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High-Speed Turbulent Reacting Flows: Intrinsic Flame Instability and its Effects on the Turbulent Cascade[1]

ALEXEI POLUDNENKO, Texas AM University

Turbulent reacting flows are pervasive both in our daily lives on Earth and in the Universe. They power modern society being at the heart of many energy generation and propulsion systems, such as gas turbines, internal combustion and jet engines. On astronomical scales, thermonuclear turbulent flames are the driver of some of the most powerful explosions in the Universe, knows as Type Ia supernovae. Despite this ubiquity in Nature, turbulent reacting flows still pose a number of fundamental questions often exhibiting surprising and unexpected behavior. In this talk, we will discuss several such phenomena observed in direct numerical simulations of high-speed, premixed, turbulent flames. We show that turbulent flames in certain regimes are intrinsically unstable even in the absence of the surrounding combustor walls or obstacles, which can support the thermoacoustic feedback. Such instability can fundamentally change the structure and dynamics of the turbulent cascade, resulting in a significant (and anisotropic) redistribution of kinetic energy from small to large scales. In particular, three effects are observed. 1) The turbulent burning velocity can develop pulsations with significant peak-to-peak amplitudes. 2) Unstable burning can result in pressure build-up and the formation of pressure waves or shocks when the flame speed approaches or exceeds the speed of a Chapman-Jouguet deflagration. 3) Coupling of pressure and density gradients across the flame can lead to the anisotropic generation of turbulence inside the flame volume and flame acceleration. We extend our earlier analysis, which relied on a simplified single-step reaction model, by demonstrating existence of these effects in realistic chemical flames (hydrogen and methane) and in thermonuclear flames in degenerate, relativistic plasmas found in stellar interiors. Finally, we discuss the implications of these results for subgrid-scale LES combustion models.

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