
(A) 49 sec (C) 6000 sec
(B) 450 sec (D) 40000 sec

Statement for Linked Answer Qns 14 & 15:
Air enters the compressor of a gas turbine engine with velocity 127 m/s, density 1.2 kg/m^3 and stagnation pressure 0.9 MPa. Air exits the compressor with velocity 139 m/s and stagnation pressure 3.15 MPa. Assume that the ratio of specific heats is constant and equal to 1.4.

14. The compressor pressure ratio is
(A) 0.22 (C) 3.50
(B) 0.28 (D) 3.90

15. If the polytropic efficiency of the compressor is 0.89, then the isentropic efficiency of the compressor is
(A) 0.613 (C) 0.89
(B) 0.869 (D) 0.98

GATE AE - 2008

One Mark Questions.

16. The degree of reaction of an impulse turbine is

(A) 1 (C) 0.5

(B) 0.75 (D) 0

17. In a scramjet engine, the Mach number at the entry to the combustion chamber is around

(A) 0 (C) 2

(B) 0.3 (D) 6

18. DB denotes double base solid propellant.

LOX-RP1 denotes liquid oxygen - kerosene combination.

LOX-LH_2 denotes liquid oxygen - hydrogen combination.

The correct order of increasing specific impulse is

(A) DB < LOX-RP1 < LOX-LH_2

(B) LOX-RP1 < DB < LOX-LH_2

(C) LOX-LH_2 < DB < LOX-RP1

(D) DB < LOX-LH_2 < LOX-RP1

Two Marks Questions.

19. A turbofan engine has a bypass ratio of 5 and a total mass flow rate of 120 kg/s. The mass flow rate through the bypass duct is

(A) 20 kg/s (C) 120 kg/s

(B) 100 kg/s (D) 600 kg/s

20. A turbojet engine is operating with afterburner off. If the afterburner is switched on, then

(A) both thrust and sfc decrease

(B) thrust increases and sfc decreases

(C) thrust decreases and sfc increases

(D) both thrust and sfc increase

21. A centrifugal compressor operates with a tip blade speed of 340 m/s. The air leaves the impeller with a radial velocity of 88 m/s. If the slip factor is 0.85, the relative velocity at the blade tip is

(A) 101.7 m/s (C) 132.6 m/s

(B) 120.3 m/s (D) 135.8 m/s

22. An ideal ramjet engine is flying at a Mach number M. The exhaust gas static temperature at the outlet of the nozzle is T_e. The ambient static temperature is T_a. Gas constant R and specific heat ratio γ do not vary through the ramjet. Assuming that nozzle exhaust static pressure is equal to the ambient pressure and fuel air ratio f << 1, the thrust per unit mass flow rate is

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

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

23. A 50 percent degree of reaction axial flow turbine operates with a mean blade speed of 180 m/s. The flow leaves the stator and enters the rotor at an angle of 60 degrees to the axial direction. The axial velocity is 150 m/s, and remains constant throughout the stage. The turbine power per unit mass flow is

(A) 29.76 kJ/kg (C) 58.33 kJ/kg

(B) 41.12 kJ/kg (D) 61.13 kJ/kg

24. The chamber stagnation temperature inside a rocket motor is T_c. Only a convergent nozzle is used, and the flow at the exit of this nozzle is choked. Assume that the nozzle exhaust static pressure is equal to ambient static pressure. Gas constant for exhaust gases is R and ratio of specific heats is γ. The specific impulse of the rocket motor is

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

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

25. Air enters the combustor of a gas turbine engine at total temperature of 500 K and leaves the combustor at total temperature of 1800 K. If c_P remains constant at 1.005 kJ/kgK and heating value of the fuel used is 44 MJ/kg, the fuel to air ratio is

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

26. The initial temperature sensitivity of burn rate of a solid rocket motor propellant is positive. If the initial temperature increases then

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

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

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

Common Data for Questions 28 and 29: A liquid rocket engine with oxidizer to fuel ratio of 5:1 produces a thrust of 1 MN. The initial mass of the rocket engine is 100,000 kg and its mass at burn out is 10,000 kg. The characteristic velocity C^* and thrust coefficient C_F for the engine are 2386 m/s and 1.4, respectively.

28. The mass flow rate of fuel is

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

29. Neglecting gravity and drag effects, if the initial velocity of the liquid rocket engine is 2.5 km/s, the velocity of the rocket at burnout is

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

Statement for Linked Answer Qns 30 and 31:
A multi-stage axial flow compressor operating at an adiabatic efficiency of 0.9 develops a total pressure ratio of 11. The total temperature at inlet to the compressor is 335 K and the stagnation enthalpy rise across each stage is 37 kJ/kg. Ratio of specific heats is 1.4 and specific heat at constant pressure is 1.005 kJ/kg K.

30. The total temperature rise across the compressor is

(A) 310. 1K (C) 392. 1K
(B) 366.3 K (D) 405.4 K

31. The total number of stages required are

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

GATE AE - 2009

One Mark Questions.

32. The propulsive efficiency of a turbo-jet engine moving at velocity U_∞ and having exhaust velocity U_e with respect to the engine is given by

(A) $\frac{2}{U_\infty/U_e + 1}$ (C) $\frac{2U_\infty U_e}{U_\infty^2 + U_e^2}$
(B) $1 - \frac{U_\infty}{U_e}$ (D) $\frac{2U_\infty}{U_e + U_\infty}$

33. The division of feed air to an aircraft gas-turbine combustor into primary and secondary streams serves which of the following purposes?

P. a flammable mixture can be formed
Q. cooling of combustor liner and flame tube can be accomplished

R. specific fuel consumption can be reduced

(A) P and R (C) P and Q

(B) Q and R (D) P, Q and R

34. Classify the following propellants as: cryogenic (C), semi-cryogenic (SC), compressed gas (CG) and earth storable (ES)

N_2O_4 – UDMH (nitrogen tetra oxide and unsymmetrical di-methyl hydrazine)

LOX-RP1 (liquid oxygen and kerosene)

LOX-LH_2 : (liquid oxygen and liquid hydrogen)

N_2 (nitrogen gas)

(A) N_2O_4 – UDMH (ES), LOX – RP1(C), LOX – LH_2(C), N_2(C)

(B) N_2O_4 – UDMH (SC), LOX – RP1(SC), LOX – LH_2 (C), N_2(C)

(C) N_2O_4 – UDMH (ES), LOX – RP1(SC), LOX – LH_2 (C), N_2 (CG)

(D) N_2O_4 – UDMH (ES), LOX – RP1(C), LOX – LH_2 (C), N_2 (CG)

Two Marks Questions.

35. Let M_0 be the total mass of a single stage rocket, M_P be the total mass of propellant, M_L be the mass of payload carried by the rocket and M_S be the mass of inert structural components. If I_{SP} is the specific impulse of the propulsion system (in seconds) and g is the acceleration due to gravity, then the maximum velocity that can be attained by the rocket vehicle in the absence of gravity and atmospheric drag is given by

(A) $gI_{SP}\ln\left(\frac{M_0}{M_P}\right)$ (C) $gI_{SP}\ln\left(\frac{M_0}{M_S}\right)$

(B) $gI_{SP}\ln\left(\frac{M_0}{M_L+M_S}-1\right)$ (D) $gI_{SP}\ln\left(\frac{M_0}{M_0-M_P}\right)$

36. An ideal axial compressor is driven by an ideal turbine across which the total temperature ratio is 0.667. If the total temperature at turbine inlet is T_0 = 1500 K and specific heat of gas c_p = 1 kJ/kg/K , the power drawn by the compressor per unit mass flow rate of air is approximately

(A) 300 kW/kg/s (C) 600 kW/kg/s

(B) 1000 kW/kg/s (D) 500 kW/kg/s

37. The performance of a solid rocket motor is improved by replacing the old propellant with a new one. The new propellant gives a combustion temperature 40% higher than the previous propellant without appreciable change in molecular weight of combustion products and other operating parameters. By approximately what percentage is the specific impulse of the new motor higher than the old one?

