ENG64

UNIVERSITY OF GREATER MANCHESTER

NATIONAL CENTRE FOR MOTORSPORT ENGINEERING

B.ENG. (HONS) AUTOMOTIVE PERFORMANCE ENGINEERING

SEMESTER 2 2024/2025

THERMODYNAMICS & FLUID MECHANICS

MODULE MSP5028

Date: Friday 16 May 2025 **Time: 14:00 – 16:00**

INSTRUCTIONS TO CANDIDATES:

The paper has **SEVEN** questions

Attempt **FOUR** questions.

The marks for each question are shown in brackets

Marks are awarded mainly for the development of an answer; using four significant figures for numbers and including units as appropriate with the numbers

Electronic calculators may be used

There is an information sheet on the next page

This is a closed book examination

Question 1

Figure 1 illustrates a 2D view of a side-pod. The depth of the side-pod into the diagram is constant at 200mm. The velocity at the entrance ① is 40 m/s with the dimensions 180mm by 200mm. Section ③ has a flow area with dimensions 240mm by 200mm. Section ② is through a radiator with the flow area of the radiator having the dimensions 340mm by 180 mm. The dimensions include the effects of blockage of the radiator. Assume an inviscid flow throughout this question. The density of the air is 1.2 $kg.m^{-3}$

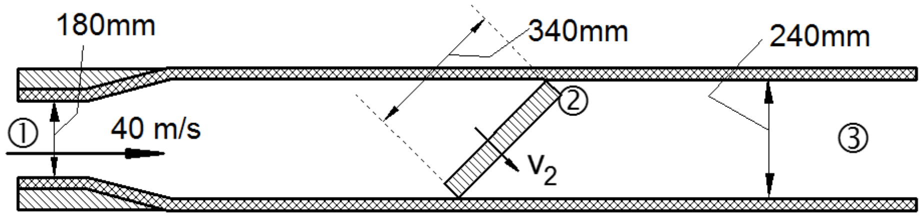

Figure 1

a) Calculate the average velocity at section ③ along the side pod. **(4 marks)**

b) Calculate the average velocity through the radiator at section ② in the direction of v_2. **(4 marks)**

c) Calculate the changes in static pressure along the side-pod relative to the pressure at the inlet, ①. I.e. calculate (p_2-p_1) and (p_3-p_1). **(10 marks)**

d) Using the three sections, ①, ② & ③ sketch the static pressure along the side pod relative to the static pressure at the entrance. **(7 marks)**

(Total marks 25)

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Question 2

(a) Explain the terms used and the context of equation (2a) for Stoke's law. Using a suitable diagram explain the relationship between the terms and forces involved for Stoke's Law. **(9 marks)**

$$R = 3\,\pi\,v\,\mu\,d$$

Equation (2a)

(b) A steel ball falls through an oil at a constant velocity. The displacement is 900 mm in 6 seconds. The ball is spherical and has a diameter of 1.6 mm and a mass of 17 milli-grammes. The density of the oil is 870 kg.m^{-3}

i. Using Stokes's law determine the viscosity of oil. **(13 marks)**
ii. Comment on the validity of the calculation **(3 marks)**

The volume of a sphere is $\frac{\pi D^3}{6}$

(Total marks 25)

Please turn the page

Question 3

Figure 3a is a cross sectional view of a model in the working section of a wind tunnel. Figure 3b shows a side view of the model in the wind tunnel. Section A-A is 8 metres upstream of the model and has a pitot-tube and wall tapping to indicate the air speed. The air is flowing at 60 m/s through the rectangular section A-A. The dimensions of the section A-A are 2.5 metres by 1.8 metres.
The temperature of the air is 300 kelvin. The vehicle model is 1200 mm wide. The full-scale width of the vehicle is 2000mm.

a) Calculate the volumetric flow rate through the section A-A. Calculate the average velocity of the flow at the centre line of the model. **(5 marks)**

b) Calculate a value for the speed of sound in the air {=square root(gamma*R*T)}. Calculate a value for the Mach number of the flow at the model and comment. **(5 marks)**

c) Calculate a Reynolds number for the flow based on the distance from section A-A to the vehicle model. Comment on the type of flow. **(5 marks)**

d) Calculate a representative velocity for the full-scale vehicle. The wind tunnel is an open wind tunnel. **(5 marks)**

e) Calculate the percentage blockage caused by the model and comment. **(5 marks)**

The specific gas constant and ratio of specific heats for air are R=287.1 J/(kg.K) and γ=1.4. The air has a dynamic viscosity of 18.5×10^{-6} kg/(m.s). The density of the air is 1.2 kg/m^{-3}.

