First Semester Examination
2021/2022 Academic Session

February/March 2022

EME 451 – Computational Fluid Dynamics

Duration : 2 hours

Please ensure that this examination paper contains **TWELVE (12)** pages and **FOURTY OBJECTIVE (40)** question before you begin the examination.

Instructions : Answer **ALL** questions.

Answer all questions in **English** OR **Bahasa Malaysia** OR a combination of both.

Each question must begin from a new page.

1. State the method to determine the accuracy of numerical simulation to be second order
   a) By analyzing the residual plot to see that it is converged.
   a) By looking at the variables plot (i.e., p,u,v) decreasing at second order rate.
   b) By analyzing the plot of errors vs the grid size and see the slope of close to 2 for errors reduction.
   c) By analyzing the log-log plot of errors vs grid size and see the slope of close to 2 for errors reduction
   d) None of the answers are correct

2. Predict the suitable stopping criterion when using a pressure-based CFD solver
   a) If the errors are decreasing.
   b) If the residuals are decreasing.
   c) If the residuals decrease below the errors level.
   d) If errors decrease below the residuals level.
   e) None of the answers are correct

3. Identify following statement that best describes a hyperbolic type of PDE
   a) Waves moving in omni-direction.
   b) Waves moving in a preferred direction.
   c) Losses of energy through friction.
   d) Steady-state computations.
   e) None of the answers are correct

4. Identify the type of pde that represents the physics of linearized aerodynamics flow (potential flow)
   a) Elliptic
   b) Parabolic
   c) Hyperbolic.
   d) Hyperbolic or Parabolic
   e) Elliptic or Hyperbolic.

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5. Describe the information that can be gathered by analyzing the Truncation Errors (TE) of a numerical method
   a) To calculate the global errors of the numerical method.
   b) To see if the numerical method is stable.
   c) To compute the local errors of the numerical method.
   d) To approximate the local errors of the numerical method.
   e) To approximate the stability of the numerical method.

6. Describe the primary challenge in solving elliptic PDE
   a) To get high order accuracy.
   b) To get low order accuracy.
   c) To remove diffusion errors.
   d) To remove high frequency errors.
   e) To remove low frequency errors.

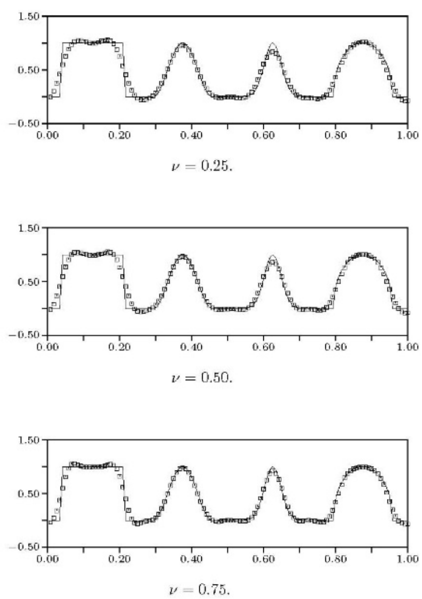

Figure 1

7. Figure 1 show the results of a simple fluid transport in time and space. Estimate the order of accuracy of the numerical method being used

   a) First order.
   b) Second order.
   c) Third Order.
   d) Fourth Order.
   e) Zeroth Order.

8. Given the following system of equations, derive the eigenvalues for the system.

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

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

   Hint : Start by expressing the equations in the form of $U_t + AU_x = 0$, with U=$\begin{bmatrix} u \\ \rho \end{bmatrix}$

   a) $u \pm [a]^{\frac{1}{2}}$
   b) u+a, u-a
   c) $u \pm [\rho]^{\frac{1}{2}}$
   d) u, u
   e) None of the answers are correct

9. State the type of pde for the system that you solve for the eigenvalues?

   a) Elliptic
   b) Hyperbolic
   c) Parabolic or elliptic
   d) Elliptic of hyperbolic
   e) None of the answers are correct

10. The velocity at the centerline of a 2D pipe-flow subjected to a fixed wall boundary conditions has been calculated using a finite volume (FV) scheme on a uniform cells of 30 x 30 intervals and the value is 725 (mm)/s. The calculation is repeated on a mesh of 15 x 15 intervals, giving 743 (mm)/s. Assuming grid size $\Delta x = \Delta y = h$. Consider the FV method is second order accurate. Assuming $h \rightarrow 0$, calculate the best velocity prediction using this method?

a) 719 (mm)/s
b) 713 (mm)/s
c) 715 (mm)/s
d) 721 (mm)/s
e) 709 (mm)/s.

