From Air to Water – Translating Active Flow Control Technology for Maritime Applications

Thesis Summary
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Motivation and State of the Art

The maritime industry continuously seeks innovative solutions to enhance ship performance, reduce fuel consumption, and decrease environmental impact. Active Flow Control (AFC) technology, originally developed and extensively studied in aerodynamic contexts, presents a promising yet relatively unexplored method for maritime applications. This thesis specifically addresses the adaptation and potential benefits of fluidic oscillators—devices that produce periodic fluid jets without moving parts—to improve ship rudder performance. Such improvements aim to delay flow separation, thus enhancing maneuverability and reducing drag, directly contributing to fuel efficiency and lower emissions.

Methods

The research undertaken employs a comprehensive combination of computational, experimental, and analytical approaches. Initially, computational fluid dynamics (CFD) simulations were analyzed to examine internal flow patterns of fluidic oscillators, establishing a relationship between jet deflection and pressure differentials.

Subsequently, extensive experimental work was performed, including Particle Image Velocimetry (PIV) and time-resolved pressure measurements, to validate these findings and explore the performance of a water-based fluidic oscillator. A analytical advancement was introduced by applying the FitzHugh-Nagumo (FHN) equations, traditionally used in neuroscience, to model the complex oscillatory dynamics observed in these fluidic devices.

Finally, practical experiments in towing tanks, using ship rudder models equipped with optimized AFC systems, evaluated the real-world applicability and effectiveness of this technology.

Findings and Conclusion

The presented work successfully demonstrates the potential of translating AFC technologies from aerodynamics to maritime applications. The experimental studies confirm that fluidic oscillators can effectively delay flow separation around ship rudders, significantly enhancing maneuverability and offering potential reductions in fuel consumption.

The FitzHugh-Nagumo equations proved to be a capable modeling framework for capturing the intricate flow dynamics within fluidic oscillators operating in water, providing valuable insights and practical guidance for AFC actuator design.

Overall, this research validates the substantial benefits of implementing AFC in maritime engineering, promising considerable efficiency gains and reduced environmental footprints for shipping operations.

Outlook

Future research directions should focus on further refining the analytical models and optimizing fluidic oscillator designs for a broader range of maritime conditions and vessel types. Investigations into scalability, reliability under various environmental conditions, and integration with existing ship control systems are essential next steps. Additionally, exploring cost-effectiveness and long-term performance under real maritime operational scenarios will further validate AFC technology as a practical solution for the shipping industry's challenges. Continued interdisciplinary collaboration between fluid dynamics, maritime engineering, and computational modeling will be vital for fully realizing the potential of AFC in enhancing maritime sustainability and efficiency.