Computational Fluid Dynamics 2017 **PATTERN A**

Notes:

1. There are a total of 60 questions divided into Sections A to F. Questions in Sections A and B are generic questions covering the entire course material. Sections C to F are thematic.

2. All questions are of objective type. Section A has questions that have ONLY ONE correct answer. Questions in Section B have two correct answers each. Questions in Sections C to F have only one correct answer.

3. Each correct answer is worth one mark. The credit for the correct answer is given only when ONLY THE CORRECT answer is identified in that question. Therefore in Sections A, C, D, E and F, only one answer should be entered. For questions in Section B, you will get TWO marks if you identify both the correct answers and only these two. Partial mark can be given only if only correct answers are identified. For example, if (b) and (d) are the correct answers for a question, then you will get two marks if you identify both (b) and (d) as the correct answers and do not tick any other option. If you identify only (b) or only (d) as the correct answer, you will get ONE mark. If you identify either (a) or (c) as the correct answer, you will not get any marks irrespective of how many correct answers you identified correctly. Thus, the credit for the entire question is lost if you choose an incorrect answer.

4. The total marks are 70. Section A is worth 30 marks and Section B is worth 20 marks. Sections C to F account for 5 marks each.

Section A: General Questions (30 marks)

The questions in this section contain ONLY ONE correct answer.

1. Consider the Laplace equation describing steady state heat conduction in a two dimensional rectangular domain. If the equation is discretized using finite difference approximations with uniform grid spacing in both directions, and if the resulting equations are properly arranged and written in the form of a matrix equation, then the non-zero coefficients in the coefficient matrix will

(a) have a tridiagonal structure with three adjacent diagonals including the main diagonal.
(b) have a pentadiagonal structure with five adjacent diagonals including the main diagonal.
(c) have a pentadiagonal structure with three adjacent diagonals and two other diagonals separated diagonals separated by diagonals containing zeroes.
(d) be the sum of two tridiagonal matrices each containing three adjacent diagonals.

2. Which of the following fluids is not Newtonian:

(a) ammonia gas
(b) mercury
(c) petrol
(d) blood

3. For a Newtonian fluid, τ_{yz} is given by

(a) 1/2 μ $(\partial u_i/\partial x_j + \partial u_j/\partial x_i)$
(b) 1/2 μ $(\partial u/\partial y + \partial v/\partial x)$
(c) 1/2 μ $(\partial w/\partial y + \partial v/\partial z)$
(d) none of the above.

4. The convective heat transfer thermal boundary condition is an example of which type of boundary condition:

(a) Dirichlet type (b) Neumann type (c) Robin type (d) None of the above.

5. If we expand $f(x_0 + 3\Delta x)$ about the point x_0 in Taylor series, then the fourth term in the expansion is given by

(a) $(3/2)\ d^2f/dx^2|_{x0}\ \Delta x^2$ (b) $1/2\ d^3f/dx^3|_{x0}\ \Delta x^3$ (c) $(9/2)\ d^3f/dx^3|_{x0}\ \Delta x^3$
(d) $(9/2)\ d^2f/dx^2|_{x0}\ \Delta x^2$

6. $d^3f/dx^3|_i = (-3\ f_{i+4} + 14\ f_{i+3} - 24\ f_{i+2} + 18\ f_{i+1} - 5\ f_i)/(2\Delta x^3)$ is an approximation of what order of accuracy?

(a) 1 (b) 2 (c) 3 (d) 4

7. For which of the following von Neumann stability analysis can be used:

(a) non-linear problems with Dirichlet boundary conditions
(b) linear problems with periodic boundary conditions
(c) linear problems with Neumann boundary conditions
(d) all of the above.

