Advancing Computational Frameworks for Dynamic Towing Stability: A Review and Perspective

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ABSTRACT

Maritime towing operations involve complex interactions between vessels, towlines, and environmental forces. These dynamic forces critically influence the stability and safety of workboats, especially under extreme operating conditions. Failures and incidents in towing operations frequently arise due to sudden environmental changes, excessive towline forces, and vessel manoeuvres under unpredictable conditions, leading to severe operational and safety risks. The dynamic interplay of wind, waves, and currents significantly affects the stability of both the tug and the assisted vessel, as well as the tension within the towline, often resulting in slack-to-taut transitions that exceed design thresholds and contribute to material fatigue or sudden failures.

Several studies have explored numerical approaches to address stability and safety concerns in workboat operations. Computational modelling is a critical tool for analysing vessel–towline–environment interactions, enhancing risk assessment, and supporting operational decision-making. Experimental studies and real-time monitoring approaches, such as strain gauges and sensor-equipped towlines, have demonstrated potential for enhancing predictive accuracy.

Despite significant advancements, a major limitation persists: the absence of an integrated computational framework capable of accurately capturing transient dynamic effects, such as sudden changes in towing conditions, environmental fluctuations, and operational actions, and validating these results against real-world data. To address these gaps, this paper outlines early research objectives for a modular computational framework to simulate dynamic forces in towing operations. The proposed framework integrates multiple numerical models, enabling adaptive switching between steady-state and transient towing conditions within simulation environments. While real-time sensor integration is a future goal, the current focus is on developing and validating simulation-driven responses based on manoeuvring coefficients and environmental inputs.

This paper presents a framework for advancing computational models in towing stability by integrating dynamic force modelling, which offers a novel approach to predictive safety assessment. By synthesizing significant contributions, identifying research gaps, and highlighting emerging methodologies, this study establishes a foundation for future improvements in towing stability assessment and real-time monitoring integration.

Keywords: Stability Assessment, Towing Operations, Dynamic Forces, Sudden Manoeuvres, Numerical Modelling.