Second Semester Examination
Academic Session 2017/2018

May/June 2018

EMH 222 – Fluid Dynamics
[Dinamik Bendalir]

Duration : 3 hours
[Masa : 3 jam]

Please check that this paper contains **ELEVEN [11]** printed pages including appendix before you begin the examination.

*[Sila pastikan bahawa kertas soalan ini mengandungi **SEBELAS [11]** mukasurat bercetak beserta lampiran sebelum anda memulakan peperiksaan.]*

INSTRUCTIONS : Answer **ALL FIVE [5]** questions.
*[**ARAHAN** : Jawab **SEMUA LIMA [5]** soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.]

1. [a] **Describe ONE difference between a Newtonian and a non-Newtonian fluids. Give ONE example of a Newtonian fluid and ONE example of a non-Newtonian fluid.**

*Bincangkan **SATU** perbezaan antara bendalir Newtonian dan bendalir bukan Newtonian. Berikan **SATU** contoh bendalir Newtonian dan **SATU** contoh bendalir bukan Newtonian.*

(20 marks/*markah***)**

[b] **As depicted in Figure 1[b], fluid flows through a pipe with a circular cross-section with radius $r = R$. The fluid flow is driven by a constant pressure gradient (dp/dz) along the axial direction. Ignore the pressure gradient in the radial and circumferential directions, $dp/dr = dp/d\theta = 0$. Also, ignore the gravitational effect and assume no velocity components in the radial and circumferential directions, i.e., $u_r = u_\theta = 0$.**

Seperti yang digambarkan dalam Rajah 1[b], bendalir mengalir melalui paip dengan keratan rentas bulat dengan jejari $r = R$. Aliran bendalir didorong oleh kecerunan tekanan malar (dp/dz) sepanjang arah paksi. Abaikan kecerunan tekanan dalam arah jejari dan lilitan, $dp/dr = dp/d\theta = 0$. Abaikan kesan graviti dan anggap tiada komponen halaju dalam arah jejari dan lilitan, iaitu, $u_r = u_\theta = 0$.

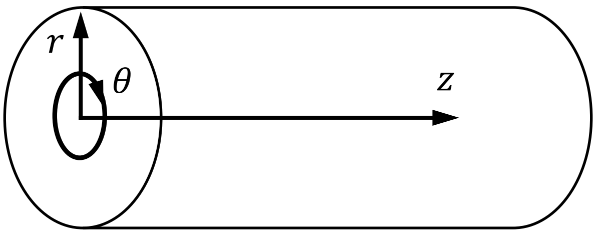

Figure 1[b]
Rajah 1[b]

(i) **Show that the flow is a fully developed flow with velocity field independent of z.**
Tunjukkan bahawa aliran adalah aliran terbentuk sepenuhnya dengan medan halaju tidak bersandar dengan z.

(10 marks/*markah***)**

(ii) **For a steady, incompressible, Newtonian fluid flows through a pipe, derive the axial velocity as**
Untuk bendalir Newtonian yang mantap, tidak boleh mampat, melalui paip, terbitkan halaju paksi sebagai

$$u_z = \frac{1}{4\mu}\frac{dP}{dz}(r^2 - R^2)$$

(70 marks/*markah*)

2. [a] **Give the definition of boundary layer thickness. For fluid flow along a long thin plate, discuss the development of the boundary layer and the velocity profile.**

Berikan definisi ketebalan lapisan sempadan. Untuk aliran bendalir atas plat panjang yang nipis, bincangkan perkembangan lapisan sempadan dan profil halaju.

(20 marks/*markah*)

[b] **Air flows past a smooth flat plate with a free-stream velocity (as shown in Figure 2[b]). The streamwise velocity component of the steady, incompressible and laminar flow can be approximated by a simple expression:**

Udara mengalir melalui satu plat rata dengan halaju aliran bebas (seperti yang ditunjukkan dalam Rajah 2[b]). Komponen halaju arah aliran bagi aliran yang mantap, tak boleh mampat dan lamina boleh dianggarkan dengan ungkapan yang ringkas:

$$u = U\left[\frac{2y}{\delta} - \left(\frac{y}{\delta}\right)^2\right]$$

where U is the free-stream velocity and δ is the boundary layer thickness.

di mana U ialah halaju aliran bebas dan δ ialah ketebalan lapisan sempadan.

