AE4202 example exam questions

CFD for Aerospace Engineers (Technische Universiteit Delft)

If you can answer about 60% of these, you're probably in decent shape.

1. **What is the oldest turbulence model still in use today, and when was it developed?**
2. **Who developed the first LES with an eddy viscosity model and when?**
3. **What did jones & Launder develop in 1972?**
4. **What did Rhie & Chow develop in 1983?**
5. **Who developed the k-omega model and when?**
6. **Who developed the dynamic eddy viscosity LES model and when?**
7. **Who developed the SST model?**
8. **Why do we use CFD, list 3 reasons?**
9. **What does CFD stand for?**
10. **What are the 3 steps of Pre-processing?**
11. **What are the 3 steps of Post-processing?**
12. **What is the equation for the Knudsen number?**
13. **What is an approximate value for the Knudsen number in continuum mechanics?**
14. **What does the Knudsen number represent?**
15. **What is the difference between a Lagrangian and an Eulerian frame of reference?**
16. **What is the equation for Reynold's Transport Theorem?**
17. **What is the continuity equation in differential form?**
18. **When do we use the Euler Equations?**
19. **When can viscous effects be ignored?**
20. **Potential flows are?**
21. **Barotropic Fluids are?**
22. **What is the difference between finite volume, finite difference, and finite element methods?**
23. **What finite method is CFX based on?**
24. **What is the incompressible navier stokes equation?**
25. **What is the number that represents inertial forces to viscous forces?**
26. **What is the equation for the Reynolds number?**
27. **What is the number that represents advection velocity to speed of sound?**
28. **What is the equation for Mach number?**
29. **What is the number that represents unsteady forces to steady forces?**
30. **What is the equation for the Strouhal Number?**
31. **What is the number that represents inertial forces to gravity?**
32. **What is the equation for Froude's number?**
33. **What is the number that represents inertial forces to surface forces?**
34. **What is the equation for the Weber number?**
35. **What is the equation that represents viscosity to conductivity?**
36. **What is the equation for Prandtls number?**
37. **What situations describe a large and small Weber number?**
38. **Which situations use a Strouhal number?**
39. **Which number describes hydraulic jumps**

40. What is the Reynold's number for creeping flow?
41. What does that represent?
42. When is flow laminar?
43. When is flow turbulent?
44. Which forces dominate creeping and turbulent flow respectively?
45. What is the difference between topology and geometry?
46. Draw a structured grid and an unstructured grid.
47. Draw a hybrid grid.
48. What is an advantage and disadvantage of a structured gride?
49. What is an advantage and a disadvantage of an unstructured grid?
50. What are the 3 different structured grid topologies?
51. Use Delauney triangulation to create a new grid to accommodate this point.
52. Use advancing front triangulation to form a grid for this piece.
53. What is numerical diffusion?
54. What is the increase in computing time for an unstructured grid?
55. How does one determine grid resolution at wall boundaries?
56. Show an example of how the octree grid method works.
57. What is the Kelvin-Helmholtz instability?
58. What can turbulence be used for?
59. Describe the turbulence energy cascade?
60. When is scale separation most pronounced?
61. Name 4 characteristics of turbulent flows.
62. How does one find the characteristics of the smallest vortices in turbulent flow?
63. Give the equations for Komogorov length, time, and velocity.
64. What does DNS stand for?
65. How many grid points are required for a DNS?
66. What about in 3D?
67. How many timesteps are needed?
68. What is the total computational cost of a DNS?
69. What do we use DNS for?
70. What does RANS stand for?
71. What is Reynolds Averaging?
72. What is the NS equation in dimensionless form?
73. What is the Reynolds Stress Tensor?
74. What are the terms for the Reynolds Stress Transport Equation?
75. What does EVM mean?
76. What does RSM mean?
77. Name 2 EVMs
78. Name 2 RSMs
79. Name an EVM + RSM
80. What is the eddy viscosity ansatz?
81. What is the transport equation for turbulence kinetic energy?
82. What is the Prandtl one-equation model good and bad for?

