MODULE X

SIMULATION OF TURBULENT FLOWS: ASSIGNMENT

X.1. For numerical solution for turbulent flows, the most accurate simulation approach is
- a) RANS simulation.
- b) LES (Large Eddy Simulation).
- c) DNS (Direct Numerical Simulation).
- d) none of the above.

X.2. A large multinational automobile company has integrated CFD simulations in its car design process to reduce the amount of prototype testing. The company has two sets of computing servers: (a) a set of powerful graphics workstation which is primarily used for initial design simulations, and (b) a massively parallel super-computer with more than 10000 processor cores which is used for final design computations and optimization. Which types of simulation --- RANS, LES or DNS --- are being used in initial and final design computations? Briefly explain the reasons for the choice of a specific simulation strategy.

X.3. You plan to develop your own code for simulation of turbulent flows. Which simulation approach (RANS, LES or DNS) would be easiest to implement in your code? Which one would require least amount of computational resources for simulation of a flow problem?

X.4. Amongst RANS turbulence models, Reynolds stress models (RSM) are considered to be the most accurate. However, in industrial CFD simulations, two-equation models (k-ε or k-ω) are most widely used in preference to RSM. What is the most probable reason for this preference?

X.5. Outline the conceptual steps involved in numerical simulation of turbulent flows using (a) RANS, (b) LES and (c) DNS approach.

X.6. LES or DNS of turbulent flows require accurate computation of time history of the flow. Should we choose an explicit or an implicit time integration scheme? Justify your answer with appropriate arguments based on stability and accuracy requirements.

X.7. What is basic idea behind large eddy simulation (LES)? What are conceptual steps involved in LES (state each step in a single sentence). What is the general definition of the filtering operation employed in LES? Apply the filtering operation to Navier-Stokes equations to obtain the filtered form of governing equations for LES and identify the subgrid stress (SGS) terms. Outline the Smagorinsky model for SGS stress tensor. What is van Driest damping, and for which class of problems is it used? What is dynamic model (provide only a brief textual outline of this model with minimal equations: detailed equations are not required)?

X.8. In LES, Smagorinsky and scale similarity models are widely used. Which of these subgrid models is likely to be (a) most accurate, and (b) most efficient (in term of computation time)?

X.9. You are required to perform numerical simulation of hydraulic turbine to analyze the flow field and estimate its performance. Three-dimensional CAD model of the turbine is available alongwith with the details of different operating parameters. Outline the steps which you must for numerical simulation. Would you need any turbulence model? If yes, indicate your choice of turbulence model(s) if your computing hardware is a small parallel cluster. Which turbulence modelling approach should you opt for if you had CFD software running on massively large parallel computer?

X.10. Experimental measurements of turbulent flow are usually reported in terms of mean and r.m.s. value of velocity components and Reynolds stresses. The r.m.s. value of a flow property ϕ is defined as

$$\phi_{rms} = \sqrt{\overline{(\phi')^2}}$$

A large eddy simulation or DNS yields complete time history of the flow field. To validate the LES or DNS, mean, r.m.s. values and Reynolds stresses are compared with corresponding experimental results. Given that the LES/DNS provide the complete time history, it is very easy to compute time average $\overline{\phi}$ of any flow property. How would you calculate the r.m.s. velocity (say, u_{rms}) and Reynolds stress ($-\overline{u'v'}$) from the available average values of u, v, w, u^2, v^2, uv etc. ?

X.11. What are main characteristics (with respect to space, time and energy transport) of turbulent flows? Define Reynolds decomposition of flow property ϕ, and define its mean $\overline{\phi}$ for a statistically stationary and unsteady turbulent flows. State the main algebraic properties of the averaging operation and employ these to derive the so-called Reynolds averaged Navier-Stokes (RANS) equations for incompressible turbulent flow. Are these equations "***closed***"? If yes, explain how. If no, what is required to enforce closure? Identify the Reynolds stress term in RANS equations. State with very brief reason whether or not the following values are admissible for Reynolds stress tensor:

$$\text{(a)}\ -\rho\overline{u_i'u_j'} = \begin{bmatrix} -0.5 & -0.1 & 0.0 \\ -0.1 & -0.3 & -0.1 \\ 0.0 & -0.1 & 0.1 \end{bmatrix},$$

$$\text{(b)}\ -\rho\overline{u_i'u_j'} = \begin{bmatrix} -1.08 & 0.32 & 0.0 \\ 0.32 & -0.40 & 0.0 \\ 0.0 & 0.0 & -0.52 \end{bmatrix}.$$