(A) 18% (C) 42%

(B) 96% (D) 112%

38. A solid rocket motor has an end burning grain of cross-sectional area A_{CS} =0.4 m^2. The density of propellant is ρ_p = 1500 kg/m^3 and has linear regression rate $\dot{r}$ = 5 mm/s. If the specific impulse of the propulsion system is I_{sp} = 200 seconds, the thrust produced by the motor is approximately

(A) 3 kN (C) 1.5 kN

(B) 6 kN (D) 12 kN

39. An ideal ramjet is flying at an altitude of 10 km with a velocity of 1 km/s. The ambient pressure is 0.25 bar and temperature is 225 K. The exhaust gases from the engine are optimally expanded and leave the nozzle at 900 K. If the specific heat ratio (γ) remains constant, the specific thrust developed by the engine is approximately

(A) 1000 N-s/kg (C) 500 N-s/kg

(B) 2000 N-s/kg (D) 4000 N-s/kg

40. A combat aircraft engine is equipped with an afterburner followed by a variable area convergent nozzle (operating with the nozzle choked). The exhaust gas temperature is 750 K when afterburner is off and 3000 K when it is on. When the afterburner is turned on, (assuming the total pressure remains the same, the mass of fuel added in the afterburner is negligible i.e., the mass flow rate remains the same, and the specific heat ratio (γ) remains constant), approximately by what factor must the nozzle area be changed ?

(A) 0.5 (C) 1
(B) 4 (D) 2

Statement for Linked Answer Qns 41 and 42:
Air enters the combustor of a gas-turbine engine at a total temperature T_0 of 500 K. The air stream is split into two parts: primary and secondary streams. The primary stream reacts with fuel supplied at a fuel-air ratio of 0.05. The resulting combustion products are then mixed with the secondary air stream to obtain gas with total temperature of 1550 K at the turbine inlet. The fuel has a heating value of 42 MJ/kg. The specific heats of air and combustion products are taken as c_p = 1 kJ/kg/K .

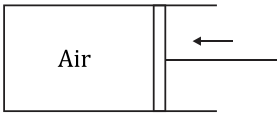
41. If the sensible enthalpy of fuel is neglected, the temperature of combustion products from the reaction of primary air stream with fuel is approximately

(E) 2100 K (G) 2600 K
(F) 3200 K (H) 1800 K

42. The approximate ratio of mass flow rates of the primary air stream to the secondary air stream required to achieve the turbine inlet total temperature of 1550 K is

(E) 2:1 (G) 1:1.5
(F) 1:2 (H) 1:1

Statement for Linked Answer Qns 43 and 44:
A piston compresses 1 kg of air inside a cylinder as shown



The rate at which the piston does work on the air is 3000 W. At the same time, heat is being lost through the walls of the cylinder at a rate of 847.5 W.

43. After 10 seconds, the change in specific internal energy of the air is

(A) 21,525 J/kg (C) 30,000 J/kg
(B) -21,525 J/kg (D) -8,475 J/kg

44. Given that the specific heats of air at constant pressure and volume are c_p =1004.5 J/kg-K and c_v =717.5 J/kg-K respectively, the corresponding change in the temperature of the air is

(A) 21.4 K (C) 30 K
(B) -21.4 K (D) -30K

GATE AE - 2010

One Mark Questions.

45. Isentropic efficiency η_d of a subsonic diffuser is defined as.

(**Note:** 'a' represents the ambient, '2' represents the exit of diffuser and 's' represents an isentropic process)

(A) $\frac{T_{02s} - T_a}{T_{02} - T_a}$ (C) $\frac{P_{02s} - P_a}{P_{02} - P_a}$
(B) $\frac{T_{02s} + T_a}{T_{02} + T_a}$ (D) $\frac{P_a - P_{02s}}{P_{02} - P_a}$

46. For a multi-stage axial compressor with constant diameter hub

(A) Blade height decreases in the flow direction
(B) Blade height increases in the flow direction

(C) Blade height remains constant
(D) Blade height first increases and then decreases in the flow direction

47. How does the specific thrust, at constant turbine inlet temperature, produced by a turbofan engine change with an increase in compressor pressure ratio?
(A) Increases
(B) Decreases
(C) First increases and then decreases
(D) First decreases and then increases

48. Among the choices given below, the Specific Impulse is maximum for a
(A) Cryogenic Rocket
(B) Solid Rocket
(C) Liquid Rocket
(D) Ramjet

49. The maximum operating flow rate through a centrifugal compressor at a given RPM is limited by
(A) Impellor stall
(B) Surge
(C) Choking of diffuser throat
(D) Inlet flow distortion

Two Marks Questions.

50. The stagnation pressure and stagnation temperature inside the combustion chamber of a liquid rocket engine are 1.5 MPa and 2500 K respectively. The burned gases have $\gamma = 1.2$ and R = 692.83 J/kgK. The rocket has a converging - diverging nozzle with a throat area of $0.025 m^2$ and the flow at ihe exit of the nozzle is supersonic. If the flow through the nozzle is isentropic, what is the mass flow rate of the gases out of the nozzle?
(A) 18.5 kg/s (C) 29.7 kg/s
(B) 31.2 kg/s (D) 19.4 kg/s

51. Consider a 1-D adiabatic, inviscid, compressible flow of air ($R = 287 J/Kg - K, C_V = 718 J/Kg - K$) through a duct of constant cross-sectional area $A = 1 m^2$. If the volumetric flow rate is $Q = 680 m^3/s$ and stagnation temperature is T_0 =580.05 K , then the air temperature inside the duct is
(A) 300 K (C) 400 K
(B) 350 K (D) 450 K

52. A two stage chemical rocket, having the same specific impulse (I_{sp}) of 300 s for both the stages is designed in such a way that the payload ratio and the structural ratio are same for both the stages. The second stage of the rocket has following mass distribution:
Propellant Mass = 10208 kg
Structural Mass = 1134 kg
Payload Mass = 1700 kg
$g_e = 9.8 m/s^2$
If the rocket is fired from rest and it flies in a zero gravity field and a drag free environment, the final velocity attained by the payload is
(A) 9729.3 m/s (C) 9360.2 m/s
(B) 897.3 m/s (D) 8973.2 m/s

53. A missile with a Ramjet engine is flying in air. The temperature at the inlet and the outlet of the combustor are 1200 K and 2500 K respectively. The heating value of the fuel is 43 MJ/kg and the burner efficiency is 90%. Considering the working fluid to be air (C_P = 1005 J/kgK and $\gamma = 1.4$), the fuel/air ratio($f = \dot{m}_f/\dot{m}_a$) for this engine is equal to:
(A) 0.032 (C) 0.042
(B) 0.036 (D) 0.026

54. The inlet stagnation temperature for a single stage axial compressor is 300 K and the stage efficiency is 0.80. Following conditions exist at the mean radius of the rotor blade:

Blade speed = 200 m/s
Axial flow velocity = 160 m/s
Inlet blade angle $\beta_1 = 44°$
Outlet blade angle $\beta_2 = 14°$
C_P= 1005 J/kgK and γ= 1.4
What is the stagnation pressure ratio (P_{RS}) for this compressor?

(A) 1.41 (C) 1.51
(B) 1.37 (D) 1.23

Statement for linked Answer Qns 55 and 56:
An aircraft with an IDEAL Turbojet engine is flying at 200 m/s at an altitude where the ambient pressure is equal to 0.8 bar. The stagnation pressure and temperature at the inlet of the turbine are 6 bar and 1400 K respectively. The change in specific enthalpy across the compressor is 335 kJ/kg. Assume the fuel flow rate to be very small in comparison to the air flow rate and consider C_P = 1117 J/kgK and γ = 1.3.

55. What is the stagnation pressure at the inlet of the nozzle?
(A) 2.8 bar (C) 2.1 bar
(B) 5.7 bar (D) 6.3 bar

56. What is the specific thrust produced by this engine under the given conditions?
(A) 586 Ns/kg (C) 686 Ns/kg
(B) 745 Ns/kg (D) 500 Ns/kg

GATE AE - 2011

One Mark Questions.