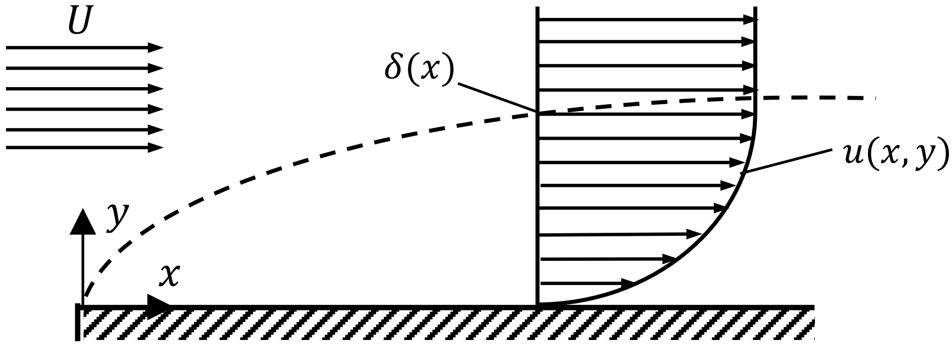

Figure 2[b]
Rajah 2[b]

(i) Calculate the displacement thickness, δ^*.
Kirakan ketebalan sesaran, δ^*.

(40 marks/*markah***)**

(ii) Calculate the momentum thickness, θ.
Kirakan ketebalan momentum, θ.

(40arks/*markah***)**

3. [a] **A spherical dust particle with 0.1 mm diameter is suspended in the air at a fixed point. The density and dynamic viscosity of air at 25^{o}C and 1 atm are ρ_f = 1.184 kg/m^3 and μ=1.849 x 10^{-5} kg/m.s. Using Stokes law, calculate the updraft velocity of air motion and the Reynolds number at the location.**

(Given dust density, ρ_s = 3.2 g/cm^3)

Satu partikel debu berdiameter 0.1 mm tergantung dalam udara pada suatu titik tetap. Ketumpatan dan kelikatan dinamik udara tersebut pada 25^{o}C dan 1 atm adalah ρ_f = 1.184 kg/m^3 and μ=1.849 x 10^{-5} kg/m.s. Dengan menggunakan Hukum Stokes, kirakan halaju draf keatas pergerakan udara dan nombor Reynolds pada lokasi tersebut.

(Diberikan ketumpatan debu, ρ_s = 3.2 g/cm^3)

(30 marks/*markah***)**

[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).

Air mengalir melepasi plat rata panjang dengan halaju 10 m/s. Dengan mengandaikan aliran ialah mantap dan tidak boleh mampat, kirakan jarak daripada tepi depan plat dimana aliran menjadi gelora, dan ketebalan lapisan sempadan pada lokasi tersebut,

(Diberikan sifat air pada 1 atm dan 25^{o}C, ketumpatan ρ = 997 kg/m^3, kelikatan dinamik μ = 0.891 x 10^{-3} kg/m.s).

(30 marks/*markah***)**

[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 acceleration of the airplane during takeoff to remain constant at standard atmospheric conditions, calculate;**

(Given the density of standard air, ρ_1=1.225 kg/m^3 at sea level, ρ_2=1.048 kg/m^3 at 1600 m altitude).

Pertimbangkan sebuah pesawat seperti Rajah 3[c] yang mempunyai laju berlepas 280 km/j mengambil 18 s untuk berlepas pada aras laut. Lapangan terbang mempunyai aras tinggi 1600 m altitud. Dengan mengandaikan pekali angkat, luas planform, dan pecutan pesawat semasa berlepas adalah malar pada keadaan tekanan piawai, kirakan;

(Diberikan tekanan udara piawai, ρ_1=1.225 kg/m^3 pada aras laut, ρ_2=1.048 kg/m^3 pada altitud 1600 m).

(a) **The takeoff speed and takeoff time.**
Laju dan jangka masa berlepas.

(b) **The additional runway length required for this airplane.**
Panjang landasan tambahan yang diperlukan untuk pesawat ini.

(40 marks/*markah***)**

Figure 3[c]
Rajah 3[c]

4. [a] Define sound and the way it is generated and travels.

Terangkan bunyi dan cara ia terhasil dan bergerak.

(20 marks/*markah***)**

[b] Hydrogen enters a converging-diverging nozzle at 90 m/s, 0.8 MPa, and 750 K. The flow through the nozzle is steady, one-dimensional and isentropic. By assuming the hydrogen is an ideal gas with constant specific heat, calculate the lowest temperature and pressure that can be obtained at the nozzle throat.

