First Semester Examination
Academic Session 2018/2019

December 2018/January 2018

EME 451 – Computational Fluid Dynamics
[Pengkomputaran Dinamik Bendalir]

Duration : 2 hours
[Masa : 2 jam]

Please check that this paper contains **SEVEN [7]** printed pages including appendix before you begin the examination.

*[Sila pastikan bahawa kertas soalan ini mengandungi **TUJUH [7]** mukasurat bercetak beserta lampiran sebelum anda memulakan peperiksaan.]*

INSTRUCTIONS : Answer **ALL FOUR [4]** questions.
*[**ARAHAN** : Jawab **SEMUA EMPAT [4]** soalan.]*

Answer Questions In **English** OR **Bahasa Malaysia**.
*[Jawab soalan dalam **Bahasa Inggeris** ATAU **Bahasa Malaysia**.]*

Answer to each question must begin from a new page.
[Jawapan bagi setiap soalan mestilah dimulakan pada mukasurat yang baru.]

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. The 1D Euler equations can be modeled by
Persamaan 1D Euler boleh dimodelkan oleh

$$\frac{\partial \mathbf{u}}{\partial t} + \frac{\partial (\mathbf{f})}{\partial x} = 0 \qquad \textbf{(1)}$$

where $\mathbf{u}$ is a vector representing the mass, momentum and energy while $\mathbf{f}$ represents the inviscid fluxes.
di mana $\mathbf{u}$ merupakan vektor merangkumi jisim, momentum dan tenaga dan $\mathbf{f}$ merupakan fluks-fluks 'inviscid'.

[a] The 1D Euler equations can be discretized using the MacCormack (two-step) scheme.

Persamaan 1D Euler boleh didiskretkan dengan menggunakan teknik MacCormack (dua langkah).

$$\begin{aligned} \mathbf{u}_j^* &= \mathbf{u}_j^n - \frac{\Delta t}{\Delta x}[\mathbf{f}_j^n - \mathbf{f}_{j-1}^n] \\ \mathbf{u}_j^{n+1} &= \frac{1}{2}[\mathbf{u}_j^n + \mathbf{u}_j^*] - \frac{\Delta t}{2\Delta x}[\mathbf{f}_{j+1}^* - \mathbf{f}_j^*] \end{aligned} \qquad \textbf{(2)}$$

where $\mathbf{f}^* = \mathbf{f}(\mathbf{u}^*)$, and $\mathbf{u}^*$ is an intermediate quantity.
di mana $\mathbf{f}^* = \mathbf{f}(\mathbf{u}^*)$, dan $\mathbf{u}^*$adalah kuantiti pertengahan.

Assume that the 1D Euler equations (Eqn. (1)) can be modeled by the linear (scalar) advection equation where $\mathbf{u} = u$, and $\mathbf{f} = au$ (*a* is constant). Using the MacCormack scheme (Eqn. (2)), solve the linear advection equation and determine what does it reduce to? What is unique about this method?

Andaikan persamaan 1D Euler dimodelkan oleh persamaan (skalar) adveksi linear di mana $\mathbf{u} = u$ dan $\mathbf{f} = au$ (a adalah pemalar). Dengan menggunakan teknik teknik MacCormack, selesaikan persamaan adveksi linear dan tentukan apa hasilnya? Apakah keunikan teknik ini?

(70 marks/*markah*)

[b] Determine the order-of-accuracy in time and space of the resulting method in part (a).

Tentukan kejituan dalam masa dan ruang untuk teknik yang dihasilkan dalam bahagian (a).

(30 marks/*markah*)

2. For isothermal conditions, the 1D Euler equations can be modeled as follows.

Dalam keadaan isotermal, persamaan 1D Euler boleh dimodelkan seperti berikut.

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} = 0 \qquad \textbf{(3)}$$

$$\frac{\partial (\rho u)}{\partial t} + \frac{\partial (\rho u^2 + a^2 \rho)}{\partial x} = 0 \qquad \textbf{(4)}$$

[a] Write the above equations in terms of $\mathbf{u}_t + A\mathbf{u}_x = 0$, where $\mathbf{u} = [\rho, \rho u]^T$.

Tuliskan persamaan di atas dalam bentuk $\mathbf{u}_t + A\mathbf{u}_x = 0$, di mana $\mathbf{u} = [\rho, \rho u]^T$.