57. An impulsive launch of a rocket minimizes the loss of burn-out velocity due to
(A) aerodynamic drag force only
(B) gravitational force only
(C) both aerodynamic drag and gravitational forces
(D) reaction jet control force

58. Multi-staging in rockets improves the burn-out performance by increasing mainly stage-wise
(A) payload mass ratios
(B) structural mass efficiencies
(C) propellant masses
(D) control system masses

59. A main objective of by-pass in a turbo-fan engine is to increase
(A) mass flow rate through engine inlet
(B) turbine inlet temperature
(C) mass flow rate through exhaust nozzle
(D) compressor pressure ratio

60. The pressure ratio in any one stage of a jet engine compressor is limited by
(A) entry stagnation temperature in that stage
(B) entry Mach number in that stage
(C) pressure gradient induced separation in that stage
(D) mass flow rate in that stage

61. Thermodynamic cycle on which the jet engine operates can be
(A) open Rankine cycle only
(B) either open or closed Rankine cycle
(C) open Brayton cycle only
(D) either open or closed Brayton cycle

62. Propulsion efficiency of a jet engine is
(A) directly proportional to both the thrust power and the air mass flow rate
(B) inversely proportional to both the thrust power and the air mass flow rate
(C) directly proportional to the thrust power and inversely proportional to the air mass flow rate
(D) inversely proportional to the thrust power and directly proportional to the air mass flow rate

Two Marks Questions.

63. A turbojet powered aircraft is flying at Mach number 0.8 at an altitude of 10 km. The inlet and exit areas of the engine are 0.7 m^2 and 0.4 m^2 respectively. The exhaust gases have velocity of 500 m/s and pressure of 60 kPa. The free stream pressure, density and speed of sound are 26.5 kPa, 0.413 kg/m^3 and 299.5 m/s respectively. The thrust of the engine (in kN) is_____.

64. A jet engine is operating at a Mach number of 0.8 at an altitude of 10 km. The efficiency of the air intake is 0.8 and that of the compressor is 0.87. The total temperatures (in K) at the exits of the air intake and the compressor respectively are
Ambient pressure = 26.5 kPa;
Ambient temperature = 223.3 K;
Gas constant, $\gamma = 14$; $p_{rc} = 8$

(A) 251.9 and 458.2 (C) 251.9 and 486.8
(B) 234.9 and 486.8 (D) 234.9 and 458.2

65. A rocket engine is tested on a test bed under the ideal condition of fully expanded jet. The exhaust velocity is 2 km/s through a nozzle of area 2.5 m^2. The mass flow rate is 200 kg/s. The specific impulse of the propellant and the thrust developed respectively are
(assume $g = 9.81\ m/s^2$)

(A) 175.87 s and 200 kN
(B) 203.87 s and 400 kN
(C) 231.87 s and 200 kN
(D) 280.87 s and 400 kN

GATE AE - 2012

One Mark Questions.

66. The ratio of flight speed to the exhaust velocity for maximum propulsion efficiency is

(A) 0.0 (C) 1.0
(B) 0.5 (D) 2.0

67. A rocket is to be launched from the bottom of a very deep crater on Mars for earth return. The specific impulse of the rocket, measured in seconds, is to be normalized by the acceleration due to gravity at

(A) the bottom of the crater on Mars.
(B) Mars standard "sea level".
(C) earth's standard sea level.
(D) the same depth of the crater on earth.

Two Marks Questions.

68. A rocket motor has combustion chamber temperature of 2600 K and the products have molecular weight of 25 g/mol and ratio of specific heats 1.2. The universal gas constant is 8314 J/kg-mole-K. The value of theoretical c* (in m/s) is ___.

69. The stagnation temperatures at the inlet and exit of a combustion chamber are 600 K and 1200 K, respectively. If the heating value of the fuel is 44 MJ/kg and specific heat at constant pressure for air and hot gases are 1.005 kJ/kg.K and 1.147 kJ/kg.K respectively, the fuel-to-air ratio is

(A) 0.0018 (C) 0.18
(B) 0.018 (D) 1.18

70. A solid propellant of density 1800 kg/m^3 has a burning rate law $r = 6.65 \times 10^{-3} p^{0.45}$ mm/s, where p is pressure in Pascals. It is used in a rocket motor with a tubular grain with an initial burning area of 0.314 m^2. The characteristic velocity is 1450 m/s. What should be the nozzle throat diameter to achieve an equilibrium chamber pressure of 50 bar at the end of the ignition transient?

(A) 35 mm (C) 41 mm
(B) 38 mm (D) 45 mm

71. A bipropellant liquid rocket motor operates at a chamber pressure of 40 bar with a nozzle throat diameter of 50 mm. The characteristic velocity is 1540 m/s. If the fuel-oxidizer ratio of the propellant is 1.8, and the fuel density is 900 kg/m^3, what should be the minimum fuel tank volume for a burn time of 8 minutes

(A) 1.65 m^3 (C) 1.85 m^3
(B) 1.75 m^3 (D) 1.95 m^3

72. The propellant in a single stage sounding rocket occupies 60% of its initial mass. If all of it is expended instantaneously at an equivalent exhaust velocity of 3000 m/s, what would be the altitude attained by the payload when launched vertically?
[Neglect drag and assume acceleration due to gravity to be constant at 9.81 m/s^2.]

(A) 315 km (C) 365 km
(B) 335 km (D) 385 km

Statement for Linked Answer Qns 73 and 74:
Air at a stagnation temperature of 15°C and stagnation pressure 100 kPa enters an axial compressor with an absolute velocity of 120 m/s. Inlet guide vanes direct this absolute velocity to the rotor inlet at an angle of 18° to the axial direction. The rotor turning angle is 27° and the mean blade speed is 200 m/s. The axial velocity is assumed constant through the stage.

73. The blade angle at the inlet of the rotor is

(A) 25.5° (C) 48.5°
(B) 38.5° (D) 59.5°

74. If the mass flow rate is 1 kg/s, the power required to drive the compressor is

(A) 50.5 kW (C) 30.5 kW
(B) 40.5 kW (D) 20.5 kW

GATE AE - 2013

One Mark Questions.

75. Consider two engines P and Q. In P, the high-pressure turbine blades are cooled with a bleed of 5% from the compressor after the compression process and in Q the turbine blades are not cooled. Comparing engine P with engine Q, which one of the following is NOT TRUE?

(A) Turbine inlet temperature is higher for engine P
(B) Specific thrust is higher for engine P
(C) Compressor work is the same for both P and Q
(D) Fuel flow rate is lower for engine P

76. The mass flow rate of air through an aircraft engine is 10 kg/s. The compressor outlet temperature is 400 K and the turbine inlet temperature is 1800 K. The heating value of the fuel is 42 MJ/kg and the specific heat at constant pressure is 1 kJ/kg-K. The mass flow rate of the fuel in kg/s is approximately _____

77. For a given inlet condition, if the turbine inlet temperature is fixed, what value of compressor efficiency given below leads to the lowest amount of fuel added in the combustor of a gas turbine engine?

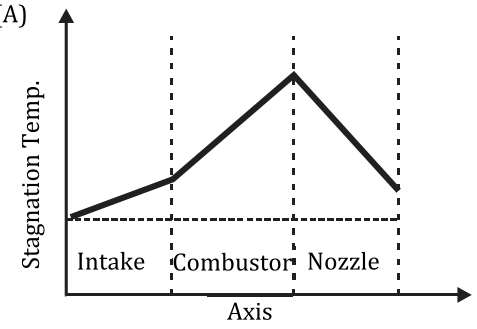
(A) 1 (C) 0.85
(B) 0.95 (D) 0.8

78. A gas turbine engine is mounted on an aircraft which can attain a maximum altitude of 11 km from sea level. The combustor volume of this engine is decided based on conditions at

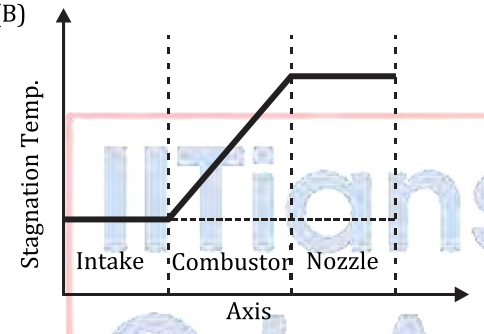
(A) sea level (C) 5.5 km altitude
(B) 8 km altitude (D) 11 km altitude

79. Which one of the following shows the CORRECT variation of stagnation temperature along the axis of an ideal ram jet engine?

