The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 3 MODULE, SPRING SEMESTER 2018-2019

Thermofluids 3 – Mock Exam

Time allowed 2 Hours

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 from Section A and ONE question from Section B

Only silent, self contained calculators with a Single-Line Display or Dual-Line Display are permitted in this examination.

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

In this examination candidates are required to answer ALL questions in Section A and one of the two questions in Section B. 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 examination mark.

ADDITIONAL MATERIAL: Tables of Thermodynamic and Transport Properties of Fluids

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.

Turn Over

1. State from the tables the value of Gibbs free energy for water vapour at 300K. In calculating the Equilibrium constant for reactions with water, what further consideration is required for the Gibbs free energy? [3]

2. Calculate the specific entropy of carbon dioxide at 600K and 20 bar. [3]

3. Briefly describe three implications of using organic Rankine cycles. [3]

4. Use the non-steady flow energy equation to derive an expression for the flow of superheated steam into an initially evacuated closed vessel. [3]

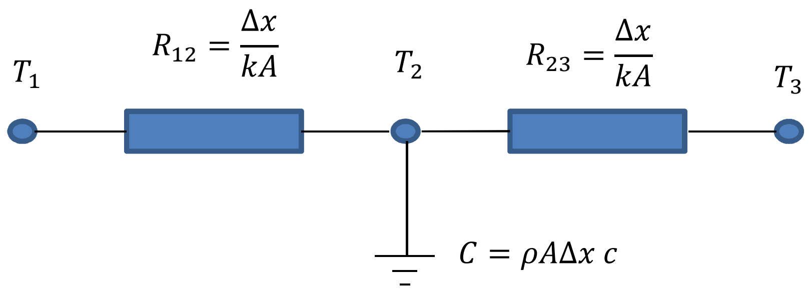
5. State two advantages of an Integrated Coal Gasification Combined Cycle Power Plant over a conventional coal-fired power plant. [3]

6. For radiation, define and explain the concept of the view factor and a diffuse surface. [4]

7. In my shower room, the water vapour in the air condenses on the cold mirror. If I wished to model the system as a mass transfer problem, what boundary conditions for the humidity should I set at the surface of the mirror? [3]

8. Fig Q5 shows the resistance network for internal nodes in an unsteady problem. Eq. Q5 shows the balance of energy in this resistance network.

Fig Q5



$$\frac{kA}{\Delta x}(T_1^0 - T_2^0) + \frac{kA}{\Delta x}(T_3^0 - T_2^0) = \rho A \Delta x c \frac{T_2^1 - T_2^0}{dt} \quad (Eq. Q8)$$

(a) Are we using the explicit or implicit solution of the differential equation? [2]

(b) Rearrange the equation in terms of the Fourier number and collect each temperature term. Show working. Marks are given for clarity of presentation. [3]

(c) What is the criteria for stability for this internal node? [2]

9. Biot number and Nusselt number are both in the form $\frac{hL}{k}$. What are their physical significance and emphasise the differences between these in terms of the variables employed? [4]

10. A vertically mounted panel on a wall is electrically heated to keep a room at constant temperature. The room is kept at 20^oC, and the panel is heated to a constant 84^oC. The panel has dimensions 1 meter in the horizontal direction and 0.5 m in the vertical direction. Using the thermodynamic tables to get air properties, Calculate the Rayleigh number for the flow and state if the flow is laminar ($Ra_L < 10^{13}$) or turbulent ($Ra_L > 10^{13}$). [8]

$$Ra_L = \frac{g\beta\left(T_p - T_\infty\right)L^3}{\alpha\nu}, \alpha = \frac{k}{\rho c} \quad Eq: Q10$$

11. For what conditions is the Reynolds analogy valid? [2]

12. What is the maximum size of computational cells you can use if you are numerically modelling transient heat transfer for the case of convection into a surface with thermal conductivity k=432W/mK and a heat transfer coefficient of h=50 W/m^{2}K and wish a stable solution? [3]

13. What is thermal contact resistance and explain how the use of “thermal greases, pastes or gels” improves the performance over those of air. Use a diagram. [4]

14. Briefly explain, with reference to the Euler work equation,

$\dot{W}_c = \dot{m}(U_2 c_{\theta 2} - U_1 c_{\theta 1})$,

why the absolute exit flow angle determines work on a rotor. [4]

15. Sketch the typical blade configuration and velocity triangles involved in an axial compressor stage. [3]

16. Sketch the situation of an oblique shock indicating the key angles involved. Using the chart in Figure Q16, determine the possible shock wave angles for a 10° wall at Mach 1.6. [6]

