AE 2203 Propulsion and Power

TU Delft

Faculty of Aerospace Engineering

1. Please fill in the answers on the answer sheet. Also the calculation sheets have to be handed in.
2. The grade will be determined on both the answers and calculations.
3. Please fill in your name and student number on both the answer sheet and calculation sheets.
4. Except from the included formula sheet, it is not allowed to use other information!
5. Please fill in the correct answers for tasks in the correct space provided in the answer sheets.
6. Please write the answers clearly. Unclear calculations/answers will be considered as wrong answers.
7. Make appropriate assumptions if required. Specify these assumptions boldly in your answer sheets.
8. ***All the tasks should be handed in on separate sheets.***
9. ***Please note that the values of constants and the formulas are provided at the end of this question paper.***

Please observe the above mentioned rules carefully. Non compliance can result in lower or no grade!

TASK-I

Q1. Adding an afterburner in a turbojet engine results in the increase of *(1 mark)*

a). Thermal efficiency
b). Turbine efficiency
c). Specific mass flow rate
d). Specific thrust
e). None of the above

Q2. The commonly used combined cycle power plants for commercial electricity generation consists *(1 mark)*

a). A combination of Otto cycle and sterling cycle
b). A combination of Otto cycle and Diesel cycle
c). A combination of Brayton cycle and Rankine cycle
d). A combination of Sterling cycle and Rankine cycle
e). A combination of Ranking cycle and Otto cycle

Q3. What effect does high ambient temperature have on the performance of a gas turbine engine? *(1 mark)*

a). The thrust will be reduced as a result of a decrease in air density
b). The thrust will remain unchanged as a result of unchanged compression of the air
c). The thrust will remain the same, because of the increase in air pressure
d). The thrust will increase due to increased turbine temperature, by which the gases have more energy when leaving the turbine section
e). The thrust will reduce due to increase in air density

Q4. The ideal Otto Cycle consists of *(1 mark)*

a). isentropic compression, constant volume combustion, isentropic expansion and constant pressure heat rejection
b). isentropic compression, constant pressure combustion, isentropic expansion and constant volume heat rejection
c). isentropic compression, constant pressure combustion, isentropic expansion and constant pressure heat rejection
d). isentropic compression, constant volume combustion, isentropic expansion and constant volume heat rejection
e). isothermal compression, constant volume combustion, isothermal expansion and constant volume heat rejection

Q5. Balance the equation $C_nH_m + X(O_2 + 3.78N_2) \rightarrow CO_2 + H_2O + N_2$ For complete combustion, the value of X is *(1 mark)*

a). $\left(n+\frac{m}{4}\right)$
b). $\left(m+\frac{n}{4}\right)$
c). $\left(n+\frac{m}{2}\right)$
d). $\left(\frac{m+n}{4}\right)$
e). $\left(\frac{m+n}{2}\right)$

Q6. A decrease in the isentropic efficiency of an unchoked turbojet engine nozzle will lead to the following *(1 mark)*

a). Decrease in the nozzle exit temperature
b). Decrease in the nozzle exit pressure
c). Increase in the nozzle exit temperature
d). Increase in the nozzle exit pressure
e). None of the above

Q7.The Combustion stability is often described by a range of fuel-to-air ratios that dictates the stability loop (shown in the adjoining Figure-1). Which of the following is true? *(1 mark)*

a). The stability increases with increase in mass flow rate
b). The stability decrease with increase in temperature
c). The stability increases with increase in pressure
d). The stability decreases with increase in pressure
e). The stability increases with decrease in temperature

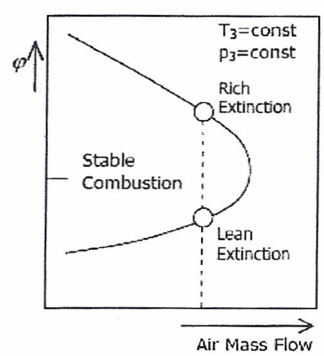


Figure.1

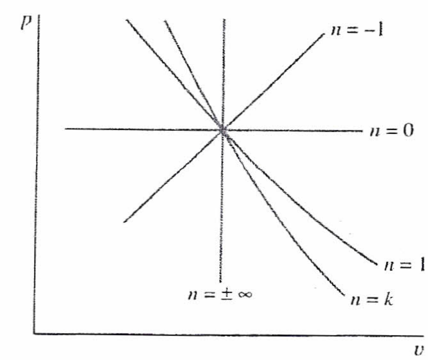


Figure.2

Q8. For the processes shown in figure-2, 'n=± ∞' represents *(1 mark)*
a). Isobaric process
b). Isochoric process
c). Isentropic process
d). Isothermal process
e). Explosion