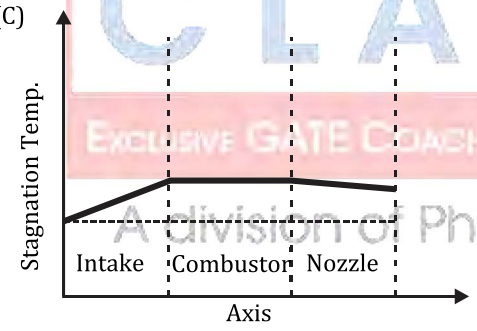
(A)



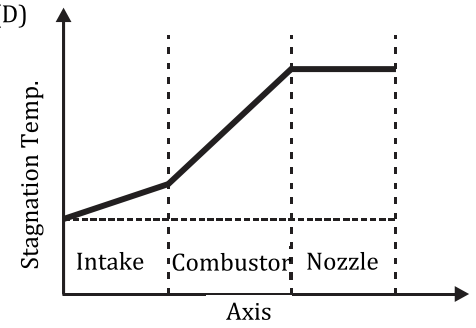
(B)



(C)



(D)



80. A rocket motor has a chamber pressure of 100 bar and chamber temperature of 3000 K. The ambient pressure is 1 bar. Assume that the specific heat at constant pressure is 1 kJ/kg-K. Also assume that the flow in the nozzle is isentropic and optimally expanded. The exit static temperature in K is

(A) 805 (C) 905

(B) 845 (D) 945

Two Marks Questions.

81. Thrust of liquid oxygen - liquid hydrogen rocket engine is 300 kN. The O/F ratio used is 5. If the fuel mass flow rate is 12.5 kg/s, the specific impulse of the rocket motor in Ns/kg is

(A) 3800 (C) 4200

(B) 4000 (D) 4400

82. In a 50 % reaction axial compressor stage, the local blade velocity is 300 m/s and the axial component of velocity is 100 m/s. If the absolute inlet flow angle $\alpha_1 = 45°$, the work per unit mass done on the fluid by the stage in kJ/kg is

(A) 30 (C) 50

(B) 40 (D) 60

83. Consider two rockets P and Q fired vertically up with identical specific impulse and a payload of 2 kg. Rocket P has 2 identical stages, and each stage has 200 kg of propellant and 20 kg of structural weight. Rocket Q has a single stage with 400 kg of propellant and 40 kg of structural weight. Neglecting drag and gravity effects, the ratio of the change in velocity of P to that attained by Q is

(A) 1.13 (C) 1.33

(B) 1.23 (D) 1.43

Common Data for Questions 84 and 85:

An aircraft is flying at Mach number M = 1.5, where the ambient temperature is 250 K. The stagnation temperature of gases at the entry to the nozzle is 800 K. The nozzle is choked and

always under expanded. Assume the molecular weight of the exhaust gases to be 29, the ratio of specific heats to be 1.4 and the universal gas constant is 8314 J/kmol-K.

84. For which one of the nozzle exit Mach numbers given below is the propulsive efficiency highest?

(A) 1 (C) 2
(B) 1.5 (D) 2.5

85. For which one of the nozzle exit Mach numbers given below is the thrust highest?

(A) 1 (C) 2
(B) 1.5 (D) 2.5

GATE AE - 2014

One Mark Questions.

86. Match the appropriate engine (in right column) with the corresponding aircraft (in left column) for most efficient performance of the engine.

a. Low speed transport aircraft
b. High subsonic civilian aircraft
c. Supersonic fighter aircraft
d. Hypersonic aircraft

i. Ramjet
ii. Turboprop
iii. Turbojet
iv. Turbofan

(A) a – iv, b – iii, c – i, d – ii
(B) a – ii, b – i, c – iii, d – iv
(C) a – i, b – ii, c – iv, d – iii
(D) a – ii, b – iv, c – iii, d – i

87. For a given fuel flow rate and thermal efficiency, the take-off thrust for a gas turbine engine burning aviation turbine fuel (considering fuel-air ratio f<< 1) is

(B) Directly proportional to exhaust velocity
(C) Inversely proportional to exhaust velocity
(D) Independent of exhaust velocity
(E) Directly proportional to the square of the exhaust velocity

88. For a fifty percent reaction axial compressor stage, following statements are given:

I. Velocity triangles at the entry and exit of the rotor are symmetrical
II. The whirl or swirl component of absolute velocity at the entry of rotor and entry of stator are same.

Which of the following options are correct?

(A) Both I and II are correct statements
(B) I is correct but II is incorrect
(C) I is incorrect but II is correct
(D) Both I and II are incorrect

89. A small rocket having a specific impulse of 200s produces a total thrust of 98kN, out of which 10kN is the pressure thrust. Considering the acceleration due to gravity to be 9.8m/s^2, the propellant mass flow rate in kg/s is

(A) 55.1 (C) 50
(B) 44.9 (D) 60.2

90. The thrust produced by a turbojet engine

(A) Increases with increasing compressor pressure ratio
(B) Decreases with increasing compressor pressure ratio
(C) Remains constant with increasing compressor pressure ratio
(D) First increases and then decreases with increasing compressor pressure ratio

Two Marks Questions.

91. A cruise missile with an ideal ramjet engine is flying at Mach 4.0 at an altitude where the ambient temperature is 100K. Consider ratio of specific heats γ = 1.4 and specific gas constant R = 287J/kgK. If the stagnation temperature in

the combustion chamber is equal to 2310K, the speed of the exhaust gases (in m/s) is _____.

92. A gas turbine engine is operating under the following conditions:

Stagnation temperature at turbine inlet	1350 K
Stagnation pressure at the turbine inlet	10 bar
Static temperature at turbine exit	800 K
Velocity at turbine exit	200 m/s
Total-to-total efficiency of turbine	0.96
γ (ratio of specific heats)	1.33
C_P(Specific heat at constant pressure)	1.147 kJ/kgK

The stagnation pressure (in bar) in the nozzle (considering isentropic nozzle) is equal to _____.

93. Air at a stagnation temperature of 300K (ratio of specific heats, γ = 1.4 and specific gas constant R = 287 J/kgK) enters the impeller of a centrifugal compressor in axial direction. The stagnation pressure ratio between the diffuser outlet and impeller inlet is 4.0. The impeller blade radius is 0.3 m and it is rotating at 15000 rev/min. If the slip factor σ_s (Ratio of tangential component of air velocity at the blade tip to the blade tip speed) is 0.88, the overall efficiency (total-to-total) of the compressor (in %) is _____.

94. A stationary two stage rocket with initial mass of 16000kg, carrying a payload of 1000kg, is fired in a vertical trajectory from the surface of the earth. Both the stages of the rocket have same specific impulse, I_{sp}, of 300s and same structural coefficient of 0.14. The acceleration due to gravity is 9.8m/s^2. Neglecting drag and gravity effects and considering both the stages with same payload ratio, the terminal velocity attained by the payload in m/s is _____.

95. An aircraft is flying at Mach 3.0 at an altitude where the ambient pressure and temperature are 50 kPa and 200 K respectively. If the converging-diverging diffuser of the engine (considered isentropic with ratio of specific heats, γ = 1.4 and specific gas constant R = 287 J/kgK) has a throat area of 0.05 m2, the mass flow rate through the engine in kg/s is

(A) 197 (C) 790

(B) 232 (D) 157

96. A cryogenic rocket has a specific impulse of 455s and characteristic velocity of 2386 m/s. The value of thrust coefficient for this rocket is

(A) 1.78 (C) 1.87

(B) 1.73 (D) 1.95

GATE AE - 2015

One Mark Questions.

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

(A) Turbojet engine without afterburner

(B) Turbojet engine with afterburner

(C) Turbofan engine

(D) Ramjet engine

98. The stoichiometric fuel-to-air ratio in an aircraft engine combustor varies with the compressor

pressure ratio as follows:

(A) increases linearly

(B) decreases linearly

(C) is independent

(D) increases nonlinearly

99. A rocket engine produces a total impulse of 112 kN. s in a burn time period of 3.5 minutes

with a propellant mass flow rate of 0.25 kg/s. The effective exhaust velocity (in m/s) of gas ejecting from the engine is _____.

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

(A) $\eta_i < \eta_c < \eta_t < \eta_n$

(B) $\eta_t < \eta_i < \eta_c < \eta_n$

(C) $\eta_c < \eta_t < \eta_i < \eta_n$

(D) $\eta_c < \eta_i < \eta_t < \eta_n$

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

(A) under-expanded condition for H > 8km

(B) under-expanded condition for H < 8km

(C) sonic exit condition for H > 8km

(D) unchoked condition for H < 8km

Two Marks Questions.

