The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, SPRING SEMESTER 2019-2020

THERMODYNAMICS AND FLUID MECHANICS 2

Time allowed AS PER SUBMISSION DEADLINE PUBLISHED ON MOODLE

Open-book take-home examination

Answer ALL questions in Section A, TWO questions in Section B, and TWO questions in Section C

You must submit a single pdf document, produced in accordance with the guidelines provided on take-home examinations, that contains all of the work that you wish to have marked for this open-book examination. Your submission file should be named in the format '[Student ID]_[Module Code].pdf*'.*

Write your student ID number at the top of each page of your answers.

This work must be carried out and submitted as described on the Moodle page for this module. All work should have been submitted via Moodle by the due date.
Work submitted after the deadline will be subject to penalty.

No teaching enquiries will be answered by staff during the assessment period Monday 18th May to Friday 12th June 2020 and no questions should be raised by students. If you believe there is a misprint note it in your submission and answer the question as written. Contact SS-Programmes-UPE@exmail.nottingham.ac.uk *for any support.*

***Plagiarism, false authorship and collusion are serious academic offences** as defined in the University's Academic Misconduct Policy and will be dealt with in accordance with the University's Academic Misconduct Procedures. The work submitted by students must be their own and you must declare that you understand the meaning of academic misconduct and have not engaged in it during the production of your work.*

This paper consists of THREE sections. Answer ALL of Section A, which is worth a total of 48 marks. Answer TWO out of THREE questions in Section B, and TWO out of THREE questions in Section C, each question in these sections is worth 13 marks. If a candidate answers more than the required number of questions, all questions will be marked and the highest marks will be used in the final mark.

ADDITIONAL MATERIAL: Five printed sheets of formulae
Thermodynamic Properties of Fluids & other data (in S.I. units, 5th edition)
Enthalpy-Entropy chart – A3 sized photocopy

SECTION A

Answer ALL questions in this section

1. For dry air at 400 K state thermal conductivity in the units of W/m K, the specific heat capacity at constant pressure, the density and the dynamic viscosity. [4]

2. For a vapour compression refrigeration cycle using a typical refrigerant, such as R134a, describe, in no more than 200 words, the role of the throttle. Include in your answer the description of the change through the throttle and what condition the refrigerant is expected at the beginning and end regarding saturation conditions and dryness fraction. Any words over the 200 word limit will not be considered. [4]

3. Biogas is a mixture of 70% Methane (CH_4) and 30% carbon dioxide (CO_2). Calculate the equivalent molar mass and specific heat at constant pressure. Hence find the specific heat at constant volume and the specific gas constant of the biogas. [4]

   Given data of the individual gases:
   molar mass: CH_4 16 kg/kmol; CO_2 44 kg/kmol;
   specific heat at constant pressure c_p: CH_4 2.226 kJ/kg K; CO_2 0.846 kJ/kg K.

   The universal gas constant is 8.3145 kJ/kmol K.

4. A Power plant operates on an ideal Rankine cycle with superheat. Sketch a T-s diagram of the process, naming the devices used in the cycle on the T-s diagram according to the following numbering: 1-2 water pump, 2-3 boiler and superheater, 3-4 turbine, 4-1 condenser heat exchanger. [4]

5. In heat transfer analysis, Reynolds number, Prandtl number and Grashof number are three important non-dimensional numbers. State which two of them are of significant importance in natural convection heat transfer and which one is not, and briefly explain why. A word limit of 100 words is required, any further words will not be considered. [4]

6. Describe how a two stage gas compression process might be improved by using intercooling. Use a diagram to illustrate your answer. A word limit of 100 words is required, any further words will not be considered. [4]

7. A thin flat plate of 2 metre length and 0.5 metre width is mounted parallel to a free stream of air in a wind tunnel, the free stream velocity is fixed to 50 m/s. Take ρ = 1.2 kg/m^3 and μ =1.8x10^{-5} kg/m s. Evaluate the drag force exerted on the plate assuming:

(a) Turbulent flow from the leading edge. [2]

(b) Laminar turbulent flow with $Re_{trans} = 3 \times 10^6$. Use Schlichting's formula for the drag coefficient:

$$C_D = \frac{0.031}{Re_L^{1/7}} - \frac{8700}{Re_L}$$

[2]

8. For the boundary layer thickness δ we can write the following general functional relationship:

δ = *f* (x, ρ, μ, V)

State how many pi groups are needed to study this problem experimentally. [4]

9. An object is moving at a velocity V equal to 680 m/s in air. The speed of sound in air, c, is equal to 340 m/s. Calculate the angle of Mach cone. [4]

10. Consider the two-dimensional momentum equation for an incompressible flow of a Newtonian fluid, along the y direction.

$$\mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) = \frac{\partial p}{\partial y} + \rho\left[\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right]$$

Write down what three forces each of the terms in this equation describe. [4]

11. An aircraft is cruising at a constant speed of 200 m/s. The engine is providing a thrust of 200000 N, the planform area of the wings is 100 m^2, and the density of the fluid in which the flight takes place is 1 kg/m^3. Assuming that the aircraft drag is generated only by the wings, calculate the drag coefficient of the wings. [4]

12. State and sketch the three main types of centrifugal pumps. [4]

SECTION B

Answer TWO questions from this section

13. A cube-shaped box of side $L = 30$ cm and mass $m = 20$ kg is dropped by an airplane from an altitude of $1{,}000$ m. For the surrounding air, you can assume a constant temperature of $T = 273$ K, density $\rho = 1.29$ kg/m^3, dynamic viscosity $\mu = 1.71 \times 10^{-5}$ kg/m s. Other parameters have standard values unless stated otherwise.