Hidrogen memasuki muncung menumpu-mencapah pada 90 m/s, 0.8 Mpa, dan 750 K. Aliran tersebut melalui muncung pada keadaan mantap, satu dimensi dan isentropik. Dengan mengandaikan hidrogen tersebut ialah gas unggul dengan haba spesifik malar, kirakan suhu dan tekanan paling rendah yang boleh didapati pada leher muncung.

(40 marks/ *markah)*

[c] In a supersonic wind tunnel, air is flowing with low velocity through a converging-diverging nozzle at temperature 300 K and pressure 1.5 MPa. At the exit nozzle, the normal shock wave occurs at Mach number, Ma= 2.5. By assuming the air is an ideal gas with constant specific heats and the flow is steady, calculate the Mach number, pressure, temperature, and velocity downstream the shock.

(Given: the properties of air, R = 0.287 kJ/kg.K, and k=1.4)

Di dalam terowong angin supersonik, udara mengalir dengan halaju rendah melalui muncung menumpu-mencapah pada suhu 300 K dan tekanan 1.5 MPa. Pada bahagian keluaran muncung, gelombang kejutan normal berlaku pada nombor Mach, Ma = 2.5. Dengan mengandaikan udara ialah gas unggul dengan haba tentu yang malar dan aliran adalah mantap, kirakan nombor Mach, tekanan, suhu dan halaju selepas kejutan

(Diberkan: sifat-sifat udara, R= 0.287 kJ/kg.K, dan k = 1.4)

(40 marks/*markah***)**

5. [a] **Figure 5[a](i) shows a plot of pump net head as a function of pump volume flow rate, or capacity. On the figure, label the shutoff head, the free delivery, the pump performance curve, the system curve and the operating point.**

Rajah 5[a](i) menunjukkan satu lakaran turus bersih pam sebagai fungsi keupayaan dan kadar aliran isipadu pam. Dalam rajah, labelkan turus tutup, penghantaran bebas, lengkung prestasi pam, lengkung sistem, dan titik pengendalian.

(25 marks/*markah***)**

Consider the flow system shown in Figure 5[a](ii). Use the Figure 5[a](i) to indicate the changes.

Rujuk kepada sistem aliran ditunjukkan dalam Rajah 5[a](ii). Gunakan Rajah 5[a](i) untuk menunjukkan perubahan.

(10 marks/*markah***)**

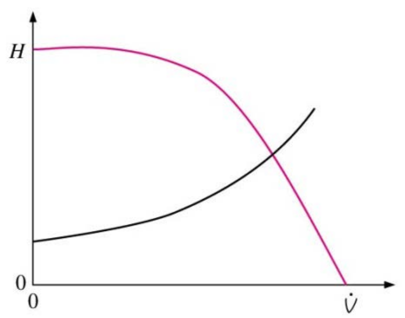

Figure 5[a](i)
Rajah 5[a](i)

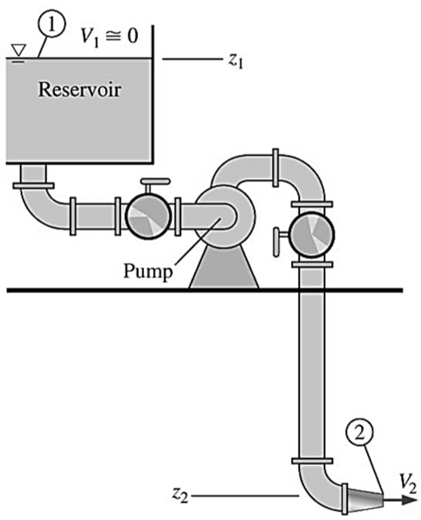

Figure 5[a](ii)
Rajah 5[a](ii)

[b] A pump rotates at $\dot{n}$ = 1200 rpm. Water enters the impeller normal to the blade (α_1 = 0°) and exits at an angle of 40° from radial (α_2 = 40°). The inlet radius is r_1 = 15.0 cm, and the blade width b_1 = 20.0 cm. The outer radius is r_2 = 30.0 cm, and the blade width b_2 = 17.5 cm. The volume flow rate is 0.812 m^3/s. Assuming 100% efficiency, and density of water = 1000 kg/m^3, calculate:

Sebuah pam berputar pada $\dot{n}$ = 1200 rpm. Air masuk pendesak normal kepada bilah (α_1 = 0°) dan keluar pada sudut 40° dari radial (α_2 = 40°). Jejari masuk ialah r_1 = 15.0 cm, dan lebar bilah b_1 = 20.0 cm. Jejari luar ialah r_2 = 30.0 cm, dan lebar bilah b_2 = 17.5 cm. Kadar aliran isipadu ialah 0.812 m^3/s. Anggap kecekapan 100%, dan ketumpatan air = 1000 kg/m^3, kirakan:

(i) The normal and tangential velocities at inlet and outlet,
Halaju tangen dan normal di masuk dan keluaran,

(ii) The net head produced by this pump in cm of water column height,
Turus bersih dihasilkan oleh pam ini dalam ketinggian cm air,

(iii) The required brake horsepower in W.
Kuasa kuda brek yang diperlukan dalam W.

(50 marks/*markah*)

This pump is requested to be modified so that the original pump casing can be used but able to achieve new net head of 10 m.

Pam ini diminta ubahsuai supaya selongsong pam asal boleh digunakan tetapi boleh mencapai turus bersih setinggi 10 m.

(iv) Justify the modification to be made, and
Wajarkan perubahan akan dibuat, dan

(v) Calculate its new outcome performance.
Kirakan kecekapan keluaran barunya.

(15 marks/*markah*)

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APPENDIX 3
LAMPIRAN 3

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

Volume flow rate: $\dot{V} = 2\pi r_1 b_1 V_{1,n} = 2\pi r_2 b_2 V_{2,n}$

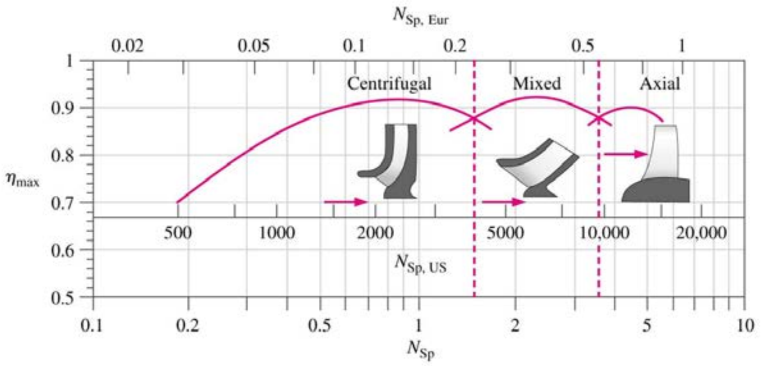
Tangential velocity, $V_{1,t} = V_{1,n} \tan \alpha_2$

Net head: $H = \frac{1}{g}(\omega r_2 V_{2,t} - \omega r_1 V_{1,t})$

Affinity laws

$$\frac{\dot{V}_B}{\dot{V}_A} = \frac{\omega_B}{\omega_A}\left(\frac{D_B}{D_A}\right)^3$$

$$\frac{H_B}{H_A} = \left(\frac{\omega_B}{\omega_A}\right)^2\left(\frac{D_B}{D_A}\right)^2$$



Maximum efficiency as a function of pump specific speed for the three main types of dynamic pump. The horizontal scales show nondimensional pump specific speed (N_{Sp}), pump specific speed in customary U.S. units ($N_{Sp, US}$), and pump specific speed in customary European units ($N_{Sp, Eur}$).

APPENDIX 1
LAMPIRAN 1

Continuity and Navier-Stokes Equations
Cartesian Coordinate

Continuity:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

N-S equation:

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial P}{\partial x}+\rho g_x+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial y}+\rho g_y+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial P}{\partial z}+\rho g_z+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)$$

Cylindrical Coordinates
Continuity:

$$\frac{1}{r}\frac{\partial(ru_r)}{\partial r}+\frac{1}{r}\frac{\partial u_\theta}{\partial \theta}+\frac{\partial u_z}{\partial z}=0$$

