Second Semester Examination
2023/2024 Academic Session

July / August 2024

EMH 222 – Fluid Dynamics
(Dinamik Bendalir)

Duration: 2 hours
(Masa: 2 Jam)

Please check that this examination paper consists of SIX (6) pages of printed material before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi ENAM (6) muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]

Instructions: Answer ALL **FOUR (4)** questions.

*[**Arahan**: Jawab **EMPAT (4)** soalan]*

Booklet for Thermodynamics properties is provided.

Appendix I (Formula list) is provided.

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1. In a two-dimensional incompressible flow, the fluid velocity components are given by: $v_x = x - 5y$ *and* $v_y = -y - 5x$.

   (a) Prove that the flow fulfils the continuity equation.

   (20 marks)

   (b) Using differential method, prove that this is a potential flow.

   (30 marks)

   (c) Derive the flow's velocity potential.

   (30 marks)

   (d) Calculate the values of velocity potential at a point (*0, 5*).

   (20 marks)

2. Consider a fluid that flows over a smooth flat plate as depicted in Figure 2.

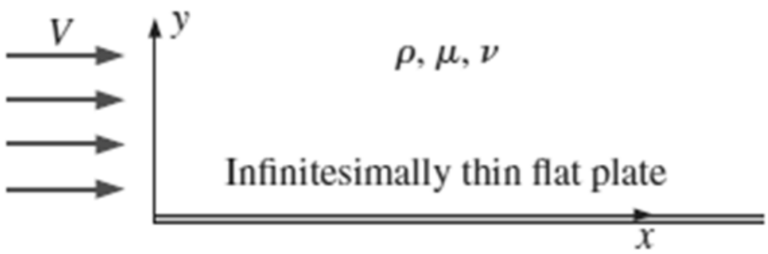

Figure 2.

Given V = 15.0 m/s, v = 1.5 x 10^{-5} m^2/s, and x = 3.0 m,
[Symbols have their usual meanings.]

   (a) Calculate the *Re*. Justify whether the flow is laminar or turbulent.

   (20 marks)

   (b) Using the Table 2 below, calculate the approximate boundary layer thickness, displacement thickness, momentum thickness and local skin friction coefficient.

   (60 marks)

   (c) State **THREE (3)** key factors that will affect the validity of the calculated answers in relation to real world applications.

   (20 marks)

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Table 2

Summary of expressions for laminar and turbulent boundary layers on a smooth flat plate aligned parallel to a uniform stream*			
		(a)	(b)
Property	Laminar	Turbulent(†)	Turbulent(‡)
Boundary layer thickness	$\frac{\delta}{x} = \frac{4.91}{\sqrt{\text{Re}_x}}$	$\frac{\delta}{x} \cong \frac{0.16}{(\text{Re}_x)^{1/7}}$	$\frac{\delta}{x} \cong \frac{0.38}{(\text{Re}_x)^{1/5}}$
Displacement thickness	$\frac{\delta^*}{x} = \frac{1.72}{\sqrt{\text{Re}_x}}$	$\frac{\delta^*}{x} \cong \frac{0.020}{(\text{Re}_x)^{1/7}}$	$\frac{\delta^*}{x} \cong \frac{0.048}{(\text{Re}_x)^{1/5}}$
Momentum thickness	$\frac{\theta}{x} = \frac{0.664}{\sqrt{\text{Re}_x}}$	$\frac{\theta}{x} \cong \frac{0.016}{(\text{Re}_x)^{1/7}}$	$\frac{\theta}{x} \cong \frac{0.037}{(\text{Re}_x)^{1/5}}$
Local skin friction coefficient	$C_{f,x} = \frac{0.664}{\sqrt{\text{Re}_x}}$	$C_{f,x} \cong \frac{0.027}{(\text{Re}_x)^{1/7}}$	$C_{f,x} \cong \frac{0.059}{(\text{Re}_x)^{1/5}}$

* Laminar values are exact and are listed to three significant digits, but turbulent values are listed to only two significant digits due to the large uncertainty affiliated with all turbulent flow fields.

† Obtained from one-seventh-power law.

‡ Obtained from one-seventh-power law combined with empirical data for turbulent flow through smooth pipes.

3. (a) Stokes' law can be used to calculate the viscosity of a fluid by dropping a spherical object into it and measuring the object's terminal velocity. This involves plotting the distance travelled against time and noting when the plot becomes linear.

In an experiment (Figure 3 [a]), a glass ball with a diameter of 3 mm (ρ = 2500 kg/m³) is dropped into a fluid with a density of 875 kg/m³. The terminal velocity of the ball is measured to be 0.12 m/s. Ignoring wall effects, calculate the viscosity of the fluid.

