The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, SPRING SEMESTER 2020-2021

THERMODYNAMICS AND FLUID MECHANICS 2

Time allowed TWO hours plus 30 minutes upload period

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 academic enquiries will be answered by staff and no amendments to papers will be issued during the examination. If you believe there is a misprint, note it in your submission but answer the question as written.
Contact your Module Teams Channel or SS-AssessEng-UPE@exmail.nottingham.ac.uk for support as indicated in your training.

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 2 thermodynamics questions and 2 fluid mechanics questions. Each question is worth 13 marks Answer all questions.

ADDITIONAL MATERIAL: Five printed sheets of formulae
Selected pages from Thermodynamic Properties of Fluids & other data (in S.I. units, 5th edition)

Part A: Thermodynamics

1. A gas stove is fuelled with butane gas (C_4H_{10}), and the gas is burned with a 15% excess air.

   (a) Write down the balanced 15% excess air combustion reaction equation, including the nitrogen from the air, and find the actual air fuel ratio by volume and by mass. [4]

   (b) Find the mass proportions of the dry products of combustion. [6]

   (c) From your existing calculations, identify the apparent molar mass of the gas mixture, and describe how you would find the gas mixture specific heat capacity at constant pressure. [3]

2. (a) A domestic radiator depends for part of its heat transfer to the environment upon natural convection heat transfer. Describe the nature of the velocity boundary layer and the temperature boundary layer on the surface of the radiator as the height increases and explain what it is about the physics of natural convection that leads to the two forms of the Nusselt number correlation for a flat plate:

$$Nu = 0.59(GrPr)^{0.25} \text{ For } 10^3 < GrPr < 10^9 \text{, and:}$$

$$Nu = 0.13(GrPr)^{0.33} \text{ For } 10^9 < GrPr < 10^{12}.$$

[3]

   (b) Explain why is it that a fluid with high Prandtl number would cause difficulties for a heat exchanger. [2]

Continued on next page

(c) A radiator, indicated in Figure Q2, has a surface temperature which may be regarded as uniform across the surface of 60°C. The air temperature far from the radiator when the heating is started is 15°C. Use the Nusselt number correlations in part a) to calculate the heat transfer coefficient and the heat transfer from one side of the radiator. Use tables p. 16 for the properties of air. [8]

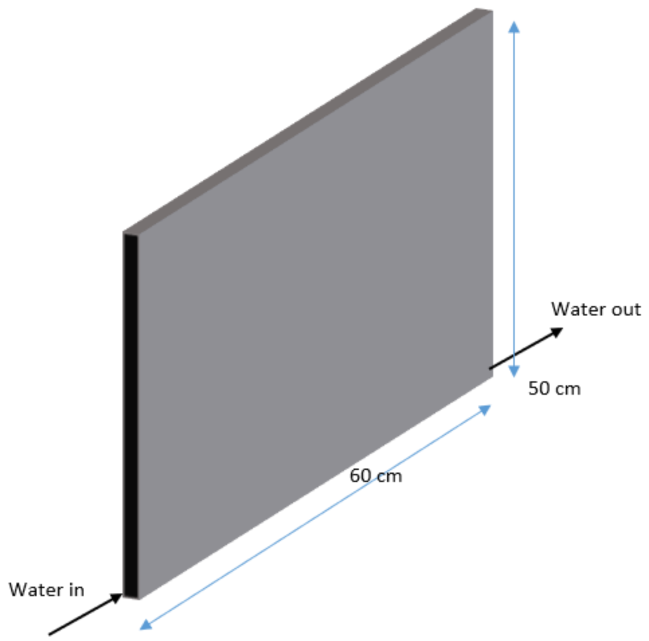


Figure Q2

Part B: Fluid Mechanics

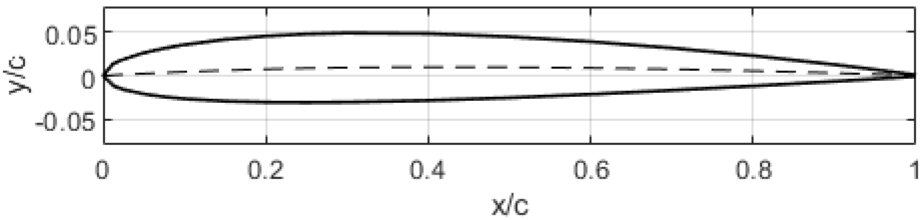
3. A powered glider employs NACA1408 airfoils, of chord length $c = 0.4\,m$ and total wingspan of $b = 20\,m$. Figure Q3(a) shows the profile of the airfoil and Q3(b) shows the plot of the lift coefficient versus angle of attack for three different values of the Reynolds number.