11. Explain the implication of the following equation?

$$u_x + v_y = 0$$

a) The flow is compressible.
b) The flow is incompressible.
c) The velocity is in steady-state condition.
d) The velocity is unsteady.
e) None of the answers are correct

12. Identify the following statements that is NOT true when using a pressure-based solver in Navier-Stokes equations?

a) The numerical solutions will always be smooth.
b) The numerical solutions will be diffused.
c) The numerical solutions will develop shockwaves.
d) The computations will be either steady-state or transient problems.
e) There will be iterations for both steady-state or transient computations.

13. Identify the following statement that best describes the CFL number?

a) Ratio between numerical speed of propagation over the analytical speed of propagation.

b) Ratio between the analytical speed of propagation over the numerical speed of propagation.
c) Ratio of advection speed over diffusion speed
d) Ratio of diffusion speed over advection speed.
e) Ratio of inertial speed over diffusion speed.

14. Consider the scheme $\frac{du}{dx} + \frac{du}{dy} = \frac{3u_{i,j} - 4u_{i-1,j} + u_{i-2,j}}{2\Delta x} + \frac{u_{i,j} - u_{i,j-1}}{`\Delta y} + O(\Delta x^p, \Delta y^q)$.

Calculate the values of p,q?
a) p=1, q=1.
b) p=2, q=2.
c) p=2, q=1.
d) p=3, q=2.
e) p=3, q=1.

15. In the RANS equations, there are turbulent stresses (or Reynolds stresses). Identify the best following statement on the origin of the Reynolds stresses?
a) The unsteady terms.
b) The pressure terms
c) The diffusion terms.
d) The nonlinear terms.
e) The density terms.

16. Identify the main challenge in solving the RANS equation?
a) The numerical methods produce unstable solutions.
b) The numerical methods produce diffusive solutions.
c) The numerical methods are faced with closure problems with the averaged-quantities.
d) The numerical methods are computational expensive.
e) None of the answers are correct

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17. Describe the concept of Gradient Transport Modeling?
    a) To solve turbulent flows.
    b) To approximate the turbulent flows.
    c) To approximate the turbulent stresses using Reynolds-Averaged quantities.
    d) To approximate gradient of fluid transport.
    e) To approximate the fluctuation quantities in turbulent flows.

18. Given that a scalar quantity Ω satisfies the following equation.

$$\frac{\partial \Omega}{\partial t} + \frac{\partial (u\Omega)}{\partial x} = \frac{\partial^2 (\Omega)}{\partial x^2}$$

If we apply the Reynolds-Averaged approach, derive the resulting equation, as described in class.

a) $\frac{\partial(\bar{\Omega})}{\partial t} + \frac{\partial(\overline{u\Omega})}{\partial x} = \frac{\partial^2(\bar{\Omega})}{\partial x^2}$

b) $\frac{\partial(\bar{\Omega})}{\partial t} + \frac{\partial(\bar{u}\,\bar{\Omega})}{\partial x} = \frac{\partial^2(\bar{\Omega})}{\partial x^2} + \frac{\partial(\overline{u'\Omega'})}{\partial x}$

c) $\frac{\partial(\bar{\Omega})}{\partial t} + \bar{u}\frac{\partial(\bar{\Omega})}{\partial x} + \bar{\Omega}\frac{\partial(\bar{u})}{\partial x} = -\frac{\partial(\overline{u'\Omega'})}{\partial x}$

d) $\frac{\partial(\bar{\Omega})}{\partial t} + \bar{u}\frac{\partial(\bar{\Omega})}{\partial x} + \bar{\Omega}\frac{\partial(\bar{u})}{\partial x} = \frac{\partial^2(\bar{\Omega})}{\partial x^2} - \frac{\partial(\overline{u'\Omega'})}{\partial x}$

e) None of the answers are correct

19. Is it physically correct to solve a heat transfer for an incompressible Navier-Stokes fluid model? Justify the reason.
    a) Yes, since heat transfer is a physical phenomenon.
    b) Yes, since physics of incompressible flow is independent of heat transfer.
    c) No, since heat transfer is an inviscid fluid feature.
    d) No, since an incompressible fluid model is an elliptic PDE.
    e) No, since heat transfer is not part of an incompressible fluid model.