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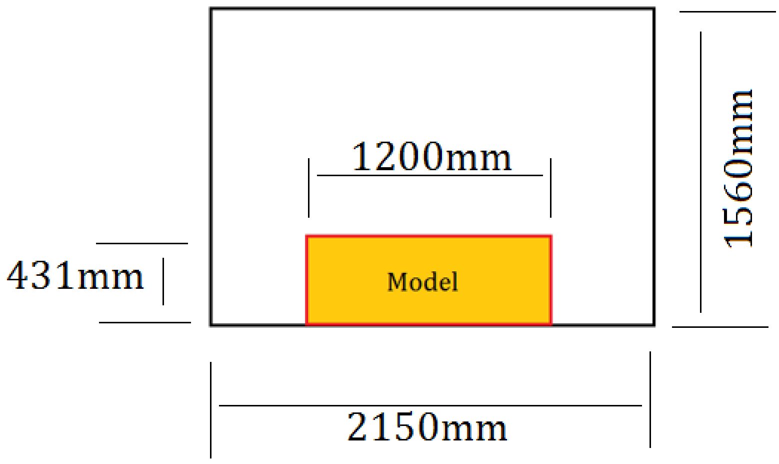

Figure 3a – Wind Tunnel Cross Section at the Model

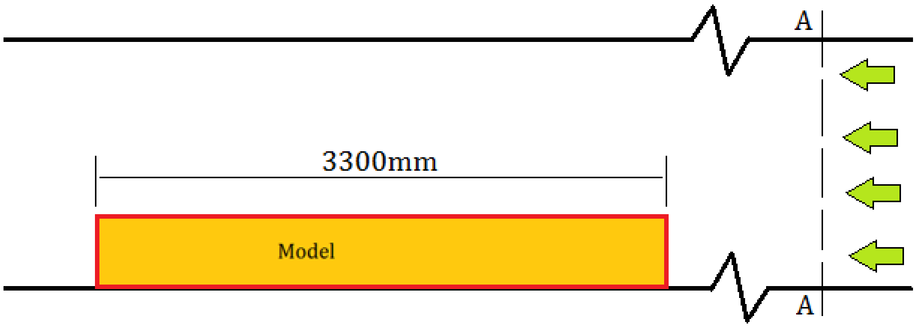

Figure 3b – Side view of Wind Tunnel

(Total marks 25)

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Question 4

(a) Explain, with the use of a suitable diagram, the operation and meanings of the terms in equation 4a. Equation 4a relates to the flow through an orifice plate flow-meter. **(8 marks)**

$$v = c\sqrt{\frac{2 * \Delta P}{\rho(1 - m^2)}}$$

Equation (4a)

(b) An investigation into the flow through a sidepod uses pitot-static tubes mounted at the side-pod entrance. The maximum speed during the tests is 75 m/s. The data acquisition system is calibrated on an air flow rig with the air flow rate at 75m/s.

i. Calculate the differential pressure across a pitot-static tube at 75 m/s **(5 marks)**

ii. Calculate the differential head on a vertical water-based manometer from a pitot-static tube in a 75m/s air flow.
Calculate the length of a reading on a water-based manometer inclined at 30 degrees to the horizontal. Using a suitable diagram and your calculations clearly explain how inclined manometers improve the reading of a differential pressure. **(6 marks)**

iii. Figure 4b is to be used to convert differential pressure readings from a manometer in units of 'mm of water' to an air speed. Choose a point on the plot and confirm, or otherwise, that it is correct and can be used to convert from mm of water to air speed in metres per second. Comment on the accuracy of such a chart. **(6 marks)**

