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UNIFIED TURBULENCE MODELING VIA INTEGRATED GOY-SHELL AND TSDIA: THEORETICAL FOUNDATIONS AND PRACTICAL APPLICATIONS

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Abstract

Turbulence modeling across a wide range of Reynolds numbers remains a significant challenge in computational fluid dynamics. This study presents a unified turbulence model integrating the GOY shell model with the Two-Scale Direct Interaction Approximation (TSDIA). The framework consistently captures both inertial and *dissipation ranges of the energy spectrum, including temporal decay characteristics. Based on this formulation, a new eddy viscosity model is derived, bridging low- and high-Reynolds-number regimes while retaining physical consistency.*

A distinctive capability of this model is its ability to continuously reconstruct the local energy spectrum E(k) at arbitrary spatial locations using computed turbulence quantities. This enables a spectrum-consistent extension of RANS into wavenumber space, allowing for the inference of subgrid-scale and dissipation-range motions without ad hoc assumptions.

The proposed model is validated through multiple benchmarks. In backward-facing step and steep terrain flows, it significantly improves reattachment point prediction and separation behavior compared to standard K- ε *and RNG models. Large eddy simulation (LES) of turbulent channel flow demonstrates accuracy comparable to DNS in predicting mean profiles and wall skin friction. Furthermore, application to the NACA 0012 airfoil confirms that the model maintains practical RANS-level accuracy for lift/drag while providing access to high-fidelity spectral diagnostics. These results confirm that the proposed approach offers a robust, physics-based path toward bridging practical engineering simulations with detailed turbulence-structure analysis within a single computational framework.*

Keywords:

Turbulence Modeling, GOY Shell Model, Two-Scale Direct Interaction Approximation (TSDIA), Eddy Viscosity, Energy Spectrum, Reynolds Number