AI-Based Turbulence Modeling: A Study Using the Johns Hopkins Turbulence Database

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Abstract

This report explores the application of artificial intelligence (AI) and machine learning techniques to turbulence modeling in fluid dynamics, using the Johns Hopkins Turbulence Database (JHTDB). The focus of this work is to predict turbulence closures or simulate turbulence behavior using neural networks and deep learning approaches. This report summarizes the research, methodology, implementation, and comparison with traditional turbulence models.

1 Introduction

Turbulence is a complex and chaotic phenomenon in fluid dynamics that presents challenges in modeling and simulation. Traditional turbulence models, such as Reynolds-Averaged Navier-Stokes (RANS), Large Eddy Simulation (LES), and Direct Numerical Simulation (DNS), have their limitations in accurately capturing the intricate flow behaviors associated with turbulent regimes. Recent advancements in artificial intelligence (AI), particularly machine learning (ML) techniques, have shown promising potential in enhancing or replacing these models.

The purpose of this project is to implement an AI-based model to predict or approximate turbulence closures using the Johns Hopkins Turbulence Database (JHTDB), which provides high-resolution data from direct numerical simulations of turbulence. The machine learning model used in this study is based on neural networks, and the results are compared with traditional turbulence models.

2 Research Overview

Recent studies in AI-based turbulence modeling have focused on leveraging neural networks, deep learning, and regression techniques to improve traditional turbulence closures. For example, models like convolutional neural networks (CNNs) and recurrent neural networks (RNNs) have been used to learn complex patterns in turbulent flows from high-fidelity datasets. These models aim to bypass the approximations in traditional turbulence models by learning the underlying flow dynamics directly from the data.

One such study, outlined in the paper [1], explores the use of machine learning methods in turbulence modeling, offering insights into the potential of AI techniques in fluid dynamics simulations.

3 Methodology

3.1 Data Selection

For this project, the Johns Hopkins Turbulence Database (JHTDB) was selected. The JHTDB provides high-fidelity, time-resolved data from direct numerical simulations of turbulence, including velocity and pressure fields at various points in a three-dimensional grid. This dataset is ideal for training and testing machine learning models due to its comprehensive and high-quality data.

3.2 Model Implementation

A simple feedforward neural network (NN) was implemented to predict turbulence closures or simulate turbulence behavior based on the available CFD data. The model takes velocity components and other flow characteristics as inputs and learns to predict turbulent quantities or closures.

The neural network architecture consists of multiple layers, with a number of neurons in each layer chosen through experimentation. The model is trained on the velocity components from the JHTDB and evaluated against traditional turbulence models like RANS and LES.

3.3 Evaluation and Comparison

The performance of the AI-based model was evaluated by comparing its predictions against the turbulence closures from traditional models. Key performance indicators include mean squared error (MSE), correlation coefficients, and visual inspection of predicted vs. actual turbulence quantities.

4 Results

4.1 Model Performance

The machine learning model showed promising results in predicting turbulence closures, with a lower mean squared error compared to traditional models in certain conditions. The model was able to capture complex flow features that are difficult for traditional turbulence models to resolve.

4.2 Comparison with Traditional Models

The AI-based model was compared to traditional turbulence models, such as RANS and LES, in terms of accuracy and computational efficiency. While RANS models provide an efficient approximation of turbulent flows, they often lack the ability to capture fine-scale turbulence dynamics. On the other hand, the AI model demonstrated a better ability to approximate these dynamics in complex flow regimes.

5 Conclusion

This study demonstrates the potential of AI and machine learning techniques in turbulence modeling, particularly in predicting turbulence closures. By training on high-fidelity data from the Johns Hopkins Turbulence Database, the model was able to capture more complex turbulent behaviors than traditional models. Further improvements could be made by optimizing the neural network architecture and training on additional datasets.

6 References

References

[1] Author(s). (2023). Title of the paper. *Journal Name*, Volume(Issue), pages. `https://doi.org/10.1007/s40314-023-02547-9`