The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, AUTUMN SEMESTER 2020-2021

THERMODYNAMICS AND FLUID MECHANICS 2

Time allowed TWENTY-FOUR hours

Open-book take-home examination

Answer ALL questions

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]_MMME2047.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 must be submitted via Moodle by the submission deadline. ***Work submitted after the deadline will not be accepted without a valid EC.***

No teaching enquiries will be answered by staff during the assessment period Monday 11 January to Friday 29 January 2021 and no questions should be raised by students. If you believe there is a misprint, note it in your submission but 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 6 thermodynamics questions and 6 fluid mechanics questions. Each question is worth 4 marks Answer all questions.

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

1. 50 grams of Water is contained in a 1 m^3 rigid cylinder at 30°C.

   (a) What is the pressure and the specific volume of the vapor in the cylinder? [2]

   (b) What will be the mass of the vapor alone if we neglected the volume of the liquid water? And what is the quality of the mixture? [2]

2. What will be the temperature and pressure inside the cylinder of Question 1 if the cylinder is heated until all the water is 100% saturated steam? [4]

3. Atmospheric air at 1.015 bar and of 80% relative humidity and a temperature of 30°C is flowing into an air conditioning duct at a volume flow rate of 1.5 m^3/s. It is required to deliver this air into a room at a condition of 24°C and 50% relative humidity. The mass flow rate of the dry air is 1.75 $kg \cdot s^{-1}$.

   (a) Calculate the specific humidity at inlet. [2]

   (b) Given the mass flow of vapour in the vapour in air at outlet is 0.0093 $kg \cdot kg^{-1}$, calculate the mass flow rate of condensate. [2]

4. A heat pump is to be used for cooling a certain space using R134A as a refrigerant, assuming the compressor is isentropic, and that the evaporator exit has 5°C superheat and the condenser has 7°C subcooling.

   (a) State the required pressure of the refrigerant in each of the condenser and the evaporator if a temperature of each is 50°C and -10°C respectively? [2]

   (b) Use the chart to find the enthalpy change across the evaporator and hence the mass flow rate of the refrigerant required in the system if heat is to be removed from the room at a rate of 3 kW? You may include your plotted chart in the answer. [2]

5. Steam enters a turbine at 40 bar and 500°C and leaves at 10 bar. The mass flow rate of the steam is 20 $kg \cdot s^{-1}$ and the isentropic efficiency of the steam turbine is 94%. Calculate the power output of the turbine using the data tables. [4]

Air compressors are not included in the January exam for 2022

6. A reciprocating air compressor has a piston diameter 0.1 m and stroke 0.1 m, and the clearance volume is 10% of the stroke volume. The polytropic coefficient of the compression and expansion strokes is 1.2, the outflow pressure is 10 bar. Calculate the mass flow rate for the speed of 180 strokes per minute, and comment on the outcome of the performance you see. The ingoing air is at 1 bar and 288 K. [4]

There are only 5 fluids questions and 5 thermodynamics questions on the January 2023 exam

7. Consider the following vector field representing a steady-state velocity field in two dimensions:

$$\boldsymbol{V}(x,y) = \left(x^2y + ax^by^c\right)\hat{\boldsymbol{\imath}} + (y - xy^2)\hat{\boldsymbol{\jmath}}$$

Find the values of the parameters *a, b, c*, that ensure that the velocity field represents an incompressible flow. [4]

8. Consider the incompressible two-dimensional flow of a Newtonian fluid in the following conditions:

- the fluid flows between two horizontal, parallel, infinitely extended walls, with the bottom wall being stationary and the top wall translating with speed U_w in the positive x direction, see the Figure Q8 below;
- the flow is steady-state;
- we are considering a section of the duct far from the inlet, and thus the streamlines of the flow are horizontal;
- the flow is subjected to a constant streamwise pressure gradient $\partial p/\partial x$;
- the gravitational force on the flow is negligible.

Starting with the 2D incompressible Navier-Stokes equations, use the information above to produce the theoretical velocity profile in the duct, $u(y)$. Given the pressure gradient is 5 Pa·m^{-1}, the wall velocity is 0.5 m·s^{-1}, the plate separation is 10 mm and the viscosity of the fluid is 0.001 kg·m^{-1}·s^{-1}, calculate the velocity at y = 7 mm [4]

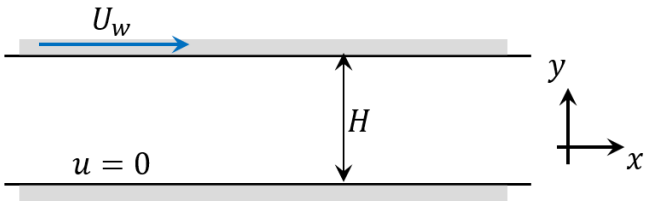

Figure Q8: Sketch of the flow configuration for Q8.