(a) Calculate the maximum thickness of the airfoil and report it in meter units. [2]

(b) The glider travels at a cruise speed of $U = 180\,km \cdot h^{-1}$ at an altitude of 4000 m (air density $\rho = 0.822\,kg \cdot m^{-3}$ and kinematic viscosity $\nu = 2 \cdot 10^{-5}\,m^2 \cdot s^{-1}$). Calculate the angle of attack of the airfoil for the glider to fly in steady horizontal conditions, given that its mass is 850 kg. Other parameters have standard values unless stated otherwise. [7]

(c) At the same speed and altitude, what is the maximum mass of the glider that the airfoils can sustain? With which angle of attack? [4]

(a)



(b)

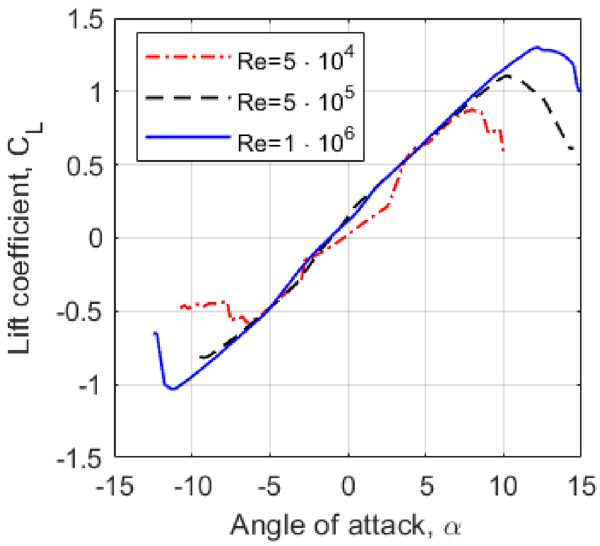


Figure Q3 (a) shows the profile of a NACA1408 airfoil; (b) shows the lift coefficient of this airfoil as a function of the angle of attack, for different values of the Reynolds number.

4. A converging-diverging nozzle, see schematic in Figure Q4, is used to accelerate the flow of a gas from subsonic inlet conditions to supersonic conditions. At the inlet section, denoted as section 1 in Figure Q4, the gas enters with $Ma_1 = 0.8$, temperature $T_1 = 600\,K$, density $\rho_1 = 5\,kg \cdot m^{-3}$; the nozzle has a circular cross-section and the inlet area is $A_1 = 0.05\,m^2$. The specific heat ratio is $\gamma = 1.4$ and the specific gas constant is $R = 287\,J \cdot kg^{-1}K^{-1}$. The flow is isoentropic and adiabatic through the nozzle.

(a) Determine the stagnation temperature and stagnation pressure of the gas at the inlet of the nozzle. [7]

(b) Calculate the diameter of the throat necessary to make the flow supersonic. [4]

(c) In order to achieve $Ma_2 = 2$ at the nozzle outlet, section 2 in Figure Q4, what must the area of the outlet section of the nozzle be? [2]

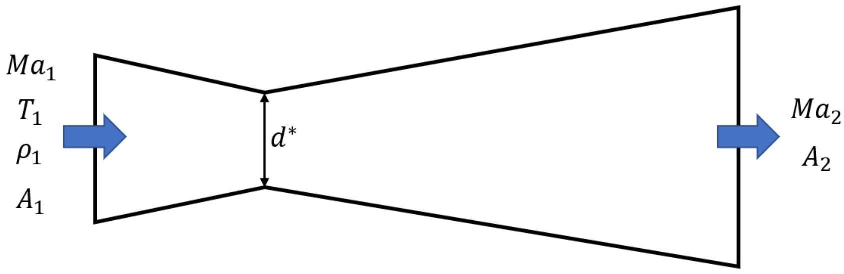


***Figure Q4**: Schematic of converging-diverging nozzle.*