

Skin Friction Drag Predictions for Fouling-control Coatings and Biofouling Roughness: A Computational Approach with RANS Model

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ABSTRACT

Hull roughness and biofouling significantly increase hydrodynamic drag, leading to higher fuel consumption and emissions—a growing concern under stringent IMO regulations such as EEXI and CII. However, accurately modeling the turbulent boundary layer over rough surfaces remains a challenge due to the complex near-wall flow behavior and the lack of standardized modeling procedures (Kadivar et al., 2021). In the marine coatings industry, developing reliable numerical models is essential for predicting skin friction drag and assessing the performance of fouling control coatings. Such advancements are crucial for optimizing ship operational efficiency, reducing environmental impact, and ensuring compliance with regulatory standards.

This study presents a computational analysis using an open-source CFD tool to investigate flow behavior over rough surfaces representative of different fouling control coatings and marine biofouling conditions. To establish a robust modeling framework, initial simulations were conducted in a 3D rectangular duct with a homogeneous rough bottom surface, validating the computational approach against existing experimental and theoretical predictions of skin friction drag. The study then extended to heterogeneous roughness, focusing on turbulence characteristics during rough-to-smooth and smooth-to-rough transitions—scenarios that commonly occur due to patchy biofouling. Additionally, various roughness topographies, including barnacle-type fouling and microbial biofilm layers, were analyzed to capture their distinct effects on boundary layer development and drag forces. Multi-scale roughness modeling techniques were preliminarily explored, aiming to integrate coating-induced and fouling-induced roughness distributions. The influence of roughness element size, shape, and spatial arrangement on turbulence structure and energy dissipation was systematically evaluated, providing a refined approach for improved drag prediction at full ship scale.

Overall, this study demonstrates the reliability of integrating the RANS model with an appropriate roughness function in a commercially viable framework, offering practical insights for shipping and marine coating industries. Additionally, this study advances the understanding of how different coatings and fouling situations influence the drag on ship hulls, and eventually helps optimise coating selection and ship maintenance for fuel and operational efficiency.

References

Kadivar, M., Tormey, D., & McGranaghan, G. (2021). A review on turbulent flow over rough surfaces: Fundamentals and theories. *International Journal of Thermofluids*, 10, 100077.
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