Second Semester Examination
2022/2023 Academic Session

July / August 2023

# EMH 222 – Fluids Dynamics
***(Dinamik Bendalir)***

Duration: 3 hours
*(Masa: 3 Jam)*

Please check that this examination paper consists of EIGHT (8) pages of printed material before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi LAPAN (8) muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

**Instructions**: Answer ALL **FIVE (5)** questions.

*[**Arahan**: Jawab **LIMA (5)** soalan]*

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1. (a) Define streamline and briefly describe THREE (3) of its main characteristics.

**(20 marks)**

(b) A two-dimensional converging duct is being designed for a high-speed wind tunnel [Figure 1(b)]. The bottom wall of the duct is to be flat and horizontal, whilst the top wall is to be curved in such a way that the axial wind speed increases approximately linearly from 100 m/s at section (1) to 300 m/s at section (2). Meanwhile, the air density decreases approximately linearly from 1.2 kg/m$^3$ at section (1) to 0.85 kg/m$^3$ at section (2). The converging duct is 2.0 m long with height of 2.0 m at section (1).

Given that the fluid is air at temperature 25 $^{O}$C, with the speed of sound at 346 m/s, so the flow is compressible but still subsonic.

(i) Derive the expression of the *y*-component of velocity, *V(x,y)*, in the duct.

**(40 marks)**

(ii) Plot the approximate shapes of the streamlines at y = 0.5 m, 1.0 m, and 1.5 m.

**(30 marks)**

(iii) Calculate the height of the duct at section (2).

**(10 marks)**

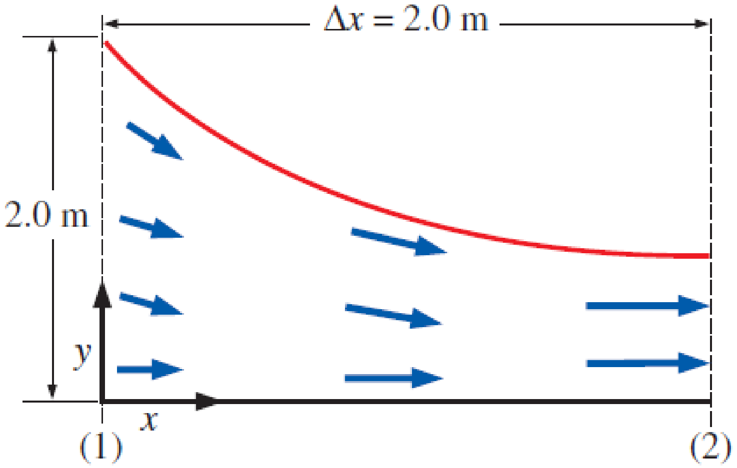


Figure 1 (b) - Converging duct, designed for a high-speed wind tunnel (not to scale).

2. (a) With the aid of a diagram, explain the boundary layer formation as a homogeneous fluid flows through an infinitely smooth flat plate.

**(30 marks)**

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

Given $V$ = 5.0 m/s, $v$ = 1.7 x $10^{-5}$ $m^2$/s, and $x$ = 1.0 m,

(i) Predict the state of the flow and justify your answer.

**(20 marks)**

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

**(40 marks)**

(iii) Justify your answers in part (ii) and compare to real life applications.

**(10 marks)**

***[Given symbols have their usual meanings.]***

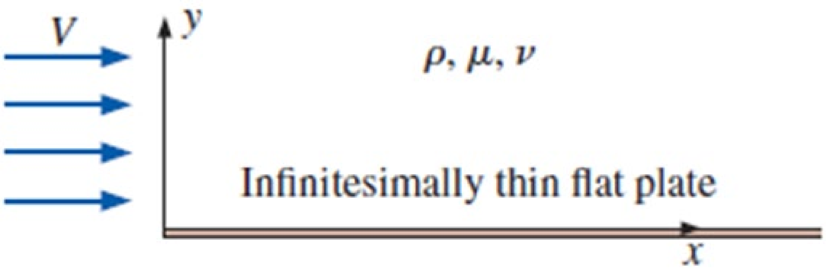


Figure 2 (b)

Table 2 (b)

Summary of expressions for laminar and turbulent boundary layers on a smooth flat plate aligned parallel to a uniform stream*

| Property | Laminar | (a) Turbulent(†) | (b) 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) A spherical plastic sphere (diameter of 3.5 mm) with a density of 1100 kg/m$^3$ is dropping into water at 30$^o$C. By assuming the fluid flow over the sphere is laminar and the drag coefficient is constant, calculate the terminal velocity of the sphere in water.

