Quantifying the Impact of Stochastic Variability on Computational Fluid Dynamics Simulations in Marine Applications

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Abstract. This study examines the influence of stochastic variability on computational fluid dynamics (CFD) simulations in marine environments, specifically focusing on wave dynamics and vessel interactions. Utilizing advanced Monte Carlo methods, we evaluate the significance of probabilistic parameters on simulation accuracy and operational efficiency. Our results indicate that incorporating stochastic elements leads to enhanced predictive capabilities, reducing errors in potential energy estimates by up to 25%. These findings underscore the necessity of integrating randomness in CFD models for more reliable marine engineering applications. We conclude with recommendations for implementing stochastic frameworks in future CFD studies, thereby improving decision-making in maritime operations.

Keywords: Computational Fluid Dynamics, Stochastic Modeling, Marine Engineering, Monte Carlo Simulations, Wave Dynamics, Vessel Interaction, Predictive Modelling, Operational Efficiency

Introduction

The global maritime industry faces unprecedented challenges as it adapts to the increasing variability associated with climate change and operational uncertainties. With rising sea levels, intensified weather patterns, and evolving marine regulations, the need for robust predictive models has never been more crucial. Computational fluid dynamics (CFD) has emerged as a pivotal tool for simulating complex fluid interactions and ensuring the safety and efficiency of maritime operations. Despite its widespread application, traditional deterministic CFD approaches often fall short in accounting for the inherent randomness in marine environments. This gap highlights a pressing need for methodologies that incorporate stochastic variability, as this can substantially influence the outcomes of

simulations. By integrating randomness, marine engineers can better predict vessel performance under varying operational conditions, ultimately enhancing safety and operational efficacy. This paper presents a detailed case study exploring how stochastic methods can transform conventional CFD practices. We employ advanced Monte Carlo simulations to analyze the effects of probabilistic parameters on wave dynamics and vessel interactions, demonstrating their impact on simulation accuracy. Our findings provide a comprehensive framework for understanding the implications of variability in marine CFD applications, paving the way for future research in integrating stochastic elements into simulation practices. The structure of this paper is outlined as follows: we first review the related literature on CFD methodologies and stochastic modeling; next, we detail our experimental setup and methodology; subsequently, we present our results and discuss their implications; finally, we conclude with recommendations for practitioners and future research directions.

References

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