Q9.In a conventional gas turbine combustor only a part of the flow entering the combustor is directed into the primary zone. The reason for this is *(1 mark)*
a). The primary zone is too small to handle all the flow entering the combustion chamber
b). The pressure losses would be high if all the flow goes into the primary zone
c). To increase the equivalence ratio in the primary zone to near stiochiometry
d). A part of the flow is burnt in the secondary zone
e). None of the above

Q10. CO2 is a green house gas because *(1 mark)*
a). Under high pressure CO2 appears green
b). CO2 absorbs radiation at all wavelength
c). CO2 absorbs UV radiation
d). CO2 is transparent to radiation at long wavelength but absorbs radiation only at short wavelength
e). CO2 is transparent to radiation at short wavelength but absorbs radiation only at long wavelength

Q11. The cryogenic main stage of the Ariane 5 launcher produces a thrust of 1150 kN. At one point in its trajectory, the rocket flies with a velocity of Mach 1.5 (velocity of sound = 300 m/s). The mass flow rate of propellant is 280 kg/s. What is the jet power produced by this engine at this point in flight? *(1.5 marks)*

a) 2.36 GW
b) 236 MW
c) 1.87 GW
d) 18.7 MW
e) 3.74 GW

Q12. A rocket motor uses hydrogen as the propellant. Molar mass is 2 gram/mol and specific heat ratio is 1.4. The hydrogen is heated at a pressure of 69 bar to a temperature of 3000 K. Given that the rocket attains optimum expansion at an atmospheric pressure of 0.1 bar, determine for this rocket the true exhaust velocity in vacuum. *(1.5 marks)*

a) Cannot be calculated using the given data
b) 8591 m/s
c) 6783 m/s
d) 4834 m/s
e) 3907 m/s

Q13. A rocket engine uses JP4 and oxygen as the propellants at an oxidizer to fuel mass mixture ratio of 2.25. The heating value (HV) of JP-4 is 20 MJ/kg. Specific heat at constant pressure (c_p) of the combustion products is 2000 J/kg-K. Determine for this rocket motor the final temperature of the combustion mixture given that the initial temperature is 300 K. *(1.5 marks)*

a) 1000 K
b) 10,000 K
c) 3377 K
d) 3037 K
e) 10,300 K

Q14. An ion engine uses Argon gas with a molecular mass of 40 as propellant. Determine the exhaust velocity that can be achieved for an accelerating potential difference of 4500 Volt given that the Argon molecules are singly ionized only? *(1.5 marks)*

a) 69.3 km/s
b) 147.2 km/s
c) 90.87 km/s
d) 120.2km/s
e) 41.5 km/s

Q15. The energy density of Jet A-1 is 43.2 MJ/kg. To provide 1500 kVA with a Power Factor (PF) of 85%, calculate the amount of fuel needed for a mission duration of 6 hrs in case the efficiency of power conversion is 35%. *(1.5 marks)*

a) 3248 kg
b) 2794 kg
c) 2521 kg
d) 2322 kg
e) 1821 kg

Q16. Which of the following statements are true: *(1.5 marks)*

1. A shunt regulator is connected in series with a solar array
2. A transformer converts an AC voltage into another AC voltage
3. A TRU converts DC into AC
4. A TEC is a device to convert thermal power into electric power

a) 1 and 3 are true
b) 1, 2 and 4 are true
c) 2 and 4 are true
d) 1, 3 and 4 are true
e) 2 and 3 are true

Q17. Which of the following statements are true: *(1.5 marks)*

1. Efficiency of the Brayton cycle is in excess of the Carnot efficiency
2. Power in kVA is power in Watts divided by the power factor (PF)
3. Fuel cell capacity doubles when placing two identical fuel cells in parallel
4. Capacitance of two identical capacitors in series doubles

a) All are true
b) None are true
c) 2 and 4 are true
d) 2, 3 and 4 are true
e) 2 and 3 are true

Q18. A single-phase AC generator running at 1200 rpm has 6 poles. What is the output frequency of the generator? *(1.5 marks)*

a) 50 Hz
b) 60 Hz
c) 120 Hz
d) 600 Hz
e) 3770 Hz

Q19. A vehicle is equipped with a solar array to support a 1500 W load. *(1.5 marks)*
Given:

• Solar cell material:	Silicon
• Cell voltage:	0.5 V
• Cell size:	2cm x 4cm
• Packing factor:	90%
• Solar cell efficiency:	11.5%
• Solar intensity:	500 W/m^2
• Lifetime degradation:	15% (EOL)

The total number of solar cells required is …:

a) 3750 cells
b) 9288 cells
c) 15536 cells
d) 38370 cells
e) 84626 cells

Q20. A secondary battery is required to provide a constant load of 1500 Watts for 45 minutes. For this battery are given the following design parameters *(1.5 marks)*

