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ABSTRACT

Turbulence is inevitable in the transportation arena: go fast enough under realistic operational conditions and flow cannot remain in the streamlined, laminar state. This transition comes with enormous cost in terms of fuel spent, noise, and emissions, in aviation, shipping, pipeline transportation and individual transportation. Further, turbulent mixing processes dominate large-scale environmental flows. Despite this ubiquity and the fundamental nature of turbulence (and over a hundred years of related research), the dynamics of turbulence are still poorly understood. Attempts to control turbulent flows close to walls remain empirical, costly and inefficient – and essentially impractical as a consequence. A successful modeling approach that is tied to the governing equations of motion, the Navier-Stokes equations, has been lacking.

In recent work, a systems representation of wall turbulence formulated directly from the Navier-Stokes equations has created a potentially revolutionary opportunity to unravel and manipulate the mechanisms by which turbulence sustains. The so-called resolvent formulation for wall turbulence revealed hitherto undiscovered structure associated with the Navier-Stokes equations, which enable utilization of state-of-the art mathematical techniques. In the proposed research, the formulation will be exploited in canonical flows to provide a pedagogy for radically different alternatives to scaling, simulation and modeling of wall turbulence, and for engineering turbulence with different global properties. An analogy can be made with the design of meta-materials with properties not exhibited in naturally-occurring materials – the resolvent framework will permit the engineering of synthetic wall turbulence with new characteristics by replacing, overriding or reinforcing natural scale interactions to change the system performance. By removing the empiricism associated with current modeling, the formulation promises to lead to unprecedented fidelity and efficiency of the representation, providing a springboard for the treatment of more complex flow configurations.