8. Which of the following describes the Beam-Warming method:

(a) Explicit,1st order accurate in time, 2nd order in space, unconditionally stable
(b) Explicit, 2nd order accurate in time, 2nd order in space, conditionally stable
(c) Implicit, 1st order accurate in time, 2nd order in space, unconditionally stable

(d) Implicit, 2nd order accurate in time, 2nd order in space, unconditionally stable

9. The conserved variables that are solved for in MacCormack method are:

(a) ρ, u, v, w, h
(b) ρ, ρu, ρv, ρw, ρe_t
(c) ρ, u, v, w, i
(d) ρ, u, v, w, T

10. Which of the following statements is true about the evaluation of pressure in MacCormack scheme:

(a) pressure is obtained from the continuity equation
(b) pressure is obtained from the momentum equation
(c) pressure is obtained from the equation of state
(d) evaluation of pressure is not necessary for compressible flows

11. A staggered grid system is used

(a) to overcome the stability problem
(b) to enable treatment of flow domain of irregular shape
(c) to simplify grid generation
(d) to eliminate chequerboard oscillations in pressure

12. Which of the following describes the solution of the momentum equation in the pressure correction method in steady flows:

(a) fully implicit except for pressure
(b) fully implicit except for non-linear and coupling terms including pressure
(c) fully implicit except for non-linear and coupling terms excluding pressure
(d) fully implicit in all terms

13. Which of the following schemes may give assurance of convergence for the unsteady advection equation:

(a) FTBS-explicit (b) FTFS-explicit (c) CTCS-explicit (d) none of the above.

14. For the 1-d scalar transport equation with no source term, which of the following will give oscillation-free stable solution with second order accuracy:

(a) FTBSCS-explicit (b) FTCSCS-explicit (c) CTCSCS-implicit (d) None of the above

15. Which of the following statements is true about the Beam-Warming method:

(a) It allows solution by marching forward from grid point to grid point
(b) It allows solution by marching forward in time from time step to time step.
(c) It requires simultaneous solution of discretized equations
(d) It has no time step limitations.

16. For compressible, two-dimensional flows, the minimum number of partial differential equations (pde) to be solved is

(a) 5 (b) 4 (c) 3 (d) 6

17. The continuity equation for compressible flow can be written as

(a) $\partial u_m/\partial x_m = 0$ (b) $\partial u_i/\partial x_j = 0$ (c) $D(\rho)/Dt = 0$ (d) None of the above.

18. The steady-state, 2-D momentum balance in the y-direction, neglecting gravity, can be written for constant property flow as

(a) $u\ \partial u/\partial x + v\ \partial v/\partial y = -1/\rho\ \partial p/\partial x + \mu/\rho\ (\partial^2 u/\partial x^2 + \partial^2 v/\partial y^2)$
(b) $u\ \partial v/\partial x + v\ \partial v/\partial y = -1/\rho\ \partial p/\partial y + \mu/\rho\ (\partial^2 v/\partial x^2 + \partial^2 v/\partial y^2)$
(c) $u\ \partial v/\partial x + v\ \partial v/\partial y = -1/\rho\ \partial p/\partial x + \mu/\rho\ (\partial^2 v/\partial x^2 + \partial^2 v/\partial y^2)$
(d) None of the above

19. Which of the following statements is INCORRECT about solution of the linear system of algebraic equations Ax =b with known coefficients:

(a) If Gaussian elimination works, then LU decomposition can also be used.
(b) If LU decomposition works, then Gaussian elimination can also be used.
(c) If Gauss-Seidel works, then TDMA can also be used.
(d) If TDMA works, then Gauss-Seidel can also be used.

20. Under optimal condition, the number of arithmetic operations required for convergence using the SOR method varies with the number of equations, n, as

(a) $n^{5/4}$ (b) $n^{3/2}$ (c) $n^{7/4}$ (d) $n^{1/2}$

21. Which of the statements is true about the transformation of the Laplace equation into a non-orthogonal curvilinear coordinate system?

