

The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 3 MODULE, SPRING SEMESTER 2022-2023

THERMOFLUIDS 3

Time allowed TWO Hours and THIRTY Minutes

Candidates may complete the front cover of their answer book and sign their desk card but must NOT write anything else until the start of the examination period is announced

Answer ALL questions.

Only a calculator from approved list A may be used in this examination.

Basic Models	Scientific Calculators
Aurora HC133	Aurora AX-582
Casio HS-5D	Casio FX82 family
Deli – DL1654	Casio FX83 family
Sharp EL-233	Casio FX85 family
	Casio FX350 family
	Casio FX570 family
	Casio FX 991 family
	Sharp EL-531 family
	Texas Instruments TI-30 family
	Texas BA II+ family

Dictionaries are not allowed with one exception. Those whose first language is not English may use a standard translation dictionary to translate between that language and English provided that neither language is the subject of this examination. Subject specific translation dictionaries are not permitted.

No electronic devices capable of storing and retrieving text, including electronic dictionaries, may be used.

DO NOT turn examination paper over until instructed to do so

ADDITIONAL MATERIAL: Thermodynamic Properties of Fluids & other data (in S.I Units)
Formula sheet
A4 compressible flow charts

INFORMATION FOR INVIGILATORS:

Question papers should be collected in at the end of the exam – do not allow candidates to take copies from the exam room.

1. A high-speed wing travels at Mach 2 in air at temperature 260 K, as indicated in Figure Q1. Using the oblique shock chart provided, determine the most likely Mach number and temperature after the shock, stating the reason for any decisions you make. You may find the normal shock data provided for two ranges of M_1 , the ingoing Mach number, related to M_2 , the outgoing Mach number, and temperature ratio T_2/T_1 across the shock useful. [6]

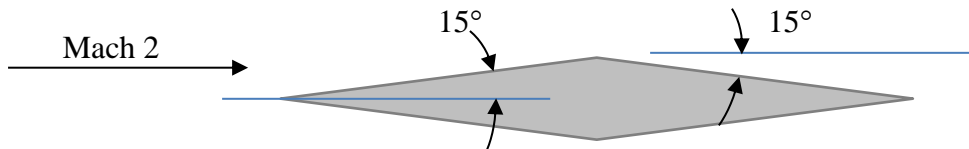


Figure Q1

Table Q1 selection of normal shock data

M_1	M_2	T_2/T_1	M_1	M_2	T_2/T_1
1.37	0.7527	1.2354	1.94	0.588	1.6394
1.38	0.7483	1.2418	1.95	0.5862	1.6473
1.39	0.744	1.2482	1.96	0.5844	1.6553
1.4	0.7397	1.2547	1.97	0.5826	1.6633
1.41	0.7355	1.2612	1.98	0.5808	1.6713
1.42	0.7314	1.2676	1.99	0.5791	1.6794
1.43	0.7274	1.2741	2	0.5774	1.6875

2. The flow over the wing in Figure Q1 continues until it reaches the point where the wing shape changes at mid section. Using the Prandtl-Meyer expansion chart provided, and initial Mach number 1.471, find the Mach number of the flow after the flow expansion at mid section. [3]

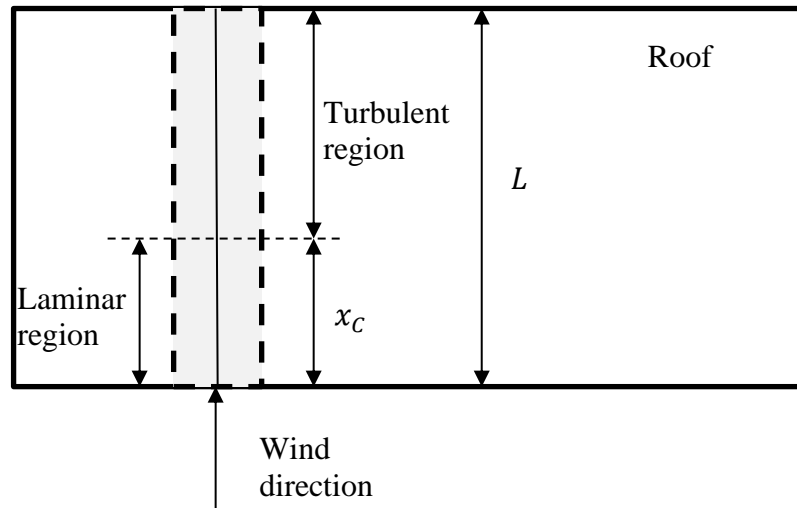


Figure Q3

3. The heat loss from the roof due to convection is determined by two correlations, depending on whether the flow on the roof is entirely laminar, or has become turbulent. These correlations are given in equations Q3a and Q3b. There are two definitions of the Reynolds number: one based on the length of the entire roof Re_L and one based on the distance to the transition to turbulence $Re_{x_c} = \frac{Ux_c}{\nu}$. The situation is summarised in Figure Q3.

The condition for laminar flow is $Re_{x_c} < 4000$.