83. What is the k-epsilon model good and bad for?
84. What is the k-omega model good and bad for?
85. What is the Spalart-Allmaras model good and bad for?
86. What do RSMs directly solve for?
87. What does the slow term of the pressure strain correlation represent?
88. What does the rapid term of the pressure strain correlation represent?
89. What does LES stand for?
90. What is the life cycle of turbulence?
91. Name 3 characteristics of large turbulence scales
92. Name 3 characteristics of small turbulence scales
93. Which scale is computed directly?
94. Which scale must be modeled?
95. Where does most dissipation occur?
96. Which is cheaper, a RANS or LES?
97. What is the Convolution Theorem?
98. What does the filter kernel look like?
99. Draw a top hat filter kernel in real and spectral space.
100. Draw a gauss filter kernel in real and spectral space.
101. Draw a spectral cutoff filter in real and spectral space.
102. What is the equation for the subgrid scale stress tensor/
103. What is the intended consequence of subgrid-scale modeling?
104. How does dissipation (too much or too little) affect the turbulence energy cascade?
105. What is the equation for the eddy viscosity model subgrid scale stress tensor as proposed by Smagorinsky?
106. What is the approximate value for the Smagorinsky constant if a flow is isotropic turbulent?
107. What must be done to correct a Smagorinsky model near walls?
108. What's the difference between the dynamic and regular Smagorinsky models?
109. Name two methods which combine RANS and LES.
110. In the Finite Volume Method, what does the solution represent?
111. What is a finite volume?
112. What is quadrature?
113. What is interpolation?
114. Draw standard compass notation.
115. What is the approximation of the midpoint rule?
116. Write the Taylor Series Expansion of the midpoint rule.
117. Draw a graph with the log(error) versus cell size for 1st, 2nd, and 4th order approximation.
118. What does the order of a method affect?
119. What is the trapezoidal rule?
120. What is simpsons rule?
121. What does UDS stand for?

122. What are the equations for Upwind Interpolation?
123. What does CDS stand for?
124. What are the equations for linear interpolation?
125. How does one find the error of a numerical scheme using taylor series?
126. What is the discrete equation for truncation error?
127. What is the numerical effect of truncation error?
128. How does one calculate the CFL number?
129. What order method should be used on an unstructured grid?
130. What is an advantage to a higher order method?
131. When should one not use a higher order method?
132. Name 3 types of interpolation schemes available in ANSYS CFX..
133. What does the solution of an unsteady problem rely on?
134. What is the simplest solution for an unsteady problem?
135. What are the two types of time-marching methods?
136. What is the equation for the euler-forward (explicit)?
137. What is the equation for the euler-backward (implicit)?
138. Name 3 implicit time marching methods?
139. What are the equations for the midpoint rule and trapezoidal rule in time marching?
140. How do we determine a sufficiently small timestep?
141. What are 3 benefits to the explicit time marching method?
142. What are 2 detriments?
143. What are 3 benefits to the implicit time marching method?
144. What are 2 detriments?
145. When should you not use an implicit method?
146. Why would one choose a local time step?
147. What is the physical time step limited by?
148. Name the four types of boundary condition and what they impose.
149. In a no-slip wall, what values are null?
150. For a supersonic inflow, how many boundary conditions must be defined?
151. For incompressible inflow, how many boundary conditions must be defined?
152. For supersonic outflow, can one assign Dirichlet boundary conditions?
153. How many boundary conditions in subsonic outflow must be Dirichlet?
154. What is the equation of state for a perfect gas?
155. What is the Poisson equation?
156. In a direct solution with N grid points, how many entries are there?
157. Why do programs generally not use direct solution methods/
158. Name 2 direct solution methods.
159. For Gauss-elimination, how many operations are required for dense matrices?
160. What are the steps for LU factorization?
161. Why does it not matter to solve matrices exactly?
162. What is the definition of error??
163. What is the definition of residuum?

164. What is the relationship between error and residuum?
165. Which converges earlier, residuum or error?
166. What is the condition for convergence?
167. What is the general equation for an iterative solution method?
168. What is the spectral radius equation for an NxM grid?
169. What is ILU matrix factorization?
170. What solver does Ansys-CFX employ?
171. Name 2 multigrid methods.
172. What is the geometric multigrid method?
173. What is the algebraic multigrid method?
174. What is the difference between verification and validation?
175. Name 3 sources of numerical errors.
176. What is the difference between bias error and precision error?
177. How does one check for a discretization error?
178. How small of a residual is acceptable?
179. How does one check for turbulence modelling error in RANS?

