

Abstract

The unifying physics of shock–turbulence interactions across vastly different Mach regimes—from high-speed aerodynamic flows to relativistic outflows from active galactic nuclei (AGNs)—has been explored in this thesis. Such interactions, which are ubiquitous in both aerospace and astrophysical environments, are encountered wherever fluids undergo rapid variations in pressure and velocity, resulting in intricate coupling between shock dynamics, vorticity generation, and turbulence modulation. Although these systems differ by many orders of magnitude in spatial and temporal scales, a shared dynamical essence has been identified: the nonlinear interplay of compressibility, vorticity, and shock-induced strain that governs the generation, amplification, and decay of turbulence. In the aerospace context, three-dimensional simulations of shock wave/boundary-layer interaction (SWBLI) over a double-wedge configuration numerical simulations were performed using a high-order compressible solver within the OpenFOAM framework. The turbulent kinetic energy (TKE) field within the separation bubble was shown to be reshaped by adverse pressure gradients and the motion of transmitted and reflected shocks. A decomposition of the TKE production term revealed that the modulation of streamwise velocity gradients, driven by shock-induced compression and relaxation induced by both transmitted shock and reflected shock, dictates the temporal attenuation of turbulent kinetic energy as the shock system propagates downstream. These results demonstrated that streamwise mean flow deceleration acts as a controlling mechanism for turbulence amplification and decay in compressible separated flows. In the astrophysical regime, high-resolution relativistic hydrodynamic simulations of AGN jets were conducted using the PLUTO code. The basic flow features associated to relativistic jet propagation inside uniform interstellar medium has been explored explicitly. Strain-dominated UN/S/S topologies were uncovered and identified via the invariants of the velocity-gradient tensor (VGT). These sheet like structures, concentrated in the jet-head and cocoon regions, were found to facilitate the conversion of huge jet kinetic energy into internal energy, thereby sustaining turbulence under extreme relativistic conditions inside the cocoon as time evolves. By juxtaposing these two canonical problems, a coherent framework for understanding

shock-mediated turbulence across physical regimes has been established—from flows surpassing the speed of sound (c) to those approaching the speed of light (C)—revealing how the universal interplay between shocks and turbulence governs the redistribution of energy in both terrestrial and cosmic environments. Keywords: Shock–Turbulence Interaction, Shock-Wave/Boundary Layer Interaction, Relativistic Jet, Velocity Gradient Tensor.