- (a) If the roof is at 37°C and the air is at 17°C , what will be the air properties at the film temperature needed to calculate the heat transfer coefficient? [4]
- (b) If the air velocity is 1 m/s and the roof length is $L=10$ m in the direction of air flow, identify the distance x_c over which the flow is laminar and use this to identify which correlation to use. [3]
- (c) Using this correlation, estimate the heat transfer coefficient for this roof in these conditions. [7]
- (d) If it rained, then evaporation would occur on this flat roof which would evaporate by mass transfer. What will be an equivalent correlation for mass transfer in this situation? [2]

$$\overline{Nu}_L = 0.037 Re_L^{\frac{4}{5}} Pr^{\frac{1}{3}}, \quad x_c < L \text{ Turbulent flow} \quad \text{Equations Q3a}$$

$$\overline{Nu}_L = 0.66 Re_L^{\frac{1}{2}} Pr^{\frac{1}{3}}, \quad x_c \geq L \text{ Laminar flow} \quad \text{Equations Q3b}$$

4. (a) Use Hess's Law to verify that the reaction energy of ethene gas, C_2H_4 burning in oxygen is $-1,323,170$ kJ/kmol. The following data may be useful: formation enthalpy of C_2H_4 , O_2 , CO_2 and H_2O are $52,470$, 0 , $-393,520$ and $-241,830$ kJ/kmol respectively. [7]

- (b) Given that the natural logarithm of the equilibrium constant for the reaction:
 $CO + \frac{1}{2} O_2 \leftrightarrow CO_2$
 at 3000 K is 1.110 , what is the approximate proportion of reactants to products? [7]

5. You have a piece of electronic equipment which is overheating. You think that you can cool it more efficiently by adding pin fins to the surface of the system. You do some preliminary calculations, and it suggests that if you design the effectiveness (ϵ) of each of the fins to 10 , then the equipment will be kept at $T_b = 40^\circ C$. The air temperature is $T_a = 15^\circ C$.

- (a) The area where the fin is going to be located loses 0.1 W with no fin present. Calculate how many watts would be removed from that area if the fin was attached with $\epsilon = 10$. [1]

- (b) Due to physical constraints, the pin fin must have a radius of 1.5 mm so it has a cross sectional area of $A = 7.07$ mm², and cannot be longer than 40 mm. It will be made out of aluminium with a thermal conductivity of $k_{al} = 200$ W/mK. Using the heat flow through the base of the fin, what m -shape factor should the pin fin have? Assume the fin is long and that the equation $\theta(x) = \theta(0)e^{-mx}$ gives the temperature difference along the fin. [4]

- (c) Using this calculation, determine the heat transfer coefficient needed for this design to give $\epsilon = 10$. [3]

6. A turbine stage has blade angles $\beta_2 = 62^\circ$ and $\beta_3 = 77^\circ$, where the axial velocity component of the absolute velocity is 126 m/s and the blade velocity 314 m/s. The mass flow rate of the gas is 66 kg/s.

Sketch the combined velocity triangles for ingoing and exiting velocity in this stage indicating approximate velocity directions and the values of velocity magnitudes, both relative and absolute, derived from the above information. [5]

Calculate the work done in the stage using the Euler work equation,

$$\dot{W} = \dot{m}(U_3 c_{\theta 3} - U_2 c_{\theta 2})$$

in which U is the blade speed and c_θ is the tangential component of the absolute velocity. [5]

Explain the significance and influence of the terms in the Zweifel criterion,

$$\frac{s}{b} = \frac{0.4}{\cos^2 \alpha_2 (\tan \alpha_1 + \tan \alpha_2)}$$

in addressing velocity 'slip' at the trailing edge. [3]

7. Heat transfers through the wall of a steel tube with exterior temperature 500°C and interior temperature of 450°C at a rate of 120 kW/m^2 . The local ambient condition is 15°C and 1 bar. Calculate the rate of exergy loss due to this situation. [8]
8. A baked potato (B) is "suspended" in a grill. The top of the grill (A) is at 500 K , and the side walls (C) are insulated. The dimensions are given in the diagram in Figure Q8. Areas stated in the diagram are given by unit depth out of plane.

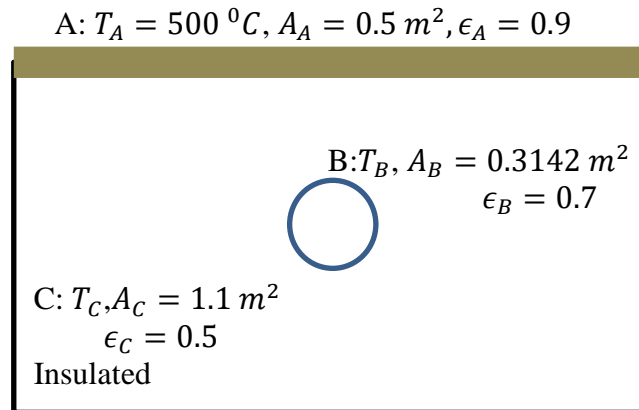


Figure Q8

- (a) If the view factor (F_{AB}) from A to B is 0.3, what are the other 8 view-factors in this configuration. For this calculation assume the grill has infinite length out of plane. [4]
- (b) Draw the resistance network for this situation and label it according to the nomenclature given here. Label the Resistances, the Radiosities and the black body potentials for full marks. [10]
9. A gas turbine has a compressor which delivers 30 kg/s of air at 10 bar and 1400°C to the first stage of the turbine cascade. The polytropic efficiency of the turbine is 90% , the mean properties of the gases as they progress through the turbine are: ratio of specific heat capacities, γ , is 1.33 ; mean specific heat capacity is 1.13 kJ/kgK . Calculate the turbine exhaust gas temperature when it exhausts at 1 bar , and the work output of the turbine. [10]
- The exhaust gases from the turbine are used in a heat recovery steam generator which has a steam pressure of 30 bar , an approach temperature 120°C lower than the turbine exhaust temperature, and a pinch temperature of 15°C . Calculate the flow rate of the steam generated. [8]

END