1. Prandtl model in 1925, oldest and still used today.

2. Smagorinsky 1963 : LES and eddy viscosity

3. First two-equation turbulence model for Reynolds averaged Navier Stokes (RANS) simulation → k-ε model

4. Methods for solving the pressure poisson equation.

5. Wilcox in 1988

6. Germano 1990

7. Menter 1994

8. Experiments can become complicated, expensive, dangerous. There is uncertain flow boundary conditions on the experiment There is measurement errors on experiments. Experiments give a view of a similar problem but rarely the same.
All quantities can be extracted everywhere without error, is cheap and hazard free.

9. Computational fluid dynamics, Colors for directors

10. Generate computational grid, define boundary conditions, define models for fluids and turbulence.

11. Visualize the results, quantify uncertainties and errors, analyze and interpret results.

12. $Kn = \frac{\lambda}{L}$ λ = mean free path L = length of transport

13. $Kn \ll 1$ for continuum mechanics

14. Ratio between a molecule hitting another and the length of the transport.

15. One is static and sees the particles enter the reference frame and the other is dynamic and follows the fluid element

16. $\frac{d}{dt}\iiint_{\tilde{V}(t)} \phi \, dV = \iiint_{\tilde{V}} \frac{\partial \phi}{\partial t} dV + \iint_{S_V} \phi u_i n_i \, dS$

17. $\frac{\partial \rho}{\partial t} + \nabla \rho \underline{u} = 0$

18. When $\mu = 0$, viscous effects can be neglected at high Mach and Reynolds 19.

20. Inviscid and rotation free flows

21. Flows where pressure depends only on density.

22. Finite volume, average at each finite volume. Finite difference: discretization at center of vertex.
Finite element: discretization of basis functions.

23. Finite volume discretization

24. $\frac{\partial \underline{u}}{\partial t} + \nabla\cdot(\underline{u}\underline{u}) + \frac{1}{\rho} - \frac{1}{Re}\nabla\cdot\nabla\underline{u} = 0$ $\nabla \underline{u} = 0$

25. Reynolds Number 26. $Re = \frac{\rho V L}{\mu}$

27. Mach number 28. $M = \frac{U_0}{C_0} = \frac{U_0}{\sqrt{\gamma R T}}$

29. Strouhal number 30. $St = f t_0 = f \cdot \frac{L}{U_0}$

31. Froude number 32. $Fr = \frac{U_0}{\sqrt{d g}}$

33. webber number 34. $We = \frac{\rho_0 L U_0^2}{\sigma_0}$

35. Prandtl number 36. $Pr = \frac{c_p \cdot \mu_0}{k_0}$

37. Small, single drop of water on calmed medium. High, Turbulent water bubles.

38. In swimming or flying animals, Sound cylinders on the wind.

39. The froude number

40. $Re << 1$: creeping flow.

41. Flow where the viscous forces are dominant, flows in porous media.

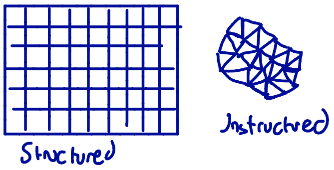
42. When $Re < Re_{crit}$

43. When $Re > Re_{crit}$

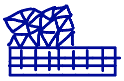
44. Creeping viscous forces, Turbulent dynamic forces

45. Topology: relations between neighboring elements. Geometry, shape and size of cells.

46.



47.

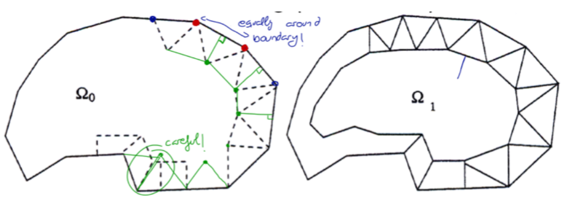


48. Simple data structure and access, also efficient. Disadvantages: less complex and automated

49. Straight forward application to complex shapes, Disadvantages: complex to access data.

50. C-grid, O-grid, H-grid

52.



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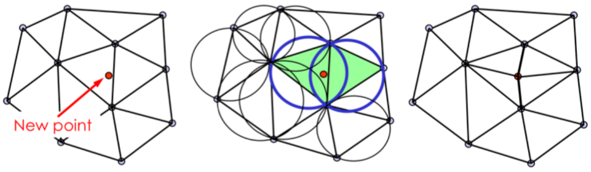
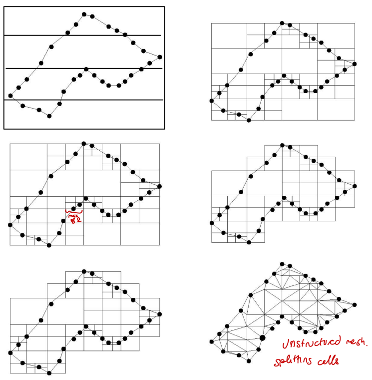


53. The truncation error of discrete approximations of the continuous operations affects the numerical solution.

54. The increase in time it takes to converge to a solution.

55. The wall shear can be computed accurately and reliably only if the first cell is within $y^+ \simeq 1$

56.