Take $g=9.81 m/s^2$ and the densities of water and air as 1000 kg/m^3 and 1.2 kg/m^3 respectively

Please turn the page Q4 Continues…

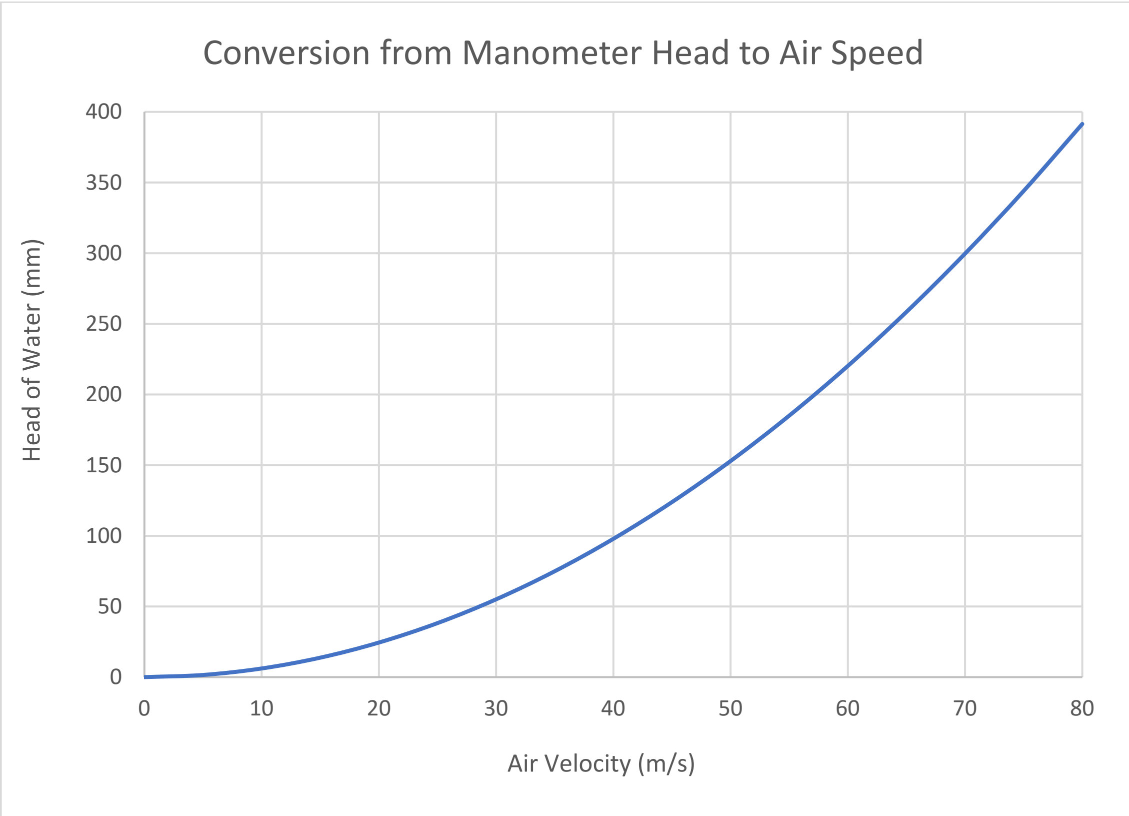

Figure 4b

(Total marks 25)

Please turn the page

Question 5

(a) Explain the terms in equation (Q5) in terms of the laminar flow over a flat plate such as the one illustrated by figure 5a and the context of figure 5a and the laminar flow over a flat plate. **(5 marks)**

$$\delta = \frac{5.2x}{\sqrt{Re}}$$

Valid for 0<Re<5E5 for the case of dry air passing over a flat plate.