9. Water enters in a duct formed by the gap between two infinitely extended, stationary, parallel walls. Due to wall friction, a boundary layer starts developing on both walls, see the sketch in Figure Q9. Treating the top and bottom walls of the duct as two flat plates, and assuming that the flow is laminar, calculate the horizontal distance from the duct entrance, that it takes for the flow to become fully developed. Take the fluid properties of water as ρ=1000 kg·m^{-3}, μ=0.001 kg·m^{-1}s^{-1}), the flow speed before entering the duct is $U = 0.2$ m·s^{-1}, and the distance between the walls is $H = 1$ cm. [4]

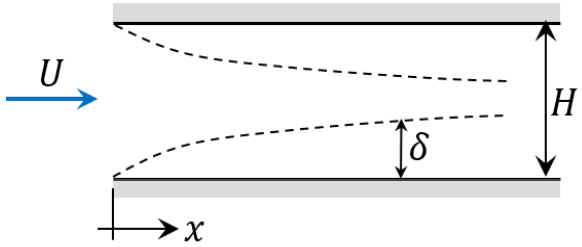

Figure Q9: Sketch of the flow configuration for Q9.

10. In Figure Q10 a visualization of a boundary layer over a flat plate is shown. Demonstrate using boundary layer theory, how an expression for the free stream velocity, U, of the fluid in which the plate is immersed can be estimated in terms of the boundary layer thickness, δ, at the end of the plate. [4]

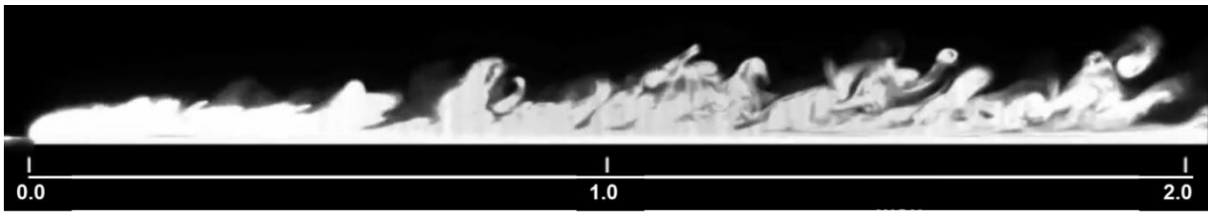

Figure Q10: visualization of a boundary layer on a flat plate by Lee J.H. et al. The University of Melbourne.

There is no dimensional analysis on the January 2023 exam

11. As a design engineer, you are required to study a wind turbine system. A model will be used in a wind tunnel to perform some experiments. The wind turbine is activated by the flow of air which impacts the blades; the blades will be rotating at a rotational speed N, and the turbine will generate power. The surface of the prototype wind turbine, is to be considered smooth. A sketch of the wind turbine is illustrated in Figure Q11. You are required to:

(a) List all the parameters that might be relevant for this problem. [3]

(b) State the number of dimensionless groups that it is possible to derive. [1]

There is no dimensional analysis on the January 2023 exam

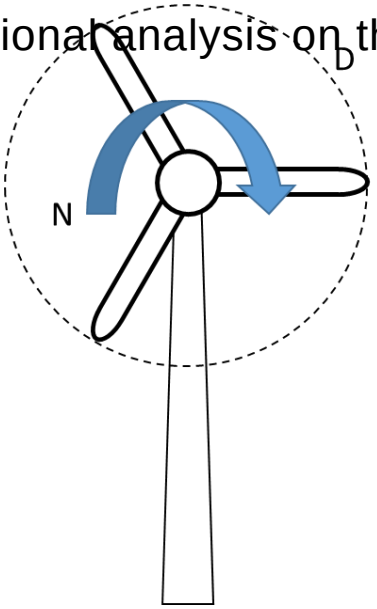

Figure Q11

There is no dimensional analysis on the January 2023 exam

12. A flow situation is subjected to Buckingham Pi analysis, and the variables affecting the flow are density, ρ, gravity, g, length, L, velocity, U, dynamic viscosity, μ and surface area, A. With ρ, L, U as repeating variables, find the dimensionless group related to g and state its relevance. [4]

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