(a) The elliptic equation becomes hyperbolic
(b) The elliptic equation becomes parabolic
(c) The transformed equation remains elliptic
(d) The transformed equation contains only normal derivatives

22. In which of the following methods is triangulation with least aspect ratio ensured:

(a) Advancing front method
(b) Bowyer-Watson algorithm
(c) Both of the above
(d) Neither of the above

23. In which of the following methods is proper triangulation of concave surfaces ensured so that no area lying outside the computational domain is triangulated:

(a) Advancing front method
(b) Bowyer-Watson algorithm
(c) Both of the above
(d) Neither of the above

24. Which of the following flows is likely to be turbulent?

(a) Flow in a circular pipe at a Reynolds number of 2000
(b) Flow over a sphere at a Reynolds number of 50000
(c) Flow over a flat plate at a Reynolds number of 100000
(d) None of the above

25. The units of turbulent kinetic energy dissipation rate are

(a) m^2/s^2 (b) m^2/s^3 (c) J (d) J/s

26. Which of the following statements is true about the turbulence closure problem?

(a) It does not arise for fully developed turbulent flow between two parallel plates
(b) It refers to the case of a mathematical problem in which there are too many equations and too few variables
(c) It arises only when do direct numerical simulation of turbulence

(d) None of the above

27. Which ranking is correct in terms of DECREASING number of floating point operations (flops), i.e., more to fewer no. of flops, for the solution of Ax = b on very fine grids:

(a) Gauss-Seidel, SIP, ADI
(b) SIP, GS, multigrid
(c) ADI, optimal successive over-relaxation, multigrid
(d) ADI, multigrid, optimal successive over-relaxation

28. Which of the following statements is NOT true about the multi-grid method of solving Ax = b:

(a) It uses several grids for the same computational domain
(b) It solves the same equations on all the grids
(c) It uses the same boundary conditions on all the grids
(d) None of the above

29. For the one-dimensional wave equation, which of the following statements is correct about the FTCS implicit scheme?

(a) Consistent, unconditionally unstable
(b) Inconsistent, unconditionally stable
(c) Consistent, conditionally stable
(d) Consistent, unconditionally stable

30. The advection term in the momentum conservation equation in the i^{th} direction for constant-property Newtonian fluid flow can be written as

(a) $u_j \, \partial u_i/\partial x_i$ (b) $u_i \, \partial u_j/\partial x_j$ (c) $u_i \, \partial u_j/\partial x_i$ (d) $u_j \, \partial u_i/\partial x_j$

Section B: General Questions (20 marks)

The questions in this section contain TWO correct answers.

31. Which of the following statements is true for a Newtonian fluid:

(a) Viscous stress vs strain relation is linear.
(b) Viscous stress is proportional to the local strain rate
(c) Viscosity is independent of shear stress.
(d) Viscosity is a material constant; it may change from material to material but will not change for a given material.

32. A small fluid element in steady, laminar, fully developed flow of an incompressible fluid between two infinitely long and wide parallel plates undergoes what kind of deformation:

(a) Rotational strain
(b) Extensional strain
(c) Shear strain.
(d) All of the above.

33. Which of the statements is true about inconsistent schemes:

(a) Inconsistent schemes cannot be stable.
(b) Inconsistent schemes cannot be convergent.
(c) Inconsistent schemes cannot match the exact solution.
(d) None of the above

34. The streamfunction-vorticity method can be used for the following problems:

(a) time-dependent flows (b) three-dimensional flows (c) incompressible flows (d) none of the above.

35. Which of the following schemes is stable and second order accurate in both time and space for the unsteady diffusion equation?

(a) FTCS-explicit (b) Crank-Nicolson's scheme (c) DuFort-Frankel scheme
(d) FTCS-implicit.

36. Which of the following statements is true about the MacCormack scheme

(a) It can be used only for incompressible flows.
(b) It is only conditionally stable.
(c) It can be used only for linear equations.
(d) It can be used for compressible flows.

37. The artificial compressibility approach can be used for

(a) three-dimensional flows (b) time-dependent flows (c) incompressible flows
(d) all of the above.

38. Which of the following statements is true about eddy viscosity?

(a) It is dimensionless. (b) It is isotropic. (c) It varies across the cross-section of a pipe even in fully developed flow. (d) None of the above.