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

(A) 43241 (C) 47940

(B) 45594 (D) 49779

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

104. A liquid propellant rocket has the following component masses:

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

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

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

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

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

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

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

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

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

GATE AE - 2016

One Mark Questions.

108. Which of the following aircraft engines has the highest propulsive efficiency at a cruising Mach number of less than 0.5?

(A) Turbofan engine
(B) Turbojet engine
(C) Turboprop engine
(D) Ramjet engine

109. Combustion in gas turbine engines is ideally represented as the following process:

(A) Adiabatic (C) Isobaric
(B) Isentropic (D) Isochoric

110. For a given chamber pressure, the thrust of a rocket engine is highest when

(A) the rocket is operating at its design altitude.
(B) the rocket is operating in vacuum.
(C) the rocket is operating at sea-level.
(D) there is a normal shock in the rocket nozzle.

111. A substance experiences an entropy change of $\Delta s > 0$ in a quasi-steady process. The rise in temperature (corresponding to the entropy change Δs) is highest for the following process:

(A) isenthalpic (C) isochoric
(B) isobaric (D) isothermal

Two Marks Questions.

112. An un-mixed turbofan engine with a bypass ratio of 6.0, flies with a velocity of 200 m/s. The core and the bypass nozzles of the engine, that are both convergent nozzles, operate under choked condition and have exhaust static temperatures of 580 K and 295 K, respectively. The specific gas constant and the ratio of specific heats for both the streams are 287 J/kgK and 1.4, respectively. If the fuel-air ratio is negligible, the thrust per unit mass flow rate generated by the engine is _____Ns/kg.

113. A single-stage gas turbine operates with an axial absolute flow at the entry and exit from the stage. The absolute flow angle at the nozzle exit is 70°. The turbine stage generates a specific work of 228 kJ/kg when operating with a mean blade speed of 440 m/s. The absolute velocity at the rotor entry is

(A) 275.7 m/s (C) 1103.0 m/s
(B) 551.5 m/s (D) 1654.5 m/s

114. An axial compressor operates such that it has an inlet and an exit total temperature of 300 K and 430 K, respectively. The isentropic efficiency of the compressor is 85 %. If the ratio of specific heats is 1.4, then the total pressure ratio across the compressor is _____.

115. A gaseous mixture of air and fuel enters a constant area combustion chamber at a velocity of 100 m/s and at a static temperature of 300 K. The heat release due to combustion is 1000 kJ/kg. The specific heat at constant pressure of the calorically perfect gas is 1000 J/kgK. The total temperature of air-fuel mixture after combustion is _____ K.

116. A launch vehicle has a main rocket engine with two identical strap-on motors, all of which fire simultaneously during the operation. The main engine delivers a thrust of 6300 kN with a specific impulse of 428 s. Each strap-on motor delivers a thrust of 12000 kN with specific impulse of 292 s. The acceleration due to gravity is 9.81 m/s^2. The effective (combined) specific impulse of the vehicle is _____ s.

117. A rocket, with a total lift-off mass of 10000 kg, moves vertically upward from rest under a constant gravitational acceleration of 9.81 m/s^2. The propellant mass of 8400 kg burns at a constant rate of 1200 kg/s. If the specific impulse of the rocket engine is 240 s, neglecting drag, the burnout velocity in m/s is

(A) 3933.7 (C) 4245.9
(B) 4314.6 (D) 4383.3

GATE AE - 2017

One Mark Questions.

118. Consider a system consisting of certain amount of perfect gas enclosed in a cylinder fitted with a frictionless piston. This system can undergo following processes

(i) Expansion with finite pressure difference with the surrounding.
(ii) Compression with infinitesimal pressure difference with the surrounding.
(iii) Heat transfer with finite temperature difference with the reservoir.
(iv) Heat transfer with infinitesimal temperature difference with the reservoir.

Out of these which processes are reversible?

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

119. Among the following engines, which one is expected to have the maximum Specific Impulse?

(A) Cryogenic Rocket
(B) Solid Propellant Rocket
(C) Liquid Propellant Rocket
(D) SCRAM Jet

120. The maximum gas flow rate that can be handled by a multistage axial compressor at a given rotational speed is dictated by

(A) Compressor Surge
(B) Rotating Stall
(C) Choking
(D) Optimum Design Pressure Ratio

121. For a turbine stage, which one of the following losses occurs due to the turning of the wall boundary layer through an angle due to curved surface?

(A) Profile loss
(B) Annulus loss
(C) Tip clearance loss
(D) Secondary flow loss

122. In the vane-less space between the impeller and the diffuser vanes in a Centrifugal Compressor, the angular momentum varies in the following manner in the radial direction

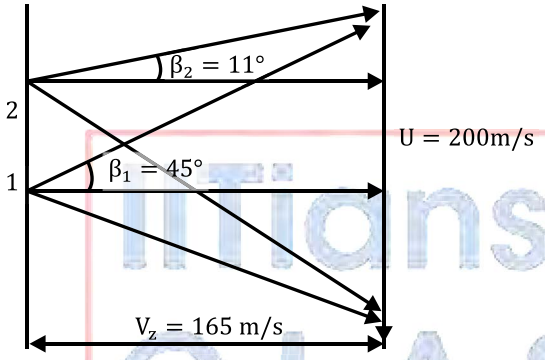
(A) Increases
(B) Remains constant
(C) Decreases
(D) First increases and then decreases

Two Marks Questions.

123. In a combustor, gaseous Octane (C_8H_{18}) and air are to be burned in stoichiometric proportions. If the required flowrate of air is 1 kg/s, what should be the corresponding flow rate of Octane?

(A) 0.066 kg/s (C) 0.16 kg/s
(B) 15.15 kg/s (D) 6.25 kg/s

124. The given diagram represents the velocity triangles at the leading edge (1) and trailing edge (2) at the mean radius of a single stage axial compressor rotor. The stage efficiency of the compressor is 0.8. The stagnation temperature of air entering the stage is 298 K and the specific heat at constant pressure for air is 1.005 kJ/kgK. The ratio of specific heats for air is 1.4. Considering actual work in the rotor is equal to the ideal work, the pressure ratio for the stage is equal to _____(in two decimal points).



125. An aircraft with a turbojet engine, having an inlet area of 1 m^2 , is flying at 270 m/s at an altitude where the atmospheric pressure is equal to 0.9 bar and the ambient temperature is equal to 290 K. The stagnation pressure and temperature at the exit of the turbine are equal to 1.6 bar and 774 K respectively. The specific heat at constant pressure of the burned gases is equal to 1.147 kJ/kgK and the ratio of specific heats is equal to 1.33. Considering ideal expansion in the nozzle with no losses, the specific thrust produced by the engine is_____ Ns/kg (in one decimal place).

126. Air, at 450 K stagnation temperature and at a rate of 50 kg/s, enters the combustor of a turbofan engine and is burned with 1 kg/s of Aviation Kerosene (Heating value 44 MJ/kg). The specific heat at constant pressure for the incoming air and the burned products are 1.005 kJ/kgK and 1.147 kJ/kgK respectively. Considering 100% burner efficiency, the stagnation temperature at the exit of the combustor is equal to _____ K. (in one decimal place).

127. A single stage chemical rocket, having an initial mass of 10,000 kg and specific impulse of 450 s, is launched from the surface of the earth and has to reach the escape velocity (11 km/s) at burn out. Consider $g_e = 9.8 m/s^2$. If the atmospheric drag and the effect of gravity are to be neglected, the mass of propellant to be carried by the rocket is equal to_____ kg (in one decimal place).

128. A centrifugal compressor requires 1800 kW of power to compress 10 kg/s of air. Consider the whirl velocity component is equal to the impeller speed (ie., no slip) and no losses in the impeller. If the impeller has to rotate at 1900 rad/s, the diameter of the impeller is to be _____ m (in two decimal place).

GATE AE - 2018

One Mark Questions.

129. The theoretical maximum velocity (in m/s) of air expanding from a reservoir at 700 K is _____ (accurate to two decimal places). Specific heat of air at constant pressure is 1005 J/(kg-K).