57. Appears if there is a velocity difference between two fluid elements or across the boundary.

58. To enhance mixing or to increase wall friction

59. Turbulence is generated on the largest scales, transfered to medium-small scale vortices and dissipated in micro-scale vortices.

60. More pronounced differences at high Re.

61. Unsteady, rotational, Viscous, Chaotic, breaking of symmetries.

62. With the Kolmogorov equations

63.

Kolmogorov length $\eta_K = \left(\frac{\nu^3}{\varepsilon}\right)^{1/4}$

Kolmogorov velocity $u_K = (\nu\varepsilon)^{1/4}$

Kolmogorov time $\tau_K = \sqrt{\frac{\nu}{\varepsilon}}$

64. Direct Numerical Simulation.

65. $N_L \sim \frac{L}{\eta_k} \sim Re^{3/4}$ 66. $\longrightarrow$ 3 Dimensions $N_L^3 \sim Re^{9/4}$

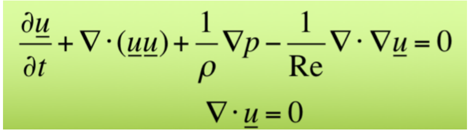
67. $N_T \sim N_L$ 68. $R_c = N_T \cdot N_L = Re^3$

69. Useful for fundamental turbulence research but not for every-day engineering flow simulations.

70. Reynolds-Averaged navier stok equations.

71. Is an averaging procedure applied to variable quantities such as speed w.r.t. time.

72.

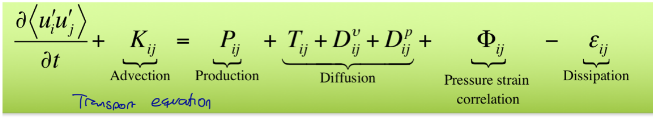


$$\frac{\partial \underline{u}}{\partial t} + \nabla \cdot (\underline{u}\underline{u}) + \frac{1}{\rho}\nabla p - \frac{1}{\text{Re}}\nabla \cdot \nabla \underline{u} = 0$$

$$\nabla \cdot \underline{u} = 0$$

73. $\underset{=}{\tau_{ij}} = -\langle u_i' u_j' \rangle$ Matrix containing all the stress forces on
Tensor the fluid element.

74.



$$\frac{\partial \langle u_i' u_j' \rangle}{\partial t} + \underbrace{K_{ij}}_{\text{Advection}} = \underbrace{P_{ij}}_{\text{Production}} + \underbrace{T_{ij} + D_{ij}^{v} + D_{ij}^{p}}_{\text{Diffusion}} + \underbrace{\Phi_{ij}}_{\text{Pressure strain correlation}} - \underbrace{\varepsilon_{ij}}_{\text{Dissipation}}$$

Transport equation

75. Eddy viscosity model   76. Reynolds stress models.

77. Jones & Launder
Wilcox } two eq. models
k-ω, k-ε, prandtl

78. wallin and Johansson
LRR and SSG

79. EARSM

80.

81. $k = \frac{1}{2}\langle u_i' u_i' \rangle = \frac{1}{2}\sum_{i=1}^{3}\langle u_i' u_i' \rangle$

82. Good for external flows and attached b-l. Bad for internal flows and flow separation

83. Good for external flows and not strong pressure gradients, or separation. Bad for predicting anisotropic influences.

84. Good for boundary layer flows and with high pressure gradients and separation. Bad, sensitive on inflow and freestream boundary conditions. Over estimates turbulence production at stagnation point.

85. Good for: simple attached flows and for flow separation location. Bad, flow reattachment and free shear layers.

86. RSM directly solve transport equations for all components of the unknown Re tensor.

87. Is the relation to isotropic equilibrium state

88. Immediate effects of mean flow gradients and external flow.

89. Large eddy simulation

90. Turbulence gets produced in the higher scales and is transmitted to the medium-small scales and finally it gets dissipated in the microscales. Backscatter produce turbulence again.

