Towards a Better Understanding of Turbulence

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"I am an old man now, and when I die and go to heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics, and the other is the turbulent motion of fluids. And about the former I am rather optimistic."

Horace Lamb, 1934

For more than a century, turbulence in fluids has been one of the greatest mysteries of physics. Indeed, turbulence has been mysterious enough to stimulate many of the greatest minds of our civilization to think about it, such as Albert Einstein, Richard Feynman, and John von Neumann. Today, most fluid dynamicists agree that not only the problem of turbulence is still far from being solved, but also that it is extremely difficult to agree on what exactly is the problem to be solved.

If I was asked to summarize all what we know today about turbulence in only one sentence, I would never find more expressive words than those used by Richardson in his rhyming verse describing the energy cascade process of turbulence: *Big whirls have little whirls that feed on their velocity, and little whirls have lesser whirls and so on to viscosity*. This energy cascade concept was first introduced in a mathematical sense by the Great Russian mathematician Andrey Kolmogorov, who proposed the first statistical theory of turbulence in 1941. In fact, the world of turbulence modeling would have never evolved in the way we know it today, if it was not for the work of Kolmogorov, succeeding the findings of Osborne Reynolds 1895, the Boussinesq hypothesis 1877, and Ludwig Prandtl concepts of boundary layer 1904, and mixing length 1925.

Since this statistical approach emphasizes the effect of turbulent eddies on the averaged quantities of the mean flow, it has gained a remarkable popularity among engineers and application oriented CFD modelers. In the past few decades, the overwhelming vast majority of CFD studies depended on statistical models in approaching the problem of turbulence. On the other hand, a group of fluid dynamicists favored to think about turbulence from a purely deterministic perspective, choosing to solve the instantaneous Navier-Stokes equations by means of direct numerical simulations. This group, motivated by the idea of finding "coherence among chaos", was able to reveal many aspects of turbulent flows that were impossible to be found by any statistical method.

The situation today has become less straightforward; in many circumstances, it is difficult to make a clear cut distinction between the two crowds. Thanks to the pioneering work of Smagorinsky, Lilly, and Deardorff, we now have a means of gaining the advantages of both the statistical and deterministic approaches in what is referred to as Large Eddy Simulation (LES). It is not a surprising fact to see that LES is today widely implemented by application CFD engineers as well as "coherence among chaos" supporters.

The concepts schematically presented above are the orthodox manners that the mainstream CFD community uses in thinking about turbulence. However, many non-orthodox views of turbulence have emerged recently that, though not very popular among the CFD community, are very revolutionary and promising. A noteworthy example of such approaches is highlighted below.

Through their attempts of explaining turbulence, scientists have debated on many aspects of turbulent flows. However, among the few aspects that the bulk of turbulence researchers agreed upon was that turbulence is a continuum phenomenon. This was indeed an indisputable feature for turbulent flows that can be found in most fluid dynamics textbooks. This 100 years old tradition was challenged recently as a new microscopic theory of turbulence was proposed by A. Mulier. Surprisingly enough, Muriel argued that transition to turbulence occurs due to molecular activity of a quantum nature, and thus, the Navier-Stokes equations are not adequate for describing fluid turbulence since they do not take into account the molecular and quantum effects. The essence of Muriel's new theory is the argument that molecular collisions are not elastic; rather, a quantum regime that includes energy excitations and de-excitations takes place. Consequently, the governing flow equations need to be modified to include such quantum model.

It seems quite ironic that the most important and last unsolved problem of classical physics, as labeled by Einstein and Feynman, may finally find a solution using the concepts of quantum mechanics. Perhaps the most important questions that need to be addressed at this moment are: is it really viable to research turbulence beyond the continuum Navier-Stokes equations? Can the solution of the turbulence problem lie in its microscopic nature? And if that is the case, is the classical kinetic theory adequate to describe the physics of the new model, or is the inclusion of a quantum model inevitable? He who is optimistic may believe that humanity would answer these questions in the first half of the third mellinium.