(a) Name the two forces acting on the box at free-fall. [2]

(b) The box falls as indicated in Fig. Q13(a). Calculate the terminal free-fall speed of the box (terminal: when all the forces acting on the box are in equilibrium). You can use the data in Table Q13. [6]

(c) In order to reduce the speed of the box, a parachute is attached to it, as depicted in Fig. 13(b), with d being the diameter of the parachute. Calculate what this diameter should be, in order to limit the terminal speed of the box to $U = 10$ m/s. The weight of the parachute is negligible. You can assume that the box does not disturb the flow of air impacting the parachute. You can use the data in Table T13 (on next page). [5]

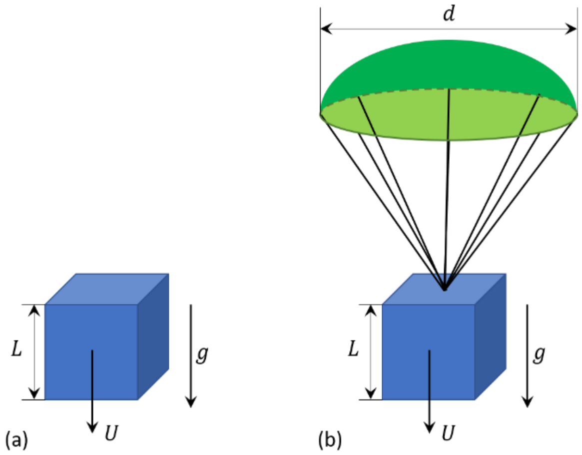

Figure Q13

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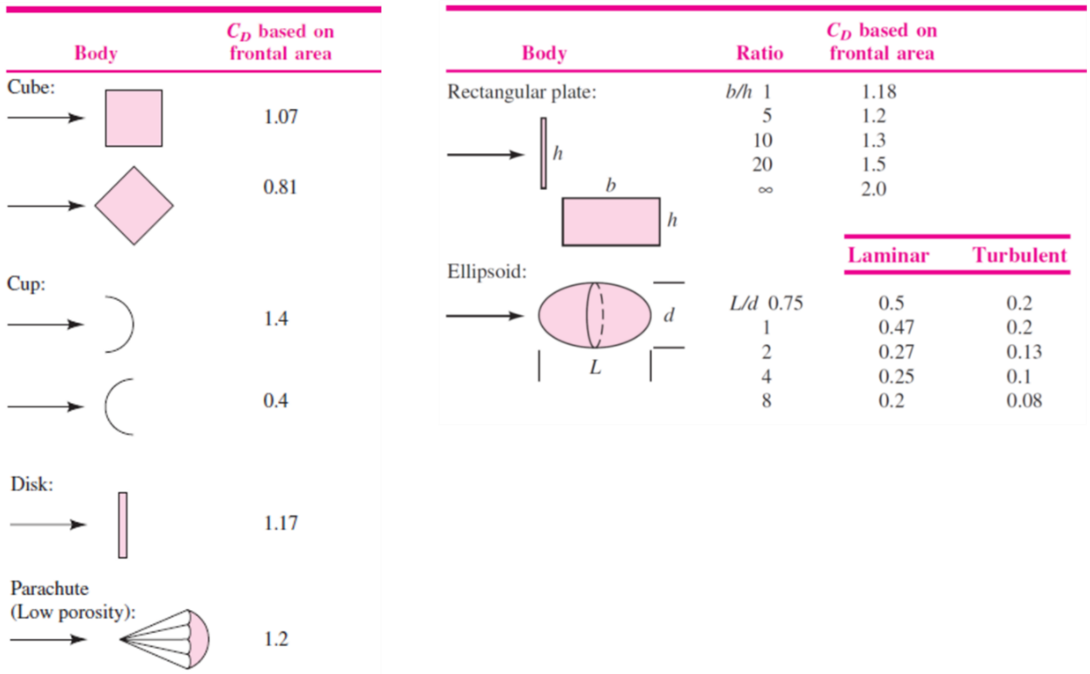

Drag of Three-Dimensional Bodies at $Re \geq 10^4$

Body	C_D based on frontal area
Cube: (face to flow)	1.07
Cube: (edge to flow)	0.81
Cup: (open side away from flow)	1.4
Cup: (open side facing flow)	0.4
Disk:	1.17
Parachute (Low porosity):	1.2

Body	Ratio	C_D based on frontal area
Rectangular plate:	b/h 1	1.18
	5	1.2
	10	1.3
	20	1.5
	∞	2.0

Body	Ratio	Laminar	Turbulent
Ellipsoid:	L/d 0.75	0.5	0.2
	1	0.47	0.2
	2	0.27	0.13
	4	0.25	0.1
	8	0.2	0.08

Table Q13 from White, Fluid Mechanics.

