

# The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 3 MODULE, Mock resit

## THERMOFLUIDS 3

Time allowed TWO Hours and 30 minute

1. Using the chart in Figure Q1s from the chart page provided, there are two possible angles of the shock wave for the case of supersonic flow at Mach 3 approaching a deflecting wall with angle  $25^\circ$  [1]. Strong shock is found at  $79 \pm 1^\circ$  [1], weak shock at  $45 \pm 1^\circ$  [1]. Strong shock is where the Mach number of the air velocity resolved perpendicular to the shock wave changes from  $M > 1$  to  $M < 1$ . Weak shock is where both Mach numbers are greater than 1 [2]. [5]

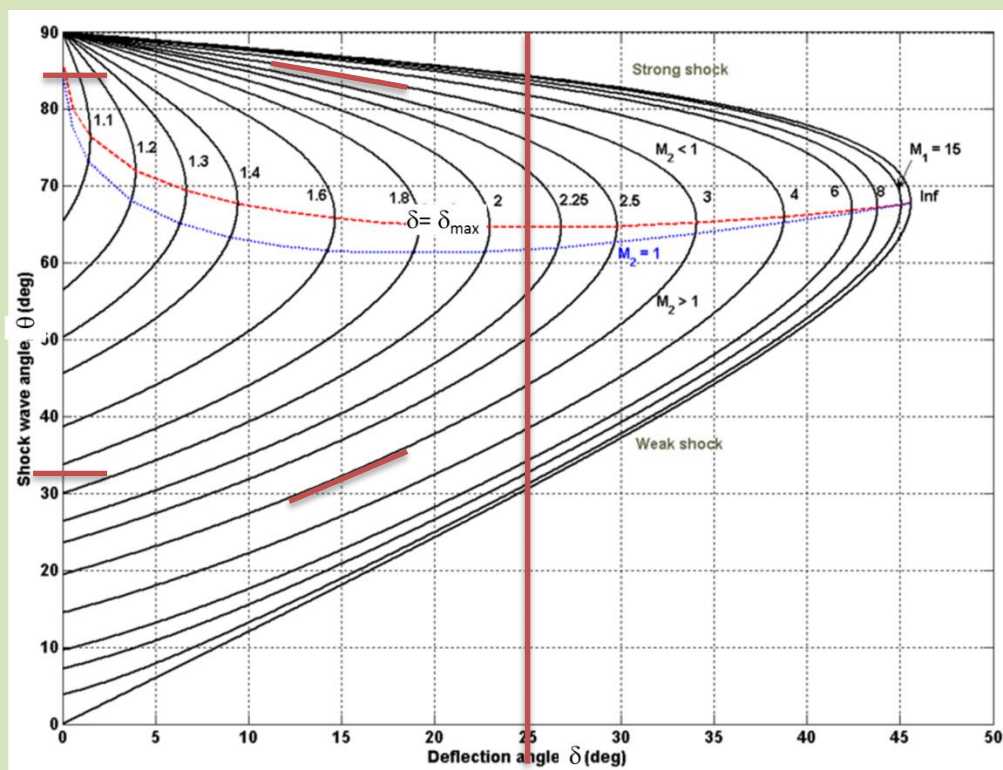
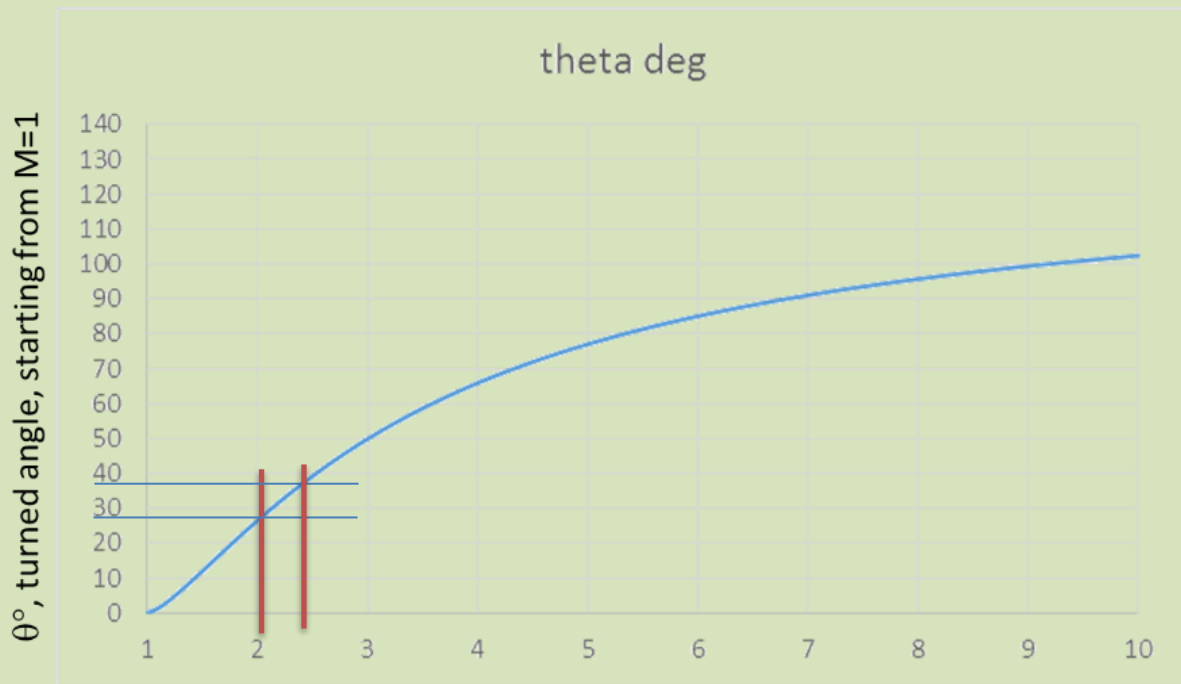


