Direct Numerical Simulation (DNS) of Turbulent Flows

Anirudh Modi (*anirudh-modi@psu.edu*)

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1 Overview

The complex behaviour of turbulence is the consequence of a fairly simple set of equations - the Navier-Stokes equations. However, analytical solutions to even the simplest turbulent flows do not exist. A complete turbulent flow, where the flow variables like velocity and pressure are known as a function of space and time can therefore only be obtained by numerically solving the Navier-Stokes equations. These numerical solutions are termed as Direct Numerical Simulations (DNS) [1].

Thus, Direct Numerical Simulation or Direct Navier Stokes (DNS) is a CFD technology implying a nearly exact solution to a unsteady, nonlinear governing systems of equations. As we are aiming at a nearly exact solution (and not "the" exact) to specific turbulent flows utilizing limited computational resources, DNS is stressed as a research tool and not as a brute-force solution. In aerodynamics, DNS is associated with a large-scale computationally intensive solution procedure which may consume hundreds to thousands of Cray Super-computing resources. The earliest use of DNS began in the 1970's and with the growth in the computational power today, it is getting more and more popular day by day [2]. Current computations typically use finite-difference schemes, or a combination of spectral and finite-difference schemes, although finite element approaches using unstructured grids are also being explored.

However, the main technical challenges of DNS remains the memory and computational speed requirements. A DNS of the flow past a complete airfoil would require a computer with exaflop (10^{18} flops) capacity to be practical, which is still not available now. The instantaneaous range of scales in turbulent flows increases rapidly with the Reynolds number and hence most practical engineering problems (e.g. flow around a car) have too wide a range of scales to be directly computed using DNS. Thus approximations like Large Eddy Simulation (LES) which computes only the large energy-containing scales, and Reynolds averaged Navier-Stokes solutions (RANS) are more prevalent than DNS. DNS can be thought of as the most desirable solution to a turbulent flow problem which is much more computationally intensive, followed by LES which is less complex and then RANS which is of the least complexity (and also the coarsest approximation).

The contributions of DNS to turbulence research in the last decade have been impressive and the future seems bright. The greatest advantage of DNS is the stringent control it provides over the flow being studied. It is expected that as flow geometries become more complex, the numerical methods used in DNS will evolve. Several DNS solutions have been in excellent agreement with the experiments thus greatly increasing the confidence in the technology.

References

[1] Parviz Moin and Krishnan Mahesh. Direct Nurface Simulation: A Tool in Turbulence Research. *Annual Review in Fluid Mechanics*, 30:539–78, 1998.

[2] Ronald D. Joslin. Discussion of DNS: Past, Present and Future. *First International Conference on DNS and LES (see http://techreports.larc.nasa.gov/ltrs/)*, 1997.