14. A thin rectangular plate having a height h and a width w is immersed in a fluid and it is moving at a velocity V in the fluid. Assume the force F that the fluid exerts on the plate is a function of h and w, the fluid density ρ and the fluid dynamic viscosity μ, and the velocity V. Determine the pi-groups involved in this problem. [13]

15. The air at the exhaust of a turbine has stagnation pressure and temperature of P_0 = 200 kPa and T_0 = 500 K, and it has to be expanded through a circular cross-section sonic convergent-divergent nozzle when operating at the maximum mass flow rate. The exit Mach number is 2.5. The capacity coefficient of the turbine is 0.1. The turbine is rotating at n = 1000 rad/sec and its diameter D is 0.5 m. Assuming isentropic flow with γ = 1.4 calculate:

(a) Mass flow rate. [4]
(b) Throat diameter. [3]
(c) Exit pressure. [4]
(d) Exit temperature. [2]

SECTION C

Answer TWO questions from this section

16. (a) A gaseous cooking fuel consists of 60 % propane (C_3H_8) and 40% butane (C_4H_{10}) by volume. The stoichiometric reaction with oxygen is:

$$0.6C_3H_8 + 0.4C_4H_4 + 5O_2 \rightarrow 3.4CO_2 + 3.2H_2O$$

The gas is burned with a 15% excess air.

i) Write down the actual 15% excess air combustion reaction equation and calculate the air to fuel ratio by volume. [5]

ii) Find the wet and dry volumetric analysis of the product gases of the actual reaction. [2]

(b) A power plant working with Rankine cycle circulates steam at a rate of 50 kg/s. Steam enters a high pressure turbine at a pressure of 100 bar and a temperature of 500 °C, and exits the turbine at 10 bar. The isentropic efficiency of the turbine is 85%.

i) Plot the high pressure turbine expansion process on the given h-s chart, showing the isentropic and the real process, stating the value of the specific enthalpy at turbine entry and turbine exit. [3]

ii) Calculate the turbine power generated and the thermal efficiency given that the external heat input is 160 MW. [3]

17. (a) A reciprocating air compressor has intake at 1 bar and 25°C. It compresses the air to 16 bar in two stages of compression. The polytropic index of the compression process is 1.3 and the mass flow rate is 0.05 kg/s. Assume the gas constant for air, R, is 0.287 kJ/kgK and the specific heat capacity at constant volume, c_v, is 0.718 kJ/kgK.

i) Calculate the ideal intermediate pressure for minimum work. [2]

ii) Using the steady flow polytropic process work formula calculate the work done in the first stage only. [4]

(b) Atmospheric air at 1 bar enters an air conditioning unit with 70% relative humidity at 25 °C. The mass flow rate of the air is 0.15 kg/s.

i) Calculate the partial pressure of the water vapour, p_s, in the air and find the dew point of the air. [4]

ii) Use the value of p_s just calculated to calculate the specific humidity, ω, of the air, and hence calculate the water vapour mass flow rate in the air. [3]

18. (a) The radiator in a domestic dwelling is a vertical flat plate with height 0.5 m and a surface temperature of 45 °C when the room temperature is 9°C. The Nusselt number correlation for a flat plate is:

$$\mathrm{Nu} = 0.59(\mathrm{GrPr})^{0.25}$$

when the product GrPr is between 10^3 and 10^9.

i) Verify that the Nusselt number correlation is valid based on the condition stated. [4]

ii) Calculate the heat transfer coefficient. [2]

(b) A two shell passes and 10 tube passes counter flow heat exchanger is shown in Figure Q18b. Hot oil enters the shell at a rate of 0.25 kg/s and a temperature of 150°C and water passes through the tubes at a rate of 0.15 kg/s with a temperature of 15°C at the inlet. The heat exchanger tubes have a wall surface area of 2.12 m^2.

The specific heat capacity of water is 4.18 kJ/kg K and of oil is 2.20kJ/kg K and the overall heat transfer coefficient of the heat exchanger is 350W/m^2 K.

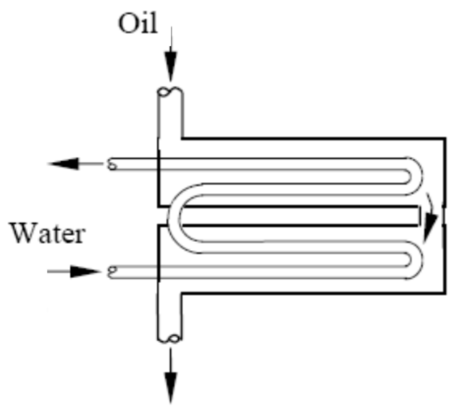

Figure Q 18b

i) Find the capacity rates of the two fluid flows and determine the minimum capacity rate and hence the number of transfer units for the heat exchanger. [4]

ii) Given the effectiveness of the heat exchanger is 0.58, calculate the actual heat transfer in the heat exchanger. [3]