Figure Q1s

2. The Mach number of the flow will increase due to the expansion [2]. Using the expansion fan chart, the starting point at Mach 2 has a starting angle of  $27 \pm 1^\circ$ . The expansion is  $10^\circ$ , giving a final turned angle of  $37 \pm 1^\circ$  [1]. Using the chart, this angle on the curve corresponds to the new Mach number of  $2.3 \pm 0.1$  [1].



Mach number corresponding to angle turned  
after starting at M=1

3. (a) For Nusselt number we need the characteristic length of the natural convection (H) [1] and the thermal conductivity of the air  $k_a$  [1] so  $Nu = \frac{h_a H}{k_a}$  [1]  
For Bio number we need the thickness of material (W) [1] and the thermal conductivity of the material  $k_m$  [1] so  $Bi = \frac{h_a W}{k_m}$  [1]
- (b) If the Biot number is larger than 1 then this means that the heat applied is larger than the heat conducted [1] and the surface of the material gets hotter in relation to the back of the material. [1]. [2] for an application such as if there is delicate electronics at the rear end that need to be protected against short bursts of heat, or if you wanted to heat treat the surface.

4. The steady flow energy equation applied to combustion may be written as:

$$\dot{Q} + \dot{W} = \sum_{\text{Products}} \dot{m}_i (h_i - h_{i0}) - \sum_{\text{Reactants}} \dot{m}_i (h_i - h_{i0}) + \dot{m}_f \Delta h_o$$

When the reactants are initially at 25°C, the adiabatic flame temperature can be calculated from:

$$T_{af} = T_0 - \frac{m_f \Delta h_o}{\sum_{\text{Products}} m_i \bar{c}_{pi}} \quad T_{af} = T_0 - \frac{m_f \Delta h_o}{\sum_{\text{Products}} m_i \bar{c}_{pi}}$$

- a) If the proportion of excess air was increased, there would be more mass in the products but no extra enthalpy in the fuel. So the adiabatic flame temperature would decrease. [3 marks]
- b) If the air was preheated above 25°C, then this would add enthalpy and result in a higher adiabatic flame temperature. (Note that enthalpy of combustion is always a negative quantity in the SFEE. When the SFEE is rearranged, the enthalpy of reaction and reactant enthalpy both add to the enthalpy of the products in an adiabatic (Q = 0) reaction. [5 marks]

5. (a) the equation for m needs the perimeter and the cross sectional area of the fins. So  $P = 2(A + C) = 84E - 3m$ ,  $A_c = AC = 80E - 6m^2$ . [2]

$$\text{So rearranging the equation, we get } h = m^2 k_c A_c / P [1] = 71^2 (2)(80E - 6) \frac{1}{84E - 3} = 9.60 \text{ W/m}^2 \text{K} [2]$$

(b) equation is  $\eta = \tanh(mL_c) / mL_c$

$$L_c = B + \frac{A}{2} = 21E - 3m [1], \text{ so } \eta = \frac{0.90}{1.491} = 0.606 [2]$$

- (c) The effectiveness is defined as the heat removed with fin/heat removed without fin. So answer is simply  $3.5 \times 10 \text{ W} = 35 \text{ W}$  [2].