N-S equation:

$$\rho\left(\frac{\partial u_r}{\partial t}+u_r\frac{\partial u_r}{\partial r}+\frac{u_\theta}{r}\frac{\partial u_r}{\partial \theta}-\frac{u_\theta^2}{r}+u_z\frac{\partial u_r}{\partial z}\right)$$
$$=-\frac{\partial P}{\partial r}+\rho g_r+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u_r}{\partial r}\right)-\frac{u_r}{r^2}+\frac{1}{r^2}\frac{\partial^2 u_r}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial u_\theta}{\partial \theta}+\frac{\partial^2 u_r}{\partial z^2}\right]$$

$$\rho\left(\frac{\partial u_\theta}{\partial t}+u_r\frac{\partial u_\theta}{\partial r}+\frac{u_\theta}{r}\frac{\partial u_\theta}{\partial \theta}+\frac{u_r u_\theta}{r}+u_z\frac{\partial u_\theta}{\partial z}\right)$$
$$=-\frac{1}{r}\frac{\partial P}{\partial \theta}+\rho g_\theta+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u_\theta}{\partial r}\right)-\frac{u_\theta}{r^2}+\frac{1}{r^2}\frac{\partial^2 u_\theta}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial u_r}{\partial \theta}+\frac{\partial^2 u_\theta}{\partial z^2}\right]$$

$$\rho\left(\frac{\partial u_z}{\partial t}+u_r\frac{\partial u_z}{\partial r}+\frac{u_\theta}{r}\frac{\partial u_z}{\partial \theta}+u_z\frac{\partial u_z}{\partial z}\right)=-\frac{\partial P}{\partial z}+\rho g_z+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u_z}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 u_z}{\partial \theta^2}+\frac{\partial^2 u_z}{\partial z^2}\right]$$

Boundary layer approximation

$\delta^*=\int_0^\infty\left(1-\frac{u}{U}\right)dy$

$\theta=\int_0^\infty\frac{u}{U}\left(1-\frac{u}{U}\right)dy$

Property	Laminar	Turbulent
Boundary layer thickness	$\frac{\delta}{x}=\frac{4.91}{\sqrt{Re_x}}$	$\frac{\delta}{x}=\frac{0.16}{(Re_x)^{1/7}}$
Displacement thickness	$\frac{\delta^*}{x}=\frac{1.72}{\sqrt{Re_x}}$	$\frac{\delta^*}{x}=\frac{0.020}{(Re_x)^{1/7}}$
Momentum thickness	$\frac{\theta}{x}=\frac{0.664}{\sqrt{Re_x}}$	$\frac{\theta}{x}=\frac{0.016}{(Re_x)^{1/7}}$
Local skin friction coefficient	$C_{f,x}=\frac{0.664}{\sqrt{Re_x}}$	$C_{f,x}=\frac{0.027}{(Re_x)^{1/7}}$

APPENDIX 2

LAMPIRAN 2

Incompressible and Compressible Flow Formula

1. Stokes law ; $F_D = 3\pi\mu VD$; $F_D = W - F_B$
2. Sphere volume; $V = \frac{4}{3}\pi R^3$
3. $Re = \frac{\rho VD}{\mu}$; $Re_x = \frac{\rho Vx}{\mu}$
4. Laminar ; $\delta = \frac{4.91x}{Re_x^{1/2}}$; $C_{f,x} = \frac{0.664}{Re_x^{1/2}}$
5. Turbulent ; $\delta = \frac{0.38x}{Re_x^{1/5}}$; $C_{f,x} = \frac{0.059}{Re_x^{1/5}}$
6. $C_L = \frac{F_L}{\frac{1}{2}\rho V^2 A}$; 7. $a = \frac{V}{t}$
8. $h_o = h + \frac{V^2}{2}$ 9. $T_o = T + \frac{V^2}{2c_p}$ 10. $\frac{P_o}{P} = \left(\frac{T_o}{T}\right)^{k/(k-1)}$
11. $\frac{T^*}{T_o} = \frac{2}{k+1}$ 12. $\frac{P^*}{P_o} = \left(\frac{2}{k+1}\right)^{k/(k-1)}$ 13. $\frac{\rho^*}{\rho_o} = \left(\frac{2}{k+1}\right)^{1/(k-1)}$
14. $\frac{T_o}{T} = 1 + \left(\frac{k-1}{2}\right)Ma^2$ 15. $\frac{P_o}{P} = \left[1 + \left(\frac{k-1}{2}\right)Ma^2\right]^{k/(k-1)}$
16. $\frac{\rho_o}{\rho} = \left[1 + \left(\frac{k-1}{2}Ma^2\right)\right]^{1/(k-1)}$ 17. $Ma = \frac{V}{c}$; 18. $c = \sqrt{kRT}$