39. Which of the statements is true about the transformation of the Poisson equation into a non-orthogonal curvilinear coordinate system

(a) The elliptic equation becomes hyperbolic
(b) The elliptic equation becomes parabolic
(c) The transformed equation remains elliptic
(d) The transformed equation contains cross-derivatives

40. Which of the following statements is true about the Rhie-Chow interpolation scheme

(a) used to evaluate the velocities at the cell centroid
(b) used to avoid chequerboard oscillations in pressure
(c) is needed only for staggered grids
(d) is needed only for non-staggered grids

Section C: Solution of Navier-Stokes Equations (5 marks)

The questions in this section contain ONLY ONE correct answer.

You wish to demonstrate your CFD skills by doing a calculation for the ***unsteady developing, constant property*** flow between two infinitely wide plates separated by a constant height H. Assume that the flow incompressible and laminar and that the fluid is Newtonian. Assume that x-direction is along the plate and y-direction is normal to the plate and you want to do a two-dimensional flow simulation. For this case:

41. The momentum balance in the x-direction, neglecting gravity, can be written as

(a) $\partial u/\partial t = -1/\rho\ \partial p/\partial x + \mu/\rho\ (\partial^2 u/\partial x^2 + \partial^2 v/\partial y^2)$
(b) $\partial u/\partial t + u\ \partial u/\partial x + v\ \partial u/\partial y = -1/\rho\ \partial p/\partial x + \mu/\rho\ (\partial^2 u/\partial x^2 + \partial^2 v/\partial y^2)$
(c) $\partial u/\partial t + u\ \partial u/\partial x + v\ \partial u/\partial y = -1/\rho\ \partial p/\partial x + \mu/\rho\ (\partial^2 u/\partial x^2 + \partial^2 u/\partial y^2)$
(d) $\partial u/\partial t = \mu/\rho\ (\partial^2 u/\partial x^2 + \partial^2 u/\partial y^2)$

42. For this problem, which of the following statements is true?

(a) We do not need to solve the continuity equation.
(b) We can assume pressure gradient in the x-direction to be constant.
(c) We can neglect pressure variation within the flow domain.
(d) We need to solve three partial differential equations.

43. Taking advantage of symmetry, we wish to solve only for the flow field up to mid-height, ie., from y=0 (bottom plate) to y = H/2. The boundary condition at y = H/2 is:

(a) u = 0 (b) v=0 (c) p = 0 (d) none of the above.

44. Regarding the solution of coupled equations, which of the following methods can be used:

(a) artificial compressibility method
(b) streamfunction-vorticity method
(c) the MacCormack method.
(d) None of the above.

45. A momentum source term of the form S_u = ku is added to the x-momentum equation. For what value of k may the source term lead to loss of diagonal dominance of the discretized equation if the source term is discretized implicitly?

(a) k > 0 (b) k < 0 (c) any non-zero value of the k (d) the source term does not have any influence on the diagonal dominance.

Section D: Solution of Linear Algebraic Equations (5 marks)

The questions in this section contain ONLY ONE correct answer.

You wish to solve the Poisson equation in a rectangular two-dimensional domain spanning a length L in the x-direction and width W in the y-direction. You have divided the length L into 20 equal intervals, and the width W into 30 equal intervals. You have Dirichlet boundary conditions on all sides. You discretize the Poisson equation using central difference approximation. The source term is a constant. You wish to solve the resulting set of linear algebraic equations, which you express as Ax = b. For this problem, answer the following questions.

46. The number of equations to be solved will be

(a) 600 ± 5 (b) 550 ± 5 (c) 650 ± 5 (d) 50 ± 5

47. The following method CANNOT be used to solve the set of algebraic equations:

(a) the Gaussian elimination method (b) the Jacobi method (c) the tridiagonal matrix algorithm
(d) None of the above

48. You wish to solve the set of equations using the Gauss-Seidel method. A sufficient condition for this method to converge is:

(a) matrix A is non-singular (b) the spectral radius of A must be less than one (c) matrix A is diagonally dominant (d) none of the above.