6. a) to find the turbine blade height, it is simply a case of working out the gas flow rate formula  $\dot{m} = \rho A c_x$  in which  $c_x$  is the axial velocity, 127 m/s,  $\rho$  is gas density which is in the table as 8.7 kg/m<sup>3</sup>, and  $\dot{m}$  is given in the table as 67 kg/s.

$$\dot{m} = \rho A c_x \rightarrow 67 = 8.7 \times A \times 127$$

[1 formula, 1 for values]

therefore  $A = 0.0606 \text{ m}^2$ . Therefore using the annular area formula

$$A = \pi(r_o^2 - r_i^2) \rightarrow 0.0606 = \pi(r_o^2 - 0.5^2) \rightarrow r_o = 0.519$$

[2]

and the blade height is  $r_o - r_i = 0.519 - 0.500 = 0.019 \text{ m}$  or 19 mm.

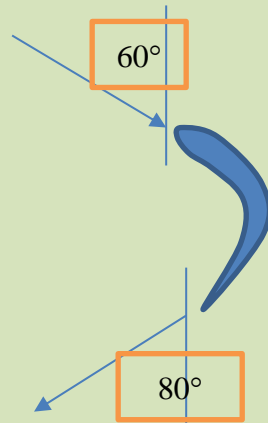
[1]

- b) the rotational velocity can be worked out using the formula for flow coefficient

$$\phi = \frac{c_x}{U_m} \rightarrow U_m = \frac{c_x}{\phi} = \frac{127}{0.4} = 317.5$$

[3]

And the relative velocity angles can be indicated thus:



1 for full turn indication, 1 for each angle [3]

7. **For this question students need Pages 4 and 7 of Steam Tables**

The rate of irreversibility is equal to the reduction in flow exergy of the steam.

Flow exergy is given by:  $\dot{m}((h - h_0) - T_0(s - s_0))$

Enthalpy and entropy of the dry saturated steam at 15 bar are 2792 kJ/kgK and 6.445 kJ/kgK respectively.

The flow exergy of the flow of dry saturated steam is:

$$10((2792 - 29.4) - 280(6.445 - 0.106)) = 9.88 \text{ MW} \quad [7 \text{ marks}]$$

In the throttle, the enthalpy remains constant but the pressure reduces to 5 bar. The

entropy after the throttle is thus 6.922 kJ/kgK 3 [3 marks]

The flow exergy after the throttle is:

$$10((2792 - 29.4) - 280(6.922 - 0.106)) = 8.54 \text{ MW}$$

So the rate of irreversibility is  $9.88 - 8.54 = 1.34 \text{ MW}$  [4 marks]

8. (a) The 2 view factors that can be deduced are:  $F_{BB} = 0, F_{HH} = 0$  [1]

The 4 sides will get equal radiation so the view factors from the base are:

$F_{BH} = 0.25, F_{BI} = 0.75$  by symmetry considerations. [2]

The remaining 8 can be found from reciprocity and view factor equations

$$F_{BB} + F_{BI} + F_{BH} = 1, F_{HB} + F_{HI} + F_{HH} = 1, F_{IB} + F_{II} + F_{IH} = 1$$

$$A_B F_{BH} = A_H F_{HB}, A_B F_{BI} = A_I F_{IB}, A_H F_{HI} = A_I F_{IH}$$

$$A_B = 0.48^2 = 0.2304 \text{ m}^2, A_H = 0.1030 \text{ m}^2 \text{ (from question)}, A_I = 0.309 \text{ m}^2 [2]$$

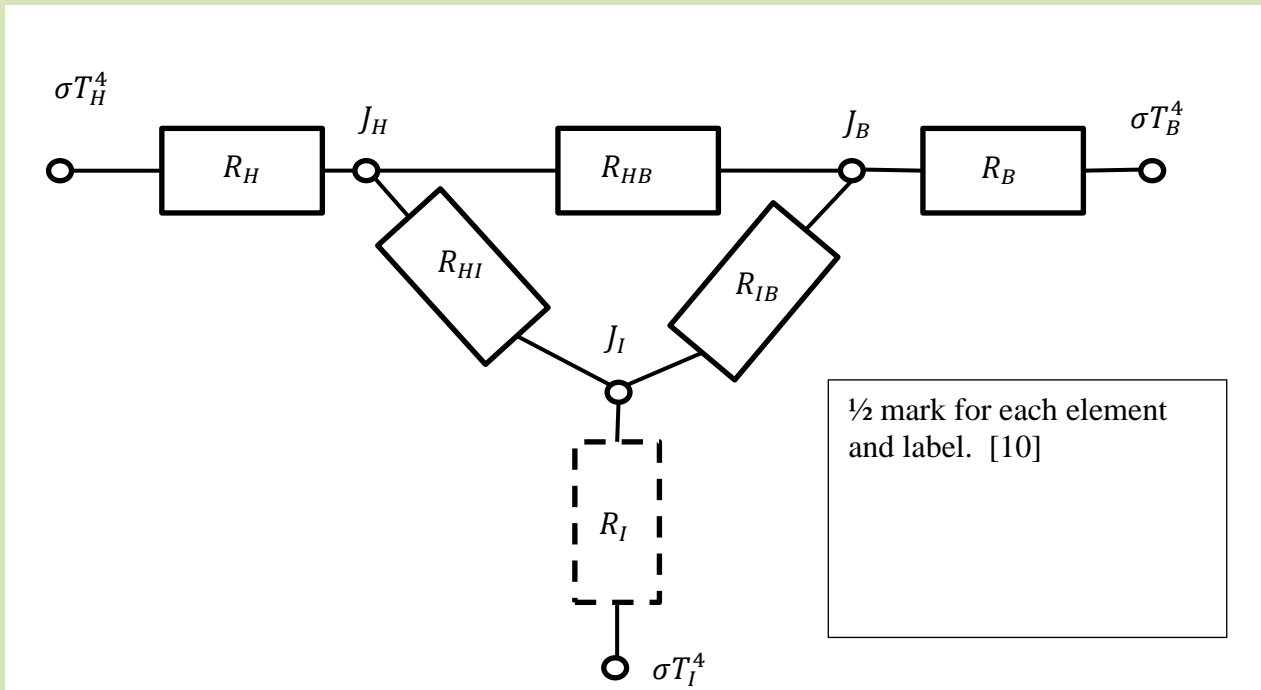
$$\text{So } F_{HB} = \frac{A_B}{A_H} F_{BH} = 0.56 [1], F_{IB} = \frac{A_B}{A_I} F_{BI} = 0.56 [1], F_{HI} = 1 - F_{HB} = 0.44 [1]$$

