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Studying Complex Fluid Dynamics - From Direct Numerical Simulations to Tomographic Digital Holographic Particle Image Velocimetry

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Abstract

Fluid Mechanics is an example of a complex dynamical system with uncountable applications in industry, transportation, manufacturing, medicine, atmospheric sciences, oceanography, hydrology, ionised gases or plasma, the earth's interior and space plasma turbulence. The scales of the fluid flows in these applications vary widely in the range from microns, as seen in the blood flow of living organisms, micro electro-mechanical system and micro-reactors to thousands of km in atmospheric, oceanographic and astrophysical flows. There are basically two approaches to the study of the three-dimensional spatio-temporal dynamics of complex fluid flows: experimental and numerical with both relying heavily on theory to interpret and explain the results.

Complex flows such a turbulence, interaction between shear flows and fluidic actuators (flow control) are examples of flows which exhibit a wide range of coherent structures interacting in a complex fashion. The identification of the coherent structures is important in order to extract knowledge regarding the scales, kinematics and dynamics of these structures. The use of invariant quantities and topological methodology is a useful approach in this endeavor. In the topological approach introduced by [6], which has its roots in critical point theory [10], the structure and evolution of the velocity gradient tensor, the rate-of-strain tensor and the rate-of-rotation tensor are carried out by not studying these tensors directly but by studying their invariants.

Examples of studies that have used this methodology to gain physical insight into the structure of various complex flows include the study of: transitional mixing layer and wakes [4, 11, 13, 12, 9]; the structure of homogeneous and homogeneous isotropic turbulence [14, 2, 3, 5, 8]; and wall-bounded turbulent flows [1, 7]. Topological methodology will be reviewed and how topological methodology can be used to visualize spatial and temporal structures using data from direct numerical simulations and some novel experimental measurement techniques will be illustrated. The main and more recent techniques in numerical and experimental techniques are also reviewed and by drawing on examples from research in our laboratory and that of others the specific and complementary nature of these two approaches is presented.

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