Equation (Q5)

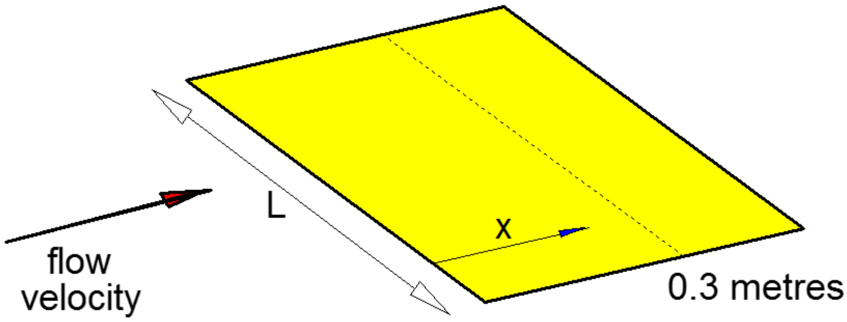

Figure 5a

The plate in figure 5a has L=1.2 metres with dry air flowing over one surface at 25 m/s. The dry air has viscosity 18.10^{-6} kg/(ms) and density 1.2 kg/m^3.

Sketch a graph of the boundary layer thickness from the leading edge to a line 0.3 metres into the plate. The sketch should include appropriate numerical values. Include significant characteristics of the regions on the graph. The sketch should include results for say δ at x=0, x=0.15m and x=0.3m. Label characteristics of the regions on the graph. **(10 marks)**

It is suggested that you express equation (Q5) in the form

$$\delta = \text{constant} * \sqrt{x}$$

by substituting for Reynolds number into equation Q5 whilst keeping x as a variable.

Please turn the page Q5 Continues…

Question 5 continued

(b) A race car has a single element rear wing with a chord of 220mm and width of 960mm. It is travelling at 75 m/s. Figure 5b illustrates the lift coefficient against angle of attack. The race log for the car indicates that a good aerodynamic balance can be achieved with the rear wing generating 850 N. Take the density of the air as 1.2 kg/m^3. The lift=0.5*ρ*A*v^2*cL for an aerofoil where the A is the product of the width and the chord.

i. What angle of attack does the wing need to be set at? **(7 marks)**

ii. Comment on the effect of having a higher angle of attack of the aerofoil. **(3 marks)**