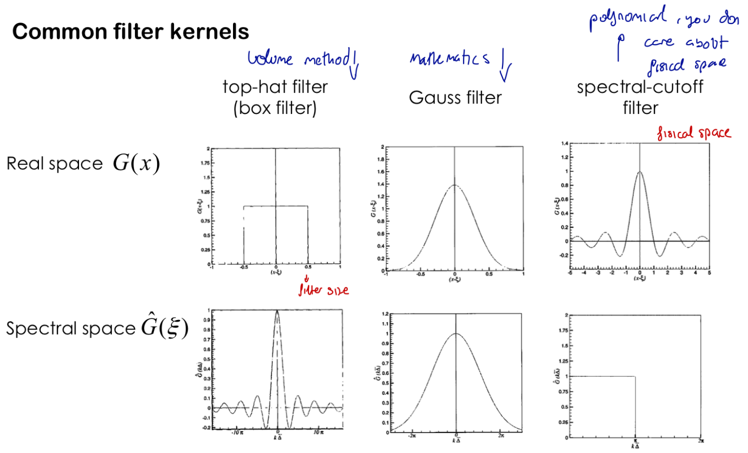
91. Produced by external energy input, depend on geometry and boundary conditions, inhomogeneous and anisotropic. Large and long living. High energy content. Modelling is difficult.

92. Receive energy through cascade from large scales. Similar in all turbulent flows. Homogeneous and isotropic usually. Easy to model.

93. Large scales 94. Small scales 95. Small scales 96. RANS is cheaper

97. Convolution in the real space (physical) corresponds to multiplication in Fourier (spectral) space

98. Has different looks



Q 99:

Q100:

Q101:

Q102: $\tau_{ij} = \overline{u_i u_j} - \overline{u}_i \overline{u}_j$

Q103: Model the effect of the turbulence on the large resolved scales.

Q104: Too much dissipation: energy drops before
Too little dissipation: energy grows

Q105: $\tau_{ij} = \frac{1}{3}\tau_{kk}\delta_{ij} - 2\nu_{SGS}\overline{S}_{ij}$

Q106: $C_S = 0.14 - 0.25$

Q107: Correct the Cs by Van-Driest damping.

Q108: Dynamic makes Cs vary depending on the location and time.

Q109: Zonal coupling, detached eddy simulation (ILES)

Q110: The cell center average value of all the cells.

Q111: Control volume (CV) for which we compute the evolution of the mean values.

Q112: Surface integral of fluxes is a sum of discrete values at one or several points at the cell surface

Q113: Values of φ at the cell surfaces are reconstructed from the values φ at the cell center.

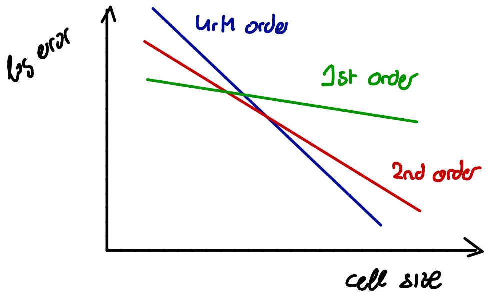
Q114:

NW	N	NE
W	P	E
SW	S	SE

Q115: The average value is simply the center point of the function.

Q116: $\frac{1}{h} = \varphi_0 + \frac{h^2}{24} \cdot \frac{\partial \varphi^2}{dx^2}\Big|_0$

Q117:



Q118: The convergence speed of the model.

Q119: The integration is done by measuring the area between two points when this two compose a trapezoid with the x axis.

Q120: The integration is done with paraboles instead of trapezoids.

Q121: Upwind differencing scheme

Q122:

$$\Psi_e = \begin{cases} \Psi_P, \text{ if } (\underline{u}\cdot\underline{n})_e > 0 \\ \Psi_E, \text{ if } (\underline{u}\cdot\underline{n})_e < 0 \end{cases}$$

Q123: Central differencing scheme

Q124:

$$\Psi_e = \Psi_E\lambda_e + \Psi_P(1-\lambda_e)$$

$$\lambda_e = \frac{x_e - x_P}{x_E - x_P}$$

Q125: By analysing it with the taylor expansion. When comparing it with the initial equation there is an extra term of higher order. This is the error.

Q126:

Q127:

Q128: With equation $CFL = \Delta t \frac{U}{\Delta x} \longrightarrow \frac{U^2 \Delta t}{2} - \frac{U \Delta x}{2} = 0 \quad U\Delta t = \Delta x$

$CFL = \frac{U\Delta t}{\Delta x}$

Q129: 1st order method should be used.