130. The stagnation pressures at the inlet and exit of a subsonic intake are 100 kPa and 98 kPa, respectively. The pressure recovery of this intake will be _____ (accurate to two decimal places).

131. A combustor is operating with a fuel-air ratio of 0.03. If the stoichiometric fuel-air ratio of the fuel used is 0.06, the equivalence ratio of the combustor will be _____ (accurate to two decimal places).

132. The first law of thermodynamics is also known as conservation of

(A) mass. (C) energy.
(B) momentum. (D) species.

133. In an ideal gas turbine cycle, the expansion in a turbine is represented by

(A) an isenthalpic process.
(B) an isentropic process.
(C) an isobaric process.
(D) an isochoric process.

Two Marks Questions.

134. An aircraft with a turbojet engine flies at a velocity of 100 m/s. If the jet exhaust velocity is 300 m/s, the propulsive efficiency of the engine, assuming a negligible fuel-air ratio, is

(A) 0.33 (C) 0.67
(B) 0.50 (D) 0.80

135. An axial compressor that generates a stagnation pressure ratio of 4.0, operates with inlet and exit stagnation temperatures of 300 K and 480 K, respectively. If the ratio of specific heats (γ) is 1.4, the isentropic efficiency of the compressor is

(A) 0.94 (C) 0.72
(B) 0.81 (D) 0.63

136. A rocket has an initial mass of 150 kg. After operating for a duration of 10 s, its final mass is 50 kg. If the acceleration due to gravity is 9.81 m/s^2 and the thrust produced by the rocket is 19.62 kN, the specific impulse of the rocket is

(A) 400 s (C) 200 s
(B) 300 s (D) 100 s

137. An axial compressor rotor with 50 % degree of reaction, operates with an axial velocity of 200 m/s. The absolute flow angle at the inlet of the rotor is 22° with reference to the axial direction. If the axial velocity is assumed to remain constant through the rotor, the magnitude of the relative velocity (in m/s) at the rotor exit is _____ (accurate to one decimal place).

138. The relative velocity of air leaving a straight radial impeller of a centrifugal compressor is 100 m/s. If the impeller tip speed is 200 m/s, for a slip free operation, the absolute velocity (in m/s) at the impeller exit is _____ (accurate to one decimal place).

GATE AE - 2019

One Mark Questions.

139. For a quasi-one-dimensional isentropic supersonic flow through a diverging duct, which of the following is true in the direction of the flow?

(A) Both the Mach number and the static temperature increase.
(B) The Mach number increases and the static temperature decreases.
(C) The Mach number decreases and the static temperature increases.
(D) Both the Mach number and the static temperature decrease.

140. The propulsive efficiency of a ramjet engine is lower than that of a low bypass turbofan engine operating under the same conditions and producing the same thrust, primarily because the ramjet engine

(A) has larger kinetic energy lost in the exhaust jet.
(B) has lower thrust power.
(C) is not self-starting.
(D) has higher thrust to weight ratio.

141. While flying at Mach 2.0, 11 km altitude and producing the same thrust, what is the correct order from the lowest thrust specific fuel consumption (tsfc) to the highest tsfc?

(A) Turbofan, Ramjet, Turbojet

(B) Turbofan, Turbojet, Ramjet

(C) Ramjet, Turbojet, Turbofan

(D) Turbojet, Turbofan, Ramjet

142. For a single stage subsonic compressor, which of the following statements about the highest possible compressor pressure ratio (CPR) is correct?

(A) CPR of an axial compressor > CPR of centrifugal compressor.

(B) CPR of an axial compressor < CPR of centrifugal compressor.

(C) CPR of an axial compressor = CPR of centrifugal compressor.

(D) CPR of any value can be attained with either an axial or a centrifugal compressor.

143. For the complete combustion of 1 mole of ethanol (C_2H_5OH), the required number of moles of oxygen is

144. One kg of diatomic gas is heated and its temperature increases from 100 K to 600 K. The energy added at constant pressure during this process is 500 kJ. The specific heat at constant volume for the gas is _____ kJ/kgK. (round off to 2 decimal places).

Two Marks Questions.

145. In a turbojet engine, the compressor outlet temperature increases with decreasing efficiency of the compressor. If the turbine inlet temperature remains constant, with decreasing efficiency of the compressor, the thrust specific fuel consumption of the engine

(A) decreases, as the heat input is lower.

(B) remains unchanged.

(C) increases, as the compressor needs more work input from the turbine.

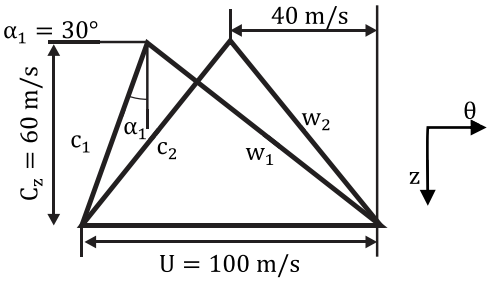
(D) decreases, as the thrust produced is higher.

146. For a rocket engine, the velocity ratio r is V_a/V_e, where V_a is the vehicle velocity and V_e is the exit velocity of the exhaust gases. Assume the flow to be optimally expanded through the nozzle. For r = 2, if F is the thrust produced and $\dot{m}$ is the mass flow rate of exhaust gases, then, $F/(\dot{m}V_e)$ is ____.

147. The specific impulse of a rocket engine is 3000 Ns/kg. The mass of the rocket at burnout is 1000 kg. The propellant consumed in the process is 720 kg. Assume all factors contributing to velocity loss to be negligible. The change in vehicle velocity Δu is _____ km/s (round off to 2 decimal places).

148. The combustion products of a gas turbine engine can be assumed to be a calorically perfect gas with γ = 1.2. The pressure ratio across the turbine stage is 0.14. The measured turbine inlet and exit stagnation temperatures are 1200 K and 900 K, respectively. The total-to- total turbine efficiency is ___ % (round off to the nearest integer).

149. The figure shows the velocity triangles for an axial compressor stage. The specific work input to the compressor stage is _____ kJ/kg (round off to 2 decimal places).



GATE AE - 2020

One Mark Questions.

150. The ratio of exit stagnation pressure to inlet stagnation pressure across the rotating impeller of a centrifugal compressor, operating with a closed exit, is

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

151. Which one of the following is a hypergolic propellant combination used in rocket engines?

(A) Liquid hydrogen – liquid oxygen
(B) Unsymmetrical dimethyl hydrazine – nitrogen tetroxide
(C) Rocket fuel RP-1 – liquid oxygen
(D) Liquid hydrogen – liquid fluorine

152. In aircraft engine thermodynamic cycle analysis, perfectly expanded flow in the nozzle means that the static pressure in the flow at the nozzle exit is equal to

(A) the stagnation pressure at the engine inlet.
(B) the stagnation pressure at the nozzle exit.
(C) the ambient pressure at the nozzle exit.
(D) the static pressure at the nozzle inlet.

153. Air enters the rotor of an axial compressor stage with no pre-whirl ($C_\theta = 0$) and exits the rotor with whirl velocity, C_θ = 150 m/s. The velocity of rotor vanes, U is 200 m/s. Assuming C_p = 1005 J/(kg K), the stagnation temperature rise across the rotor is _____ K (round off to one decimal place).

Two Marks Questions.

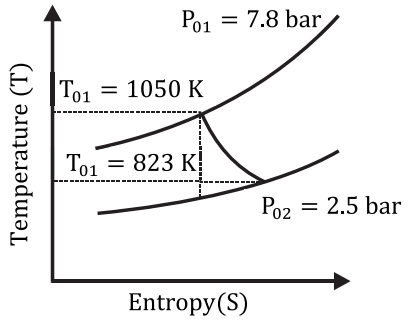
154. An axial compressor is designed to operate at a rotor speed of 15000 rpm and an inlet stagnation temperature of 300 K. During compressor testing, the inlet stagnation temperature of the compressor measured was 280 K. What should be the rotor speed for the compressor to develop the same performance characteristics during this test as in the design condition?

(A) 14000 rpm (C) 15526 rpm
(B) 14491rpm (D) 16071 rpm

155. The design flight Mach number of an ideal ramjet engine is 2.8. The stagnation temperature of air at the exit of the combustor is 2400 K. Assuming the specific heat ratio of 1.4 and gas constant of 287 J/(kg K.), the velocity of air at the exit of the engine is _____ m/s (round off to one decimal place).