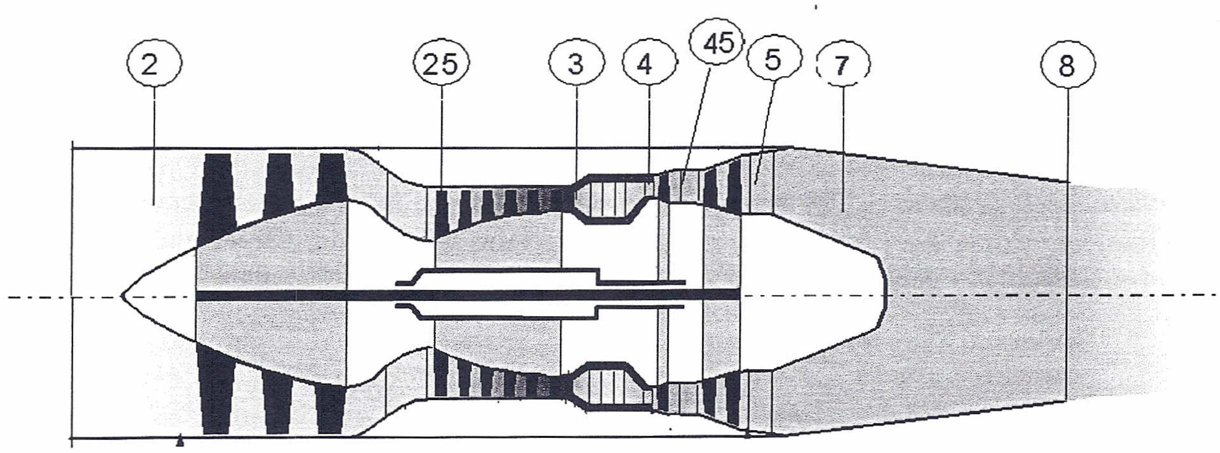
- Constant bus voltage of 28 volts
- 30% Depth of Discharge
- Battery efficiency: 90%
- Nickel-hydrogen batteries using cells with a minimum cell voltage (EoD) of 1.2 Volts and 1.35 Volts when fully charged.

Determine for this battery the required cell capacity in Ah.

a) 2.7 Ah
b) 6.0 Ah
c) 55.3 Ah
d) 116.9 Ah
e) 139.2 Ah

TASK-2 (15 marks)

A twin spool turbojet engine is shown in the figure below.



General characteristics at ISA take off conditions

Type: Twin spool turbojet Engine
Intake Pressure ratio= 0.9 (at take off)
Engine Air Mass flow rate = 100 kg/s
LPC Pressure Ratio = 3.5
HPC Pressure Ratio = 5.0
Mechanical efficiency = 0.99
Combustor Exit Temperature (T4) = 1400K
Main combustor efficiency = 0.98
Combustion chamber pressure ratio =0.97
Nozzle= Convergent
Nozzle efficiency = 0.95
LPC & HPC isentropic efficiency = 0.8
LPT & HPT isentropic efficiency = 0.85
CP air = 1000; *kappa air* = 1.4
CPgas = 1150; *kappa gas* = 1.33
Gas constant= 287 J/kg K
Fuel calorific value (LHV) = 43.0 MJ /kg
Ambient Pressure = 101325 Pa
Ambient Temperature = 288K

Station Numbers	
0	Ambient/ undisturbed
1	Aircraft-engine interface/ inlet face
2	LPC inlet
25	High-pressure compressor inlet
3	High pressure compressor exit
4	Burner exit
45	HPT Exit
5	LPT Exit
7	Nozzle Inlet
8	Nozzle Exit

Q1:- Calculate the pressure and temperature at each of the following stations "2", "25", "3", "4", "45", "5", "7", and "8". *(8 marks)*

Q2:- Calculate the fuel flow rate *(1 marks)*

Q3:- Evaluate if the nozzle is choked *(1 marks)*

Q4:- Calculate the total takeoff thrust *(3 marks)*

Q5:- Draw the cycle on the TS diagram *(2 marks)*

TASK-3 **(10 marks)**

A liquid propellant rocket motor using a JP-4/RFNA propellant combination must produce 19.6kN of thrust at sea level. The characteristics of the combustion products are combustion chamber temperature T_c=3000K, average specific heat ratio γ=1.2, molecular weight W=27, and chamber pressure p_c=19.34 atmospheres. For this motor, we have optimum expansion at sea level. Calculate:

(a) Effective exhaust velocity v_{eff} and specific impulse at sea level; *(2.5 marks)*
(b) Characteristic velocity c^* and propellant flow rate m; *(2.5 marks)*
(c) Throat and exit areas, A_t and A_e; *(3.5 marks)*
(d) Thrust developed at an altitude of 11.5km where the pressure is p_0=0.2 atmospheres. *(1.5 marks)*