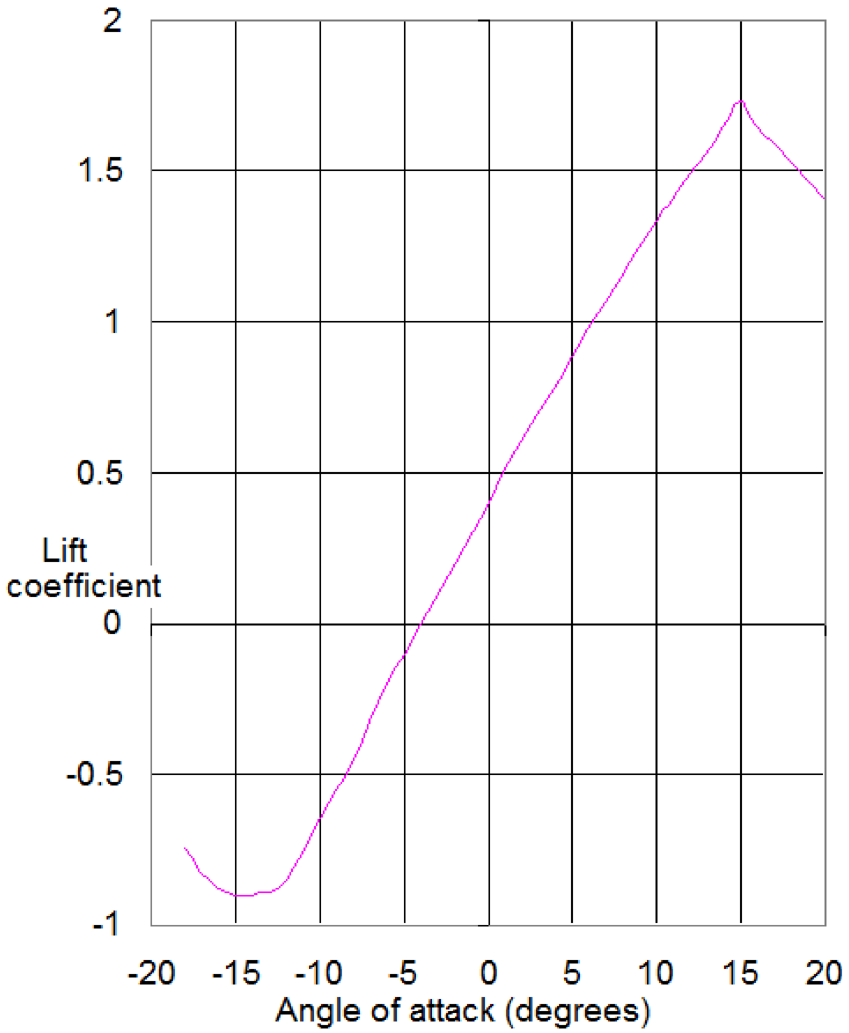

Figure 5b

(Total marks 25)

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Question 6

(a) Draw the processes with annotations onto T-s axes, as in figure 6a, to explain the context and use of equations Q6a and Q6b in relation to the compression of a gas in a rotary compressor. Define the variables in the equations.

(8 marks)

$$\eta_{isencomp} = \frac{W_{isentropic}}{W_{actual}} = \frac{(T_{2s} - T_1)}{(T_2 - T_1)}$$

Equation (Q6a)

$$T_{2s} = T_1 \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

Equation (Q6b)

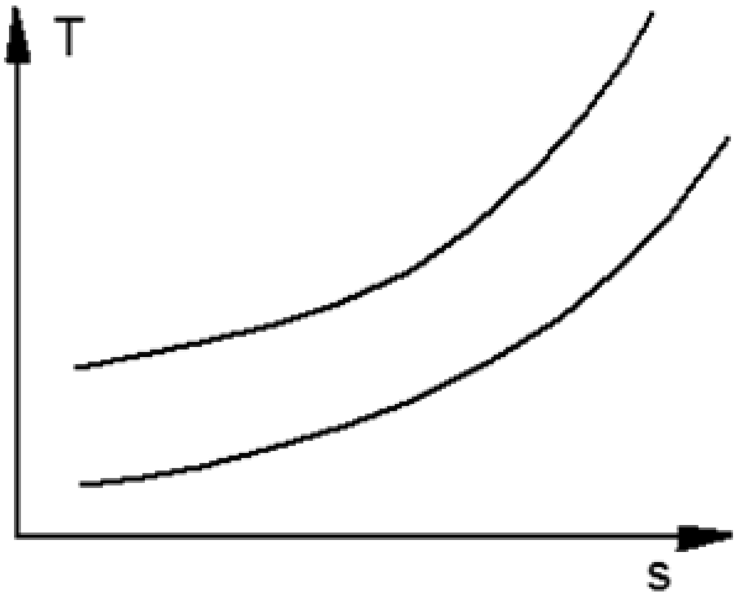

Figure 6a

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Question 6 continued

(b) A compressor delivers air at a mass flow rate 0.15 kg/s from an entry state of 0.9 bar, 280K to an exit pressure of 2.5 bar. The isentropic efficiency of the compressor is 78%. Take the specific heat of the air as c_p=1.005 kJ/(kg.K) and the ratio of the specific heats as γ_{turb}=1.4

i. Calculate the unknown temperatures **(6 marks)**

ii. Calculate the work required to achieve the actual compression **(7 marks)**

iii. Use a second method to calculate the work delivered to check the result and comment. **(4 marks)**

(Total marks 25)

Please turn the page

Question 7

(a) Sketch a p-V diagram for the air standard Otto cycle of table Q7a. The cycle has isentropic processes where appropriate. **(2 marks)**

i. Use the diagram to explain the processes in the air standard Otto cycle. Clearly state whether any heat energy transfers, work transfers and changes in internal energy are zero or non-zero. **(4 marks)**

ii. Write down an equation that defines the compression ratio. Explain what determines the maximum pressure in an Otto cycle in practice. **(2 marks)**