156. The operating conditions of an aircraft engine combustor are as follows.
The rate of total enthalpy of air entering the combustor = 28.94 MJ/s.
The rate of total enthalpy of air leaving the combustor = 115.42 MJ/s.
Mass flow rate of air = 32 kg/s.
Air to fuel mass ratio = 15.6.
Lower heating value of the fuel = 46 MJ/kg.
The efficiency of the combustor is _____% (round off to two decimal places).

157. The figure shows the T-S diagram for an axial turbine stage



Assuming specific heat ratio of 1.33 for the hot gas, the isentropic efficiency of the turbine stage is ____ % (round off to two decimal places).

158. A rocket engine has a sea level specific impulse of 210 s and a nozzle throat area of 0.005 m^2. While testing at sea level conditions, the characteristic velocity and pressure for the thrust chamber are 1900 m/s and 50 bar, respectively. Assume the acceleration due to gravity to be 9.8 m/s^2. The thrust produced by the rocket engine is _____ kN (round off to one decimal place).

GATE AE - 2021

One Mark Questions.

159. The combustion process in a turbo-shaft engine during ideal operation is:

(A) isentropic (C) isochoric

(B) isobaric (D) isothermal

160. How does the specific thrust of a turbojet engine change for a given flight speed with increase in flight altitude?

(A) Increases monotonically

(B) Decreases monotonically

(C) Remains constant

(D) First increases and then decreases

161. How does the propulsion efficiency of a turbofan engine, operating at a given Mach number and a given altitude, change with increase in compressor pressure ratio?

(A) Remains constant

(B) Increases monotonically

(C) Decreases monotonically

(D) First decreases and then increases

162. A solid propellant rocket producing 25 MN thrust is fired for 150 seconds. The specific impulse of the rocket is 2980 Ns/kg. How much propellant is burned during the rocket operation?

(A) 8390 kg (C) 1.26×10^6 kg

(B) 82300 kg (D) 11.2×10^6 kg

Two Marks Questions.

163. An aircraft with a turbojet engine is flying at 270 m/s. The enthalpy of the incoming air at the intake is 260 kJ/kg and the enthalpy of the exhaust gases at the nozzle exit is 912 kJ/kg. The ratio of mass flow rates of fuel and air is equal to 0.019. The chemical energy (heating value) of fuel is 44.5 MJ/kg and the combustion process is ideal. The total loss of heat from the engine to the ambient is 25 kJ per kg of air. The velocity of the exhaust jet is _____m/s (round off to two decimal places)

164. Hot gases are generated at a temperature of 2100 K and a pressure of 14 MPa in a rocket chamber. The hot gases are expanded ideally to the ambient pressure of 0.1 MPa in a convergent-divergent nozzle having a throat area of 0.1 m^2. The molecular mass of the gas is 22 kg/kmol. The ratio of specific heats (γ) of the gas is 1.32. The value of the universal gas constant (R_0) is 8314 J/kmol-K. The acceleration due to gravity, g, is 9.8 m/s^2. The specific impulse of the rocket is _____ seconds (round off to two decimal places)

165. A twin-spool turbofan engine is operated at sea level (P_a = 1 bar, T_a = 288K). The engine has separate cold and hot nozzles. During static thrust test at sea level, the overall mass flow rate of air through the engine and the cold exhaust temperature are measured to be 100 kg/s and 288 K, respectively. The parameters for the engine are:

Fan pressure ratio = 1.6,

Overall pressure ratio = 20,

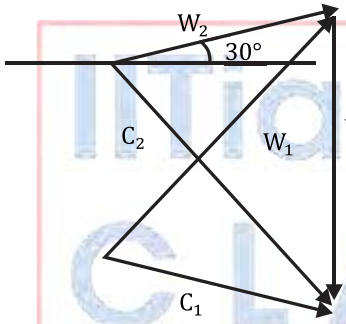
Bypass ratio = 3.0,

Turbine entry temperature = 1800 K,

The specific heat at constant pressure (C_p) is 1.005 kJ/kg-K and the ratio of specific heats (γ) is 1.4 for air.

Assuming ideal fan and ideal expansion in the nozzle, the sea-level static thrust from the cold nozzle is _____ kN (round off to two decimal places)

166. At the design conditions, the velocity triangle at the mean radius of a single stage axial compressor is such that the blade angle at the rotor exit is equal to 30°. The absolute velocities at the rotor inlet and exit are equal to 140 m/s and 240 m/s, respectively. The flow velocities relative to the rotor at inlet and exit of the rotor are equal to 240 m/s and 140 m/s, respectively.



The blade speed (U) at the mean radius of the rotor is _____ m/s (round off to two decimal places).

167. A single stage axial turbine has a mean blade speed of 340 m/s at design condition with blade angles at inlet and exit of the rotor being 21° and 55°, respectively. The degree of reaction at the mean radius of the rotor is equal to 0.4. The annulus area at the rotor inlet is 0.08 m^2 and the density of gas at the rotor inlet is 0.9 kg/m^3. The flow rate through the turbine at these conditions is _____ kg/s (round off to two decimal places).

168. The air flow rate through the gas generator of a turboprop engine is 100 kg/s. The stagnation temperatures at inlet and exit of the combustor are 600K and 1200K, respectively. The burner efficiency is 90% and the heating value of the fuel is 40 MJ/kg. The specific heats at constant pressure (C_p) for air and burned gases are 1000 J/kg-K and 1200 J/kg-K, respectively. The flow rate of the fuel being used is _____ kg/s (round off to two decimal places).
(Note: Do not neglect the fuel flow rate with respect to the air flow rate

GATE AE - 2022

One Mark Questions.

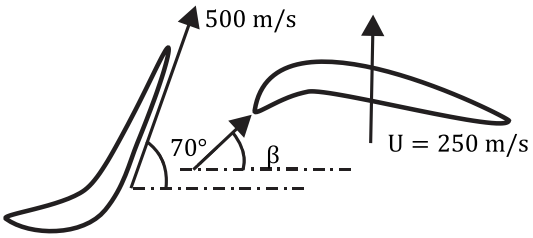
169. The region of highest static temperature in a rocket engine and the region of highest heat flux are _____, respectively.
(A) nozzle throat and nozzle entry
(B) combustion chamber and nozzle throat
(C) nozzle exit and nozzle throat
(D) nozzle throat and combustion chamber

170. A high-pressure-ratio multistage axial compressor encounters an extreme loading mismatch during starting. Which of the following technique(s) can be used to alleviate this problem?
(A) Blade cooling
(B) Variable angle stator vanes
(C) Blow-off valves
(D) Multi-spool shaft

171. In a static test, a turbofan engine with bypass ratio of 9 has core hot exhaust speed 1.5 times that of fan exhaust speed. The engine is operated at a fuel to air ratio of $f = 0.03$. Both the fan and the core streams have no pressure thrust. The ratio of fan thrust to thrust from the core engine is ____ (round off to one decimal place).

172. In a single stage turbine, the hot gases come out of stator/ nozzle at a speed of 500 m/s and at an angle of 70 degrees with the turbine axis as

shown. The design speed of the rotor blade is 250 m/s at the mean blade radius. The rotor blade angle, β, at the leading edge is _____ degrees (round off to one decimal place).



Two Marks Questions.

173. Which of the following is NOT always true for a combustion process taking place in a closed system?

(A) Total number of atoms is conserved
(B) Total number of molecules is conserved
(C) Total number of atoms of each element is conserved
(D) Total mass is conserved

174. A rocket operates at an absolute chamber pressure of 20 bar to produce thrust, F_1.

The hot exhaust is optimally expanded to 1 bar (absolute pressure) using a convergent-divergent nozzle with exit to throat area ratio $\left(\frac{A_e}{A_t}\right)$ of 3.5 and thrust coefficient, $C_{F,1} = 1.42$

The same rocket when operated at an absolute chamber pressure of 50 bar produces thrust F_2 and the thrust coefficient is $C_{F,2}$.

Which of the following statement(s) is/are correct?

(A) $\frac{F_2}{F_1} = 2.5$
(C) $\frac{C_{F,2}}{C_{F,1}} = 1$
(B) $\frac{F_2}{F_1} > 2.5$
(D) $\frac{C_{F,2}}{C_{F,1}} > 1$

175. An ideal ramjet is to operate with exhaust gases optimally expanded to ambient pressure at an altitude where temperature is 220 K. The exhaust speed at the nozzle exit is 1200 m/s at a temperature of 1100 K.