**(30 marks)**

(b) Water is flowing over a long flat plate with a velocity of 10 m/s. By assuming the flow is steady and incompressible, calculate the distance from the leading edge of the plate where the flow becomes turbulent, and the thickness of the boundary layer at the location.

(Given the water properties at 1 atm and 25$^o$C , density ρ = 997 kg/m$^3$, dynamic viscosity μ = 0.891 x 10$^{-3}$ kg/m.s)

**(30 marks)**

(c) Consider an airplane as Figure 3 (c) with a takeoff speed of 280 km/h takes 18 s to takeoff at sea level. The airport has an elevation of 1600 m altitude. By assuming the lift coefficient, the planform area, and the accelaration of the airplane during takeoff remain constant at standard atmospheric conditions, calculate:

(i) The takeoff speed and take off time.

**(20 marks)**

(ii) The additional runway length required for this airplane.

**(20 marks)**

(Given the density of standard air, $\rho_1$=1.225 kg/m$^3$ at sea level, $\rho_2$=1.048 kg/m$^3$ at 1600 m altitude)


Figure 3 (c)

4. (a) Consider the steady air enters a nozzle at a velocity 130 m/s, 325 K and 0.15 MPa. The flow is assumed as isentropic with $k$ = 1.4. Calculate the air pressure and temperature at a location of air velocity equals the speed of sound and the ratio of the area at this location to the entrance area.

(Given the air properties, Gas constant, $R$= 0.2870 kJ/ kg.K, and $c_p$ = 1.005 kJ/kg.K)

**(50 marks)**

(b) Air flowing through a nozzle experiences a normal shock at a velocity 710 m/s, pressure 23.4 kPa and temperature 219 K. By assuming the flow through the nozzle is steady, one-dimensional, and isentropic before the shock occurs, calculate:

(i) The stagnation temperature, stagnation pressure and the Mach number upstream the shock.

**(25 marks)**

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(ii) The temperature and air velocity downstream the shock.

**(25 marks)**

(Given the air properties at room temperature, $k$ = 1.4, Gas constant $R$ = 0.287 kJ/ kg.K, and $c_p$ = 1.005 kJ/ kg.K)