Q130: Convergence with second order, faster convergence.

Q131: When the cells are big.

Q132: 1st order UDS_1 2nd order CDS

2nd order UDS_2

Q133: Solution depends on initial conditions and boundary conditions.

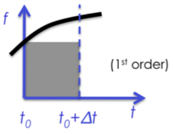
Q134: Euler forward, because it is explicit.

Q135: Mid point rule (implicit) and Euler backward (implicit)

Q136; Q137, Q138, Q139

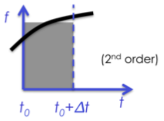
Euler forward (explicit)

$$\varphi^{n+1} = \varphi^n + f(t_n, \varphi^n)\Delta t$$



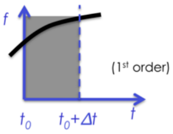
Mid-point rule (implicit)

$$\varphi^{n+1} = \varphi^n + f(t_{n+1/2}, \varphi^{n+1/2})\Delta t$$



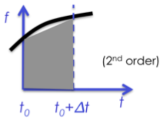
Euler backward (implicit)

$$\varphi^{n+1} = \varphi^n + f(t_{n+1}, \varphi^{n+1})\Delta t$$



Trapezoidal rule (implicit)

$$\varphi^{n+1} = \varphi^n + \frac{f(t_n, \varphi^n) + f(t_{n+1}, \varphi^{n+1})}{2}\Delta t$$



Q140: Using $CFL = \Delta t \frac{U}{\Delta x} < 0.5$ good enough.

Q141: Efficient, low memory requirements, robust, simple.

Q142: Unstable for large time steps, not so exact

Q143: Stable for large time steps, more exact, [redacted]

Q144: Large memory requirements, complex implementation

Q145: With LES

Q146: Because on some points you would need different time steps, more efficient and finally the steady state result is the same.

Q147: By the smallest cell in the domain.

Q148: Dirichet: value of variable φ
Neumann: gradient of variable $\left(\frac{\partial \varphi}{\partial n}\right)$
Robbin: combination of both
Periodic: same values at two walls.

Q149: $\left.\frac{\partial v}{\partial y}\right|_{wall} = 0$ pressure gradient

$\left.\frac{\partial u}{\partial x}\right|_{wall} = 0$ Viscous stress = 0 normal

Q150: 5 independent variables

Q151: 4 independent variables

Q152: No, only neumann

Q153: 1 variable as Dirichet

Q154: $P(\rho, e) = \rho R T = \rho R \frac{e}{c_v} = \rho e(\gamma - 1)$

Q155: $\nabla^2 P = f(\underline{u})$, equation used to determine pressure since it is not independent anymore.

Q156: N^2 [redacted]

Q157: Because modelling and discretization errors are much larger than computer round-of error.

Q158: Gauss elimination, Lower-upper factorization

Q159: $O(N^3)$

Q160: decompose matrix in two triangular matrices L and U. Solve each system

Q161: Because modelling and discretization errors are much larger than computer round-of error.

Q162: Deviation from exact solution

Q163: Deviation of equation that is solved.

Q164: $\underline{\underline{R}}^n = \underline{\underline{A}}\,\varepsilon^n$

Q165 Residum converges before

Q179: having a close look at the transition point and using LES for it.

Q166: For convergence $\rho(\underline{\underline{G}}) < 1$ spectral radius of iteration matrix $\underline{\underline{G}} = \underline{\underline{N}}^{-1}\underline{\underline{P}}$

Q167: $\varphi^{n+1} = N^{-1}(\underline{\underline{P}} \cdot \underline{\varphi}^n + \underline{b})$

Q168: $\rho(\underline{\underline{G}}) \simeq 1 - \frac{\pi^2}{4}\left(\frac{1}{N^2} + \frac{1}{M^2}\right)$

Q169: Incomplete lower upper factorization.

Q170: Coupled ILU solver for u, v, w and P.

Q171: Algebraic multigrid, geometric multigrid

Q172: Coarsening is based on user input

Q173: Coarsening based on coefficient matrix

Q177: Run simulation for different mesh resolutions

Q178: Less than 10^{-3}

Q174: Verification, comparison with known solutions
Validation, comparison with experimental data.

Q175. Insufficient spatial discretization convergence
Insufficient temporal discretization convergence
Computer round off

Q176: Bias is a systematic error and can be calibrated
Precision is random and can cancel with average.