(b) Table Q7a contains the properties for the end states of an air standard Otto cycle with a total volume of 1764cc, a swept volume of 1588cc, a compression ratio of 10:1 and a maximum cycle pressure of 50 bar. The remaining properties are in table Q7a.

i. Calculate the mass of substance. Complete the table of energy transfers, table Q7b. Carry out an appropriate calculation or calculations to determine whether your calculations are correct. **(13 marks)**

ii. Calculate the thermal efficiency for the cycle. Calculate the mean effective pressure. **(4 marks)**

(Total marks 25)

Please turn the page Q7 Continues…

Feel free to remove this sheet from the question book and include in your answer book.

Student name or number:

State	p/bar	T/K	V/cm^3
1	1	300	1764
2	25.12	753.6	176.4
3	50	1500	176.4
4	1.991	597.2	1764

Table Q7a

Changes	Q (J)	W (J)	U (J)	Changes
1 to 2	0			
2 to 3				
3 to 4				
4 to 1				
Cycle				

Table Q7b

End of Questions. Please turn for Formula Sheet

BEng (Hons) Automotive Performance Engineering
Semester Two Examination 2024/25
Thermodynamics and Fluid Mechanics
Module No. MSP5028

Information for Candidates

Unless otherwise stated take the following as constant for air

$$R=0.2871\frac{kJ}{kgK},\ c_p=1.005\frac{kJ}{kgK},\ c_v=0.718\frac{kJ}{kgK}$$

μ=18 E-6 Ns m^{-2} and ρ=1.2 kg.m^{-3}

Ideal gas law	$pv=RT\ :\ pV=mRT\ :\ p=\rho RT\ :\ \frac{pV}{T}=\text{constant}$
Cycles	$\eta_{\text{thermodynamic}}=\frac{W_n}{Q_s}\ :\ sfc=\frac{\dot{m}_f}{\dot{W}}\ :\ mep=\frac{W_n}{SV}$
Bernoulli's Equations for inviscid flow	$\dot{V}=Av\ :\ E=\frac{p}{\rho}+\frac{v^2}{2}+gz$
Aerodynamic coefficients, c_a	$\text{aerodynamic force}=\frac{1}{2}c_a\,\rho A v^2$
Process equations	$pv^{\gamma}=\text{constant}\ ;\ Tv^{\gamma-1}=\text{constant}$ p=constant : v=constant pv=constant : pv^n=constant
Energy equations based around first law	NFEE : $\Delta Q-\Delta W=\Delta U$ SFEE : $Q_{ab}-W_{ab}=\dot{m}\left\{(h_b-h_a)+\left(\frac{v_b^2}{2}-\frac{v_a^2}{2}\right)+g(z_b-z_a)\right\}$
Energy expressions	$U=mc_vT\ :\ u=c_vT\ :\ h=c_pT\ :\ H=mc_pT$

Conversion Factors

Time: 1 h = 60 min = 3600 s	Temperature difference: 1C = 1.8°F
Volume: 1m^3 = 10^3 dm^3 = 10^3 litre = 36.31ft^3 = 220 UKgal	
Energy: 1 kJ = 10^3 Nm	Force: 1 N = 0.2248 lbf
Pressure: 1 bar = 10^5 Pa (Nm^{-2}) = 14.50 lbf in^{-2} = 750 mmHg = 10.2 mH$_2$O	
Density 1 kg m^{-3} = 0.062 43 lb ft^{-3}	Mass: $1\text{kg}=\frac{1}{0.45359237}\text{lb}\approx 2.205\text{ lb}=\frac{1}{14.5939}\text{slug}$
1 mile=1760 yd≈1609m : 1 yd=3 ft=36 inches=0.914 m : $1\text{ m}=\frac{1}{0.3048}\text{ft}=3.281\text{ ft}$	
Power: $1\text{ kW} = 1\text{ kJ s}^{-1} = \frac{10^3}{9.80665\text{x}75}$ metric hp ≈ 1.359 metric hp	
Angle : 1 revolution=360°=2π	

End of Examination Paper