$$\text{So } F_{IH} = \frac{A_H}{A_I} F_{HI} = 0.147 [1], F_{II} = 1 - F_{IB} - F_{IH} = 0.293 [1]$$

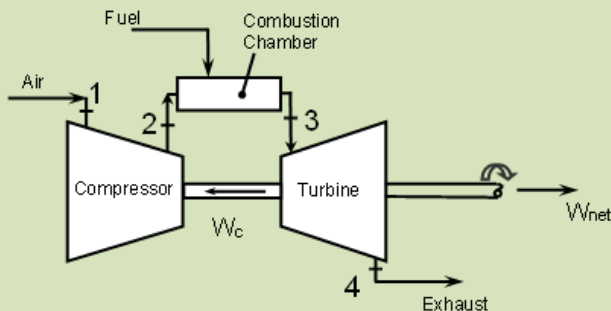
So

$$\begin{aligned} F_{BB} &= 0, F_{BI} = 0.75, F_{BH} = 0.25 \\ F_{HB} &= 0.56, F_{HI} = 0.44, F_{HH} = 0 \\ F_{IB} &= 0.56, F_{II} = 0.293, F_{IH} = 0.147 \end{aligned}$$

(b)



9. Solution calculated for a student with an ID ending in 5.  
Mass flow rate is 55 kg/s



In the compressor, the outlet temperature  $T_2$  is given by:

$$T_2 = T_1 \left( \frac{p_2}{p_1} \right)^{\frac{(\gamma-1)}{(\eta_{\infty c})\gamma}}$$

$$T_2 = (17 + 273)(12)^{\frac{1.4-1}{0.85 \times 1.4}} = 668 \text{ K (396 } ^\circ\text{C)} \quad [5 \text{ marks}]$$

So specific work input to compressor is  $c_p(T_2 - T_1) = 1.005(396-17) = 380.9 \text{ kW/kg/s}$

In turbine

$$T_4 = T_3 \left( \frac{p_4}{p_3} \right)^{\frac{(\eta_{\infty t})(\gamma-1)}{\gamma}}$$

$$T_4 = (1000 + 273) \left( \frac{1}{12} \right)^{\frac{0.85(1.333-1)}{1.333}}$$

$$T_4 = 751 \text{ K (478} ^\circ\text{C)} \quad [5 \text{ marks}]$$

So specific work output from turbine is  $\dot{m}c_p(T_3 - T_4) = 1.15(1000-478)$   
 $= 600.3 \text{ kW/kg/s}$

So the net specific power output from the turbine and compressor is:  $600.3 - 380.9 = 219.4$  kW/kg/s [5 marks]

And the actual power output from the generator, accounting for gearbox and generator efficiencies is  $0.99 \times 0.96 \times \dot{m} \times 219.4$

$$0.99 \times 0.96 \times 55 \times 219.4 = 11500 \text{ kW } 11.5 \text{ MW} \quad [3 \text{ marks}]$$

The power output for all student IDs is:

<u>Last digit of ID</u>	<u>Power output (MW)</u>
0	10.4
1	10.6
2	10.8
3	11.1
4	11.3
5	11.5
6	11.7
7	11.9
8	12.1
9	12.3

**END**