5. Briefly explain the following terms:

(a) Cut-in speed **(5 marks)**

(b) Rated speed **(5 marks)**

(c) Cut out speed **(5 marks)**

(d) Betz limit **(5 marks)**

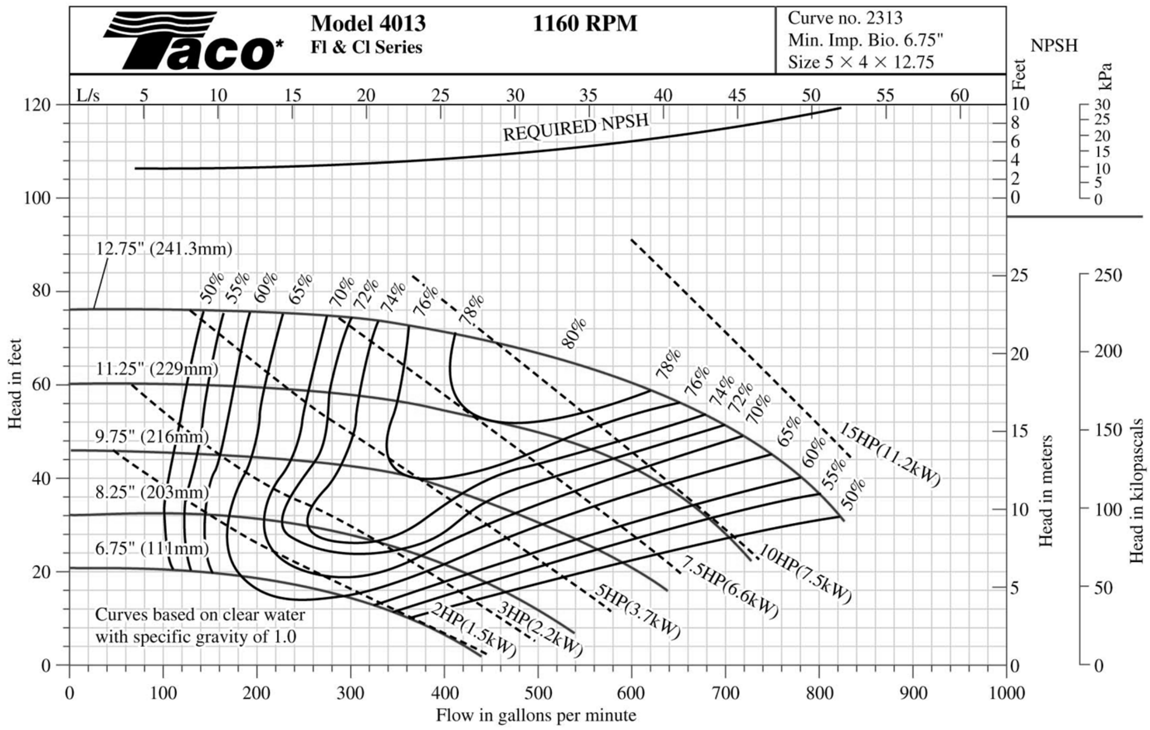


Figure 5

A client appointed you to design a water pumping system for an oceanarium's filtration system. The filtration system required to process 120 L/s of water and the net head for this system is 8.5m. The available space for pumping system can accommodate not more than four pumps.

(e) Referring to Figure 5, state **FIVE (5)** pump options.

**(25 marks)**

(f) What is the best pump option? Justify the option with calculations.

**(35 marks)**

The oceanarium has an existing HAWT wind turbine with diameter of 10 m. The power coefficient of this turbine is 0.4, the combined efficiency of the gearbox and the generator is 85%, and the recorded average wind speed is 10.5 m/s. Given $\rho_{air,30°C}$ = 1.164 kg/m$^3$, $\rho_{water,23°C}$ = 997 kg/m$^3$, $\rho_{sea\ water,23°C}$ = 1024 kg/m$^3$.

(g) Justify whether the wind turbine is producing enough power to drive the water pumping system?

**(20 marks)**

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**Formula & equation:**

*Net head:*

$$H = \left( \frac{P}{\rho g} + \frac{V^2}{2g} + z \right)_{\text{out}} - \left( \frac{P}{\rho g} + \frac{V^2}{2g} + z \right)_{\text{in}}$$

*Water horsepower:* $\dot{W}_{\text{water horsepower}} = \dot{m} g H = \rho g \dot{V} H$

*Brake horsepower:* $\text{bhp} = \dot{W}_{\text{shaft}} = \omega \text{T}_{\text{shaft}}$

*Pump efficiency:*

$$\eta_{\text{pump}} = \frac{\dot{W}_{\text{water horsepower}}}{\dot{W}_{\text{shaft}}} = \frac{\dot{W}_{\text{water horsepower}}}{\text{bhp}} = \frac{\rho g \dot{V} H}{\omega \text{T}_{\text{shaft}}}$$

*Available wind power:*

$$\dot{W}_{\text{available}} = \frac{d(\frac{1}{2} m V^2)}{dt} = \frac{1}{2} V^2 \frac{dm}{dt} = \frac{1}{2} V^2 \dot{m} = \frac{1}{2} V^2 \rho V A = \frac{1}{2} \rho V^3 A$$