(40 marks/*markah*)

[b] Evaluate the eigenvalues (λ) of the system.

Tentukan eigenvalue (λ) sistem tersebut.

(20 marks/*markah*)

[c] Determine the type of PDE of the system.

*Tentukan jenis PDE sistem tersebut***.**

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

[d] Design a computational stencil about point $\mathbf{u}_j^n$ to solve the problem, when

Rekabentuk suatu stensil pengkomputeraan pada titik $\mathbf{u}_j^n$ untuk menyelesaikan masalah ini, apabila

(i) $|u| < a$**, and/***dan*

(ii) $|u| \geq a$

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

3. What is Finite Volume Method? Explain it with suitable diagram.

Apakah Kaedah Isipadu Terhingga? Jelaskan ia dengan diagram yang bersesuaian.

(15 marks/*markah*)

[a] Describe the following multiphase flow models and give some application examples:

Terangkan aliran model multifasa berikut dan berikan beberapa contoh aplikasi:

(i) Volume of Fluid,
Isipadu Bendalir

(ii) Mixture,
Campuran

(iii) Eulerian,
Eulerian

(iv) Lagrangian.
Langrangian

(40 marks/*markah*)

[b] Discuss the initial and boundary conditions for two dimensional unsteady, supersonic, viscous flow over the flat plate. Provide sketching to support your answer.

Bincangkan keadaan awal dan keadaan sempadan bagi aliran dua dimensi tidak mantap, supersonik, dan likat ke atas plat rata. Berikan lakaran untuk menyokong jawapan anda.

(30 marks/*markah*)

[c] Differentiate the <u>THREE</u> main categories for predicting turbulent flow.

Bezakan <u>TIGA</u> kategori utama untuk ramalan aliran gelora.

(15 marks/ markah)

4. A two dimensional CFD simulation of flow over an airfoil was carried out to study the streamlines, lift, and drag coefficients through wind tunnel. The airfoil was fixed to the shaft and mounted with three axis force balancing system. The incoming velocity flow of air through the wind tunnel is 50 m/s and the average output velocity from the wind tunnel is 35 m/s.

Suatu simulasi dua dimensi CFD bagi aliran ke atas airfoil telah dijalankan untuk mempelajari garis arus, koefisien-koefisien angkat dan seret melalui terowong angin. Airfoil tersebut telah ditetapkan kepada shaf dan dilekapkan dengan sistem keseimbangan daya tiga paksi. Aliran halaju masuk bagi udara ke dalam terowong angin ialah 50 m/s dan purata halaju output daripada terowong angin ialah 35 m/s.

(i) Sketch the modelling of wind tunnel, airfoil, and three axis force balancing system. Show the boundary conditions of each simulation setting.
Lakar pemodelan terowong angin, airfoil, dan sistem keseimbangan daya tiga paksi. Tunjukkan keadaan sempadan bagi setiap tatacara simulasi.

(25 marks/*markah*)

(ii) Suggest the suitable grid type and give <u>TWO</u> important criteria of the grid selection.
Cadangkan jenis grid yang bersesuian dan berikan DUA kriteria yang penting bagi pemilihan grid tersebut.

(20 marks/*markah)*

(iii) Show the output prediction at the end of the simulation.
Tunjukkan ramalan output pada akhir simulasi.

(10 marks/*markah)*

(iv) Give THREE advantages of using CFD simulation compared to wind tunnel experiment.
Berikan TIGA kelebihan menggunakan simulasi CFD berbanding ekperimen terowong angina.

(15 marks/*markah)*

[a] Compare 1-way and 2-way coupling methods in Fluid-Structure Interaction.

Bandingkan 1-laluan dan 2-laluan kaedah gandingan dalam Interaksi Bendalir Struktur.

(30 marks/*markah)*

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APPENDIX 1
LAMPIRAN 1

Appendix-Useful formula

$$f(x \pm \Delta x) = f(x) \pm \Delta x f^{'}(x) + \frac{\Delta x^2}{2} f^{''}(x) \pm \frac{\Delta x^3}{6} f^{'''}(x) + \frac{\Delta x^4}{24} f^{''''}(x) + O(\Delta x^5) \quad (1)$$

$$u_j^n = G^n e^{ij\theta} \quad (2)$$

$$det(A - \lambda I) = 0 \quad (3)$$