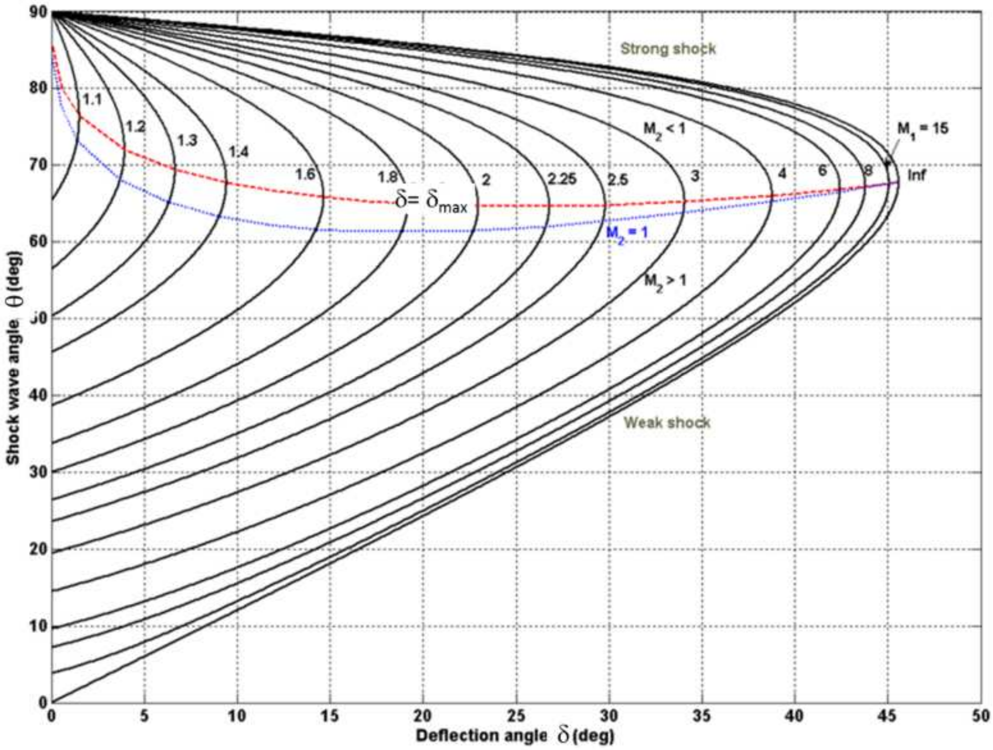

Strong shock
Weak shock
$M_2 < 1$
$M_2 = 1$
$M_2 > 1$
$M_1 = 15$
Inf
$\delta = \delta_{max}$
1.1
1.2
1.3
1.4
1.6
1.8
2
2.25
2.5
3
4
6
8
Shock wave angle θ (deg)
Deflection angle δ (deg)
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90

Figure Q.16

Part B
Answer ONE question

17. Figure QB1 shows a schematic diagram, at a particular instant of the engine cycle, of a cylinder head (Surface 1), piston crown (Surface 2) and cylinder liner (Surface 3).

(a) Using the dimensions indicated on the diagram and given that $F_{12} = 0.6$, calculate all view factors. [8]

(b) Draw the resistance network for this problem. Identify all temperatures, and resistances on the diagram. [6]

(c) The cylinder head can be represented as a **black body** at the temperature $T_1 = 1700K$, the cylinder lining is well insulated so that it is **adiabatic** and the emissivity of the piston is $\epsilon_2 = 0.75$. What is the radiosity of the cylinder head using this information and why? [3]

(d) If the surface temperature of the piston crown is, $T_2 = 600\ K$, and using the conservation of heat flow, calculate the radiosity for the piston crown. [4]

(e) Using the radiosity of the head and piston, calculate the temperature of the cylinder lining. [6]

(f) Briefly explain how this analysis could be extended to make it more realistic. [3]

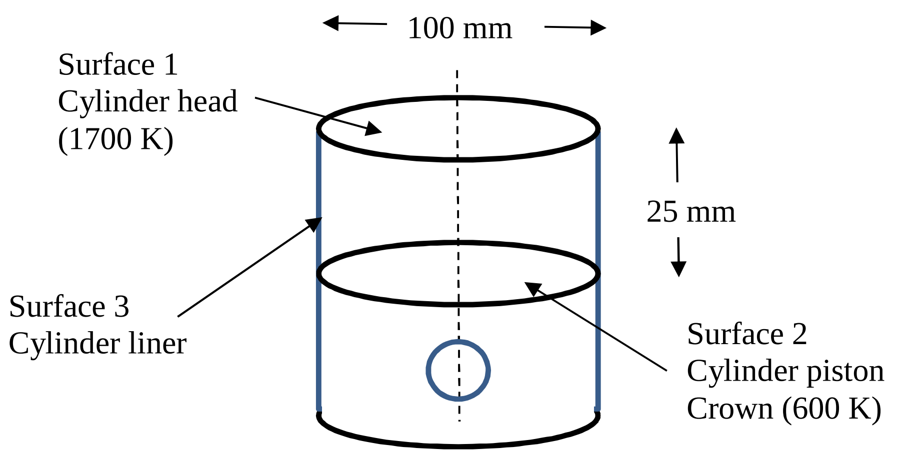


Fig BQ1

18. A gas turbine operates in an environment in ambient conditions -2°C and 985 mbar. The combustion chamber is at a pressure of 13.9 bar and the turbine inlet temperature is 1380°C. The turbine isentropic efficiency of compressor and turbine are both 88% and adiabatic index (or ratio of specific heats γ) is 1.4 in the compressor and 1.297 in the turbine.

(a)Calculate the compressor and turbine outlet temperatures. [10]

(b) Determine the cycle efficiency (assuming an ideal air cycle) [8]

(c) One of the turbine stages is to be designed with a flow coefficient of 0.6, a reaction of 50% and a stage loading of 3.5. Find the entry and exit relative flow angles and sketch the velocity triangles; calculate the axial velocity and given that the speed is 3000 rpm and the mean radius is 0.25 m, blade height is 0.02 m calculate the mass flow rate. [12]

END