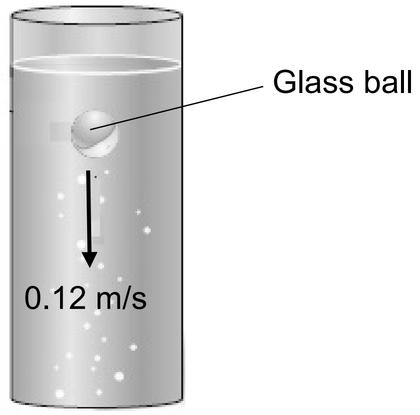

Figure 3 (a)

(50 marks)

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(b) Consider a car engine shaped like a rectangular block with the following dimensions: 0.4 m high, 0.60 m wide, and 0.7 m long as shown in Figure 3 (b). The surrounding air is at a pressure of 1 atm and a temperature of 15°C. Calculate the drag force on the bottom surface of the engine block as the car moves at 85 km/h.

(Given the density and kinematic viscosity of air at 1 atm and 15°C are ρ =1.225 kg/m^3 and v = 1.470 x 10^{-5} m^2/s)

Assumptions:

- The air behaves as an ideal gas, incompressible, and the flow is steady
- There is no significant wind (the ambient air is calm).
- The bottom surface of the engine block is flat and smooth.
- The flow over the entire surface is turbulent due to the constant movement of the engine block.

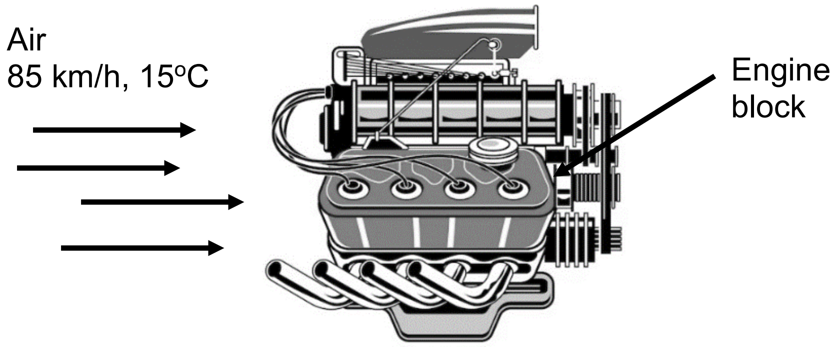

Figure 3 (b)

(50 marks)

4. (a) Nitrogen enters a steady-flow heat exchanger at 150 kPa, 10°C, and 100 m/s, receiving 120 kJ/kg of heat during its passage as shown in Figure 4 (a). It exits the heat exchanger at 100 kPa and 200 m/s. Calculate the Mach number of nitrogen at both the inlet and the outlet of the heat exchanger.

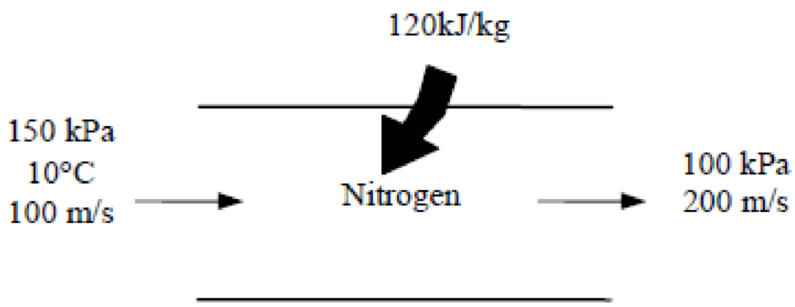

Figure 4 (a)

(50 marks)

(b) An aircraft is designed to cruise at a Mach number of 1.4 at an altitude of 8000 meters, where the atmospheric temperature is 236.15 K. Calculate the stagnation temperature at the leading edge of the wing.

(50 marks)

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APPENDIX I (Formula List)

1. $C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A}$	12. $C_f = \frac{1.33}{Re_L^{1/2}}$ $Re_L < 5\ x\ 10^5$
2. $C_L = \frac{F_L}{\frac{1}{2}\rho V^2 A}$	13. $C_f = \frac{0.074}{Re_L^{1/5}}$ $5\ x\ 10^5 \leq Re_L \leq 10^7$
3. $F_D = W - F_B = 3\pi\mu VD$	14. $F_D = F_{D,friction=}F_f = C_f A \frac{\rho V^2}{2}$
4. $Re = \frac{\rho VD}{\mu}$	15. $c = \sqrt{kRT}$
5. $V = \frac{\pi D^3}{6}$	16. $Ma = \frac{V}{c}$
6. $C_D = \frac{1}{L}\int_0^L C_{D,x} dx$	17. $\rho = \frac{P}{RT}$
7. $C_L = \int_0^L C_{L,x} dx$	18. $T_o = T + \frac{V^2}{2c_p}$
8. $W = \rho_s g V$	19. $\frac{P_o}{P} = \left(\frac{T_o}{T}\right)^{k/(k-1)}$
9. $F_B = \rho_f g V$	20. $\frac{\rho_o}{\rho} = \left(\frac{T_0}{T}\right)^{1/(k-1)}$
10. $Re_x = \frac{\rho Vx}{\mu} = \frac{Vx}{v}$	21. $q_{in} = c_p(T_2 - T_1) + \frac{V_2^2}{V_1^2}$
11. $Re_{x,cr} = \frac{\rho V x_{cr}}{\mu} = 5\ x\ 10^5$	