Given:

$\gamma = 1.4$ at 220 K; $R = 287$ J/(kg − K) for air

$\gamma = 1.33$ at 1100 K; $R = 287$ J/(kg-K) for exhaust gases.

The cruise speed of this ramjet is _____ m/s (rounded off to nearest integer).

176. A multistage axial compressor takes in air at 1 atm, 300 K and compresses it to a minimum of 5 atm.

The mean blade speed is 245 m/s and work coefficient, $\Delta C_\theta/U$ is 0.55 for each stage.

For air, use C_p =1005 J/(kg-K), $R = 287$ J/(kg-K) and $\gamma = 1.4$.

If the compression is isentropic, the number of stages required is _____ (rounded off to the next higher integer).

GATE AE - 2023

One Mark Questions.

177. 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) $W_T = 2W_C$
(C) $W_T = W_C$
(B) $W_T = 6W_C$
(D) $W_T = 3W_C$

178. For a stage of a 50% reaction ideal axial flow compressor (symmetrical blading), select the correct statement from the options given.

(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 component of the flow at the rotor exit is 50% of that at the rotor entry.
(D) The static pressure rise across the rotor is 50% of the rise across the stator.

179. 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 (C) 0.33
(B) 1.00 (D) 0.67

180. 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.

181. A supersonic vehicle powered by a ramjet engine is cruising at a speed of 1000 m/s. The ramjet engine burns hydrogen in a subsonic combustor to produce thrust. The heat of combustion for 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 acceleration due to gravity $g_0 = 10\ m/s^2$, the specific impulse of the engine is _____seconds. (round off to the nearest integer).

Two Marks Questions.

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

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

$\dot{m}_B = 70\ kg/s,\ 0 \le t \le 70$

Neglecting gravity and aerodynamic forces, the relationship between the final velocities V_A and V_B of missiles A and B, respectively, is given by

(A) $V_A = 4.1\ V_B$ (C) $V_A = 0.5V_B$
(B) $V_A = V_B$ (D) $V_A = 0.7V_B$

183. A gas turbine combustor is burning methane and air at an equivalence ratio $\phi = 0.5$, where $\phi = \frac{F/A}{\left[\frac{F}{A}\right]_{stoich}}$ and $[F/A]_{stoich}$ is the ratio of mass flow rate of fuel to the mass flow rate of air at stoichiometry. If the air flow rate is $\dot{m}_{air} = 20\ kg/s$ then the mass flow rate of methane is _____ kg/s. (round off to two decimal places)

184. A centrifugal air compressor has inlet root diameter of 0.25 m and the outlet diameter of the impeller is 0.6 m. The pressure ratio is 5.0. The air at the inlet of the rotor is at 1 atm and 25°C. The polytropic efficiency is 0.8 and slip factor is
0.92. Use $C_p = 1.004$ kJ/kg-Kand $\gamma = 1.4$. The impeller speed in revolutions per minute (RPM) is _____. (round off to the nearest integer)

185. Consider a cryogenic liquid rocket engine using an expander cycle with liquid hydrogen and liquid oxygen as the two propellants. The mass flow rate of hydrogen $\dot{m}_{H_2}$ into the combustion chamber is 32 kg/s , and the mass flow rate of oxygen $\dot{m}_{O_2}$ into the chamber is such that $\dot{m}_{O_2}/\dot{m}_{H_2} = 8$. The combustion of hydrogen and oxygen is at stoichiometry. Assuming that the rate of the forward reaction is much larger than that of the reverse reaction, the rate of formation of H_2O is _____ kmol/s. (round off to the nearest integer)

GATE AE - 2024

One Mark Questions.

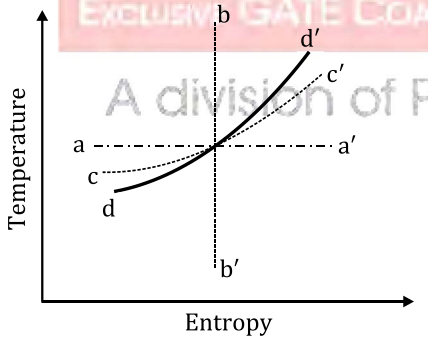
186. For an ideal gas, the specific heat at constant pressure is 1147 J/kg K and the ratio of specific heats is equal to 1.33. What is the value of the gas constant for this gas in J/kg K?

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

187. 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

188. 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

189. In an airbreathing gas turbine engine, the combustor inlet temperature is 600 K. The heating value of the fuel is 43.4×10^6 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

190. 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).

Two Marks Questions.

191. 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

192. 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 44×10^6 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

193. 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

194. 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

195. A chemical rocket with an ideally expanded flow through the nozzle produces 5×10^6 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).

196. 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).

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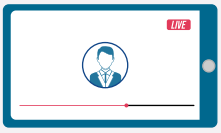

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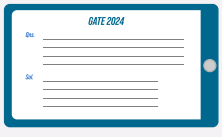

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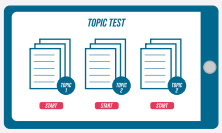

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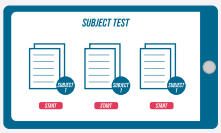

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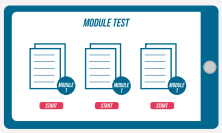

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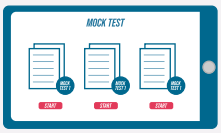

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16	D	17	C	18	A	19	B	20	D
21	A	22	C	23	D	24	D	25	C
26	D	27	B	28	D	29	C	30	B
31	B	32	D	33	C	34	C	35	D
36	D	37	A	38	B	39	A	40	D
41	C	42	D	43	A	44	C	45	A
46	A	47	C	48	D	49	C	50	A
51	B	52	D	53	B	54	D	55	C
56	D	57	C	58	A	59	C	60	C
61	C	62	C	63	29 to 32	64	C	65	B
66	C	67	C	68	1430 to 1440	69	B	70	B
71	B	72	D	73	Mark to all	74	Mark to all	75	D
76	0.3 to 0.35	77	D	78	D	79	B	80	A
81	B	82	A	83	B	84	A	85	D
86	D	87	B	88	B	89	C	90	D
91	1880 to 1881	92	1.10 to 1.25	93	74 to 76	94	6050 to 6250	95	D
96	C	97	C	98	C	99	2131.1 to 2139.1	100	C
101	A	102	D	103	1742 to 1752	104	5.42 to 5.48	105	1.33 to 1.40
106	20.5 to 21.3	107	824.0 to 832.1	108	C	109	C	110	B
111	162 to 166	112	C	113	B	114	2.9 to 3.1	115	1305 to 1305
116	310 to 315	117	C	118	D	119	D	120	C
121	D	122	B	123	A	124	1.20 to 1.30	125	215.0 to 217.0
126	1130.0 to 1145.0	127	9100.0 to 9200.0	128	0.40 to 0.50	129	1185.00 to 1186.50	130	0.98 to 0.98
131	0.50 to 0.50	132	C	133	B	134	B	135	B
136	C	137	215.0 to 216.5	138	222.0 to 225.0	139	B	140	A
141	B	142	B	143	3 to 3	144	0.70 to 0.72	145	C
146	1 to 1	147	1.60 to 1.65	148	88 to 90	149	2.50 to 2.60	150	C
151	B	152	C	153	29.8 to 30.0	154	B	155	1712.0 to 1719.0
156	91 to 93	157	87 to 89	158	27.0 to 27.2	159	B	160	A
161	D	162	C	163	605 to 607	164	216 to 220	165	20 to 22
166	274 to 282	167	18.0 to 19.5	168	2.35 to 2.50	169	B	170	B, C, D
171	5.7 to 6.0	172	51.5 to 52.6	173	B	174	B, D	175	545 to 555
176	6 or greater than 6	177	C	178	B	179	D	180	A, B
181	4800 to 4900	182	C	183	0.57 to 0.60	184	15948 to 16048	185	16 to 16
186	A	187	A	188	C	189	A	190	75000 to 75000
191	A	192	A	193	A, C	194	A, C	195	2500 to 2600
196	230 to 240								

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