49. The norm of the residual at the end of m iterations can be evaluated as

(a) the largest value in magnitude of ($b- Ax^m$) (b) the largest value of $|(x^m- x^{m-1})|$
(c) $||(x^m-x^{m-1})||2$ (d) Any of the above

50. You wish to reduce the residual by a factor of 10000 compared to the residual at the end of the first iteration. The expected number of floating point operations (multiplications and divisions) would be of the order of

(a) 10000 to 20000 (b) 1 to 2 million (c) 50 to 100 million (d) less than 10000

Section E: Turbulence Modelling (5 marks)

The questions in this section contain ONLY ONE correct answer.

51. Which of these is a characteristic feature of turbulent flows:

(a) wholly unpredictable
(b) well-defined periodicity in fluctuations
(c) high diffusivity
(d) do not obey Navier-Stokes equations

52. Which of the following statements is true about the turbulence closure problem?

(a) It arises only when we time-average the governing equations.
(b) It refers to the case of a mathematical problem in which there are too many equations and too few variables
(c) It does not arise for steady flow even if it is turbulent.
(d) It arises only when do direct numerical simulation of turbulence.

53. We are solving the case of steady, fully developed turbulent flow between two infinitely long and wide parallel plates using the k-epsilon turbulence model. For this case, the number of differential equations that we need to solve is

(a) 4 (b) 3 (c) 2 (d) 1

54. Turbulent kinetic energy dissipation rate is defined as (here <…> indicates time averaging)

(a) $(\mu/\rho)\ \langle \partial u'_i/\partial x_j\ \partial u'_j/\partial x_i \rangle$ (b) $(\mu/\rho)\ \langle \partial u'_m/\partial x_m\ \partial u'_n/\partial x_n \rangle$
(c) $(\mu/\rho)\langle \partial u'_m/\partial x_n\ \partial u'_m/\partial x_n \rangle$ (d) $(\mu/\rho)\ \langle \partial u'_i/\partial x_j\ \partial u'_m/\partial x_n \rangle$

55. Which of the following statements is true about Reynolds stresses?

(a) They are dimensionless. (b) They are constant for a given Reynolds number.
(c) They are constant across the cross-section of a pipe in fully developed flow although individual stresses are different. (d) None of the above.

Section F: Reacting Flows (5 marks)

The questions in this section contain ONLY ONE correct answer.

We need to solve for the flow in a chemical reactor in which A gets converted B (the desired product) and C (the by-product) as per the following reaction scheme:

$$aA \longrightarrow bB + cC$$

The reaction is endothermic and heat needs to be supplied. All the species are in gas phase as the reaction happens at high temperatures. We have a reactor of dimensions L x W x H. The sides of the reactor are heated and the top and the bottom surfaces are kept adiabatic. Baffle plates and fins are provided inside for good mixing and heat transfer.

We need to find out how much conversion takes place, i.e., how much of A coming through the inlet gets converted to B. We want to find this out using CFD simulation. Assuming steady, laminar flow through the reactor, answer the following questions:

56. How many mass conservation equations do we need to solve?

(a) only the one for species A (b) only the for species B (c) three, one each for species A, B and C (d) four including one overall mass balance and the three for the three species.

57. Which of the following statements is true about the momentum conservation equation for the gas mixture:

(a) Terms related to the reaction rate would need to be present in the mixture momentum equation.
(b) The equation is unaffected by the rate of chemical reaction.
(c) The equation is affected only to the extent that the properties change as the mixture composition changes.
(d) None of the above.

58. Which of the following statements is true about the energy conservation equation?

(a) Terms related to the reaction rate would need to be added to the energy conservation equation.
(b) The energy conservation equation is unaffected by the rate of chemical reaction.
(c) The energy conservation equation is affected only to the extent that the properties change as the mixture composition changes.
(d) None of the above.

59. Which of the following statements is NOT true about the chemical reaction?

(a) The kinetic parameters of the reaction need to be specified.
(b) The rate of reaction need not be specified; it will be predicted by CFD.
(c) The rate of reaction need not be specified as it can be calculated assuming thermodynamic equilibrium.
(d) The reaction rate is likely to vary with position within the reactor.

60. Assuming the flow to be three-dimensional, the total number of partial differential equations that need to be solved is

(a) 9   (b) 7   (c) 6   (d) 5