20. Using von Neumann analysis, predict the stability condition of the following scheme.

$$u_j^{n+1} = u_j^n - \frac{\nu}{2}\left(u_{j+1}^{n+1} - u_{j-1}^{n+1}\right)$$

a) Unconditionally stable
b) Conditionally stable.
c) Unconditionally unstable.
d) Neutrally stable.
e) None of the answers are correct

21. Identify the dimensionless number on the ratio of momentum diffusivity and thermal diffusivity
    a) Reynolds number
    b) Mach number
    c) Ruark number
    d) Prandtl number

22. State the term on the process in which flow in boundary layer can no longer stay attached to the surface and separates from the surface
    a) Force separation
    b) Boundary separation
    c) Flow separation
    d) Surface separation

23. When mach number < 0.8, the flow is described to be in
    a) Subsonic region
    b) Super sonic regime
    c) Sonic regime
    d) Hypersonic regime

24. When a direct computation of the dependent variables can be made in terms of known quantities, the computation is described to be
    a) Implicit
    b) Explicit
    c) Unique
    d) Dependent

25. Large eddy simulation is described to be in
    a) Laminar flow
    b) Streamline flow
    c) Steady flow
    d) Turbulent flow

26. The boundary condition which include derivative of boundary value is defined as
    a) Dirichlet boundary condition
    b) Neumann boundary condition
    c) Forced boundary condition
    d) Discrete boundary condition

27. Identify the formula of central differencing for 2nd order
    a) Δhf(x)=f(x+h)-f(x)
    b) Δh^2f(x)=f(x+h)-f(x-h)
    c) Δhf(x)=f(x)-f(x+h)
    d) 2Δhf(x)=f(x+h)-f(x-h)

28. Describe the term on the difference between the mathematical model and the real world
    a) Modeling error
    b) Discretization error
    c) Convergence error
    d) None of these

29. Define the term on the difference between the exact solution to the mathematical model and the discretized equations used to approximate
    a) Modeling error
    b) Discretization error
    c) Convergence error
    d) None of these

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30. State the forces which act directly on volumetric mass of fluid element
    a) Fluid forces
    b) Body forces
    c) Direct forces
    d) Distribution forces

31. Skewness can be described to be
    a) (optimal cell size-cell size)/cell size
    b) (optimal cell size-cell size)/ optimal cell size
    c) (cell size-optimal cell size)/ optimal cell size
    d) (optimal size-cell size)

32. Identify the deviation of the vector d that connects the two cells from the face center
    a) Mesh orthogonality
    b) Mesh skewness
    c) Mesh aspect ratio
    d) Smoothness

33. If scalar flux across the boundary is zero, predict the values of properties just adjacent to the solution domain
    A. Maximum
    B. Zero
    C. Minimum
    D. Values of nearest node

34. The transition in size between contiguous cells is defined as
    A. Mesh orthogonality
    B. Mesh skewness
    C. Mesh aspect ratio
    D. Mesh smoothness

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35. For the non-uniform time-steps, identify the correct statement.

(Note: δt is the distance between the centroids of two temporal elements. Δt is the size of a temporal element. The superscript o indicates the older time step)

A. $\delta t = \frac{(\Delta t - \Delta t^o)}{2}$

B. $\delta t = \frac{(\Delta t + \Delta t^o)}{2}$

C. $\delta t = \Delta t$

D. $\delta t = \Delta t^o$

36. With respect to the variable time-steps, identify the correct statement below.

A. The models of finite volume and finite difference do not yield analogous algebraic equations

B. Regardless of the non-uniformity, the finite volume scheme yields related algebraic equations.

C. Regardless of the non-uniformity, the finite difference scheme yields equivalent algebraic equations

D. When the grid is non-uniform, all second-order structures result in the same algebraic equation.

37. Identify the following streams that implies kinetic energy matter

A. Compressible flows

B. Compressible isothermal flows

C. Incompressible isothermal flows

D. Incompressible flows

38. Identify the flows that are subjected to periodic or cyclical boundary terms

A. External flow over blunt bodies

B. Swirling flow surrounded by a cylindrical furnace

C. Free shell flows

D. Buoyancy driven flows

39. State the boundary that can employ periodic or cyclic boundary conditions
    - A. wall
    - B. pressure outlet
    - C. inlet
    - D. symmetry
    - E. interior

40. State the best term that describe 'The angular deviation of the vector from the vector connecting the two cell centres' located at the face centre'.
    - A. Mesh orthogonality
    - B. Mesh skewness
    - C. Mesh aspect ratio
    - D. Mesh smoothness

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