2019-12

# Hydrodynamically-based Detection of the Surface and Subsurface Wakes

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http://hdl.handle.net/10945/69967

**NPS NRP Executive Summary**

Hydrodynamically-based Detection of the Surface and Subsurface Wakes

Report Date: 10/15/19 | Project Number: NPS-19-N155-A

Naval Postgraduate School, Graduate School of Engineering and Applied Sciences

MONTEREY, CALIFORNIA

# HYDRODYNAMICALLY-BASED DETECTION OF THE SURFACE AND SUBSURFACE WAKES

Period of Performance: 10/16/2018–10/15/2019

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# EXECUTIVE SUMMARY

**Project Summary**

Research into non-acoustic submarine detection methods, mainly supported in the US by the Office of Naval Research, has been ongoing since the 1960s. The interest in hydrodynamically-based detection systems was recently invigorated by (i) continuous technological advances in remote sensing methods, which have dramatically improved the accuracy of measurements in submarine wakes, and (ii) the proliferation of ultra-quiet air-independent propulsion submarines whose signal-to-noise levels fall significantly below the threshold of passive acoustic detection systems. The investigation of surface and subsurface wakes for detection purposes is timely, since the understanding of environmental influences and numerical modeling capabilities have only been enabled to represent all key physical components.

This study was designed to advance our understanding of physical principles that govern the evolution of stratified wakes, providing the basis for the development of hydrodynamically-based submarine detection methods. Results from numerical and laboratory experiments performed by the PIs and NPS thesis students are highly encouraging in terms of operational guidance, and include (i) estimates of the detection periods for wakes in active oceanic environments (Radko and Lewis, 2019), and (ii) exploration of the effects of internal waves generated by propagating submersibles (Danieletto et al., 2019). Promising findings indicate that hydrodynamically-based detection could influence the tactics of undersea warfare.

**Keywords:** *stratified wakes, non-traditional detection, undersea warfare, battlespace environment, detection and avoidance*

**Background**

The primary motivation for studies of stratified wakes comes from naval applications—the need to control, detect and monitor dynamic and thermodynamic signatures of moving underwater vehicles. At the same time, analysis of stratified wakes constitutes an important component of classical fluid mechanics (e.g., Lin and Pao, 1979; Radko, 2001; Spedding, 2014). Much of the work done to date is based on the laboratory (e.g., Voropayev et al., 1999, 2007; Merriam, 2015; Danieletto, 2018) and numerical experiments (e.g., de Stadler and Sarkar, 2012; Chongsiripinyo et al., 2017; Davis, 2018; Guerrero, 2018, Radko and Lorfeld, 2018; Radko and Lewis, 2019). Our dynamics and modeling laboratory at Naval Postgraduate School (NPS) has already made considerable inroads into the problem, particularly through thesis research of Navy students at NPS. Of particular relevance for the present proposal are our experimental results from the field programs of 2015 and 2016, which are fully consistent with modeling-based expectations. The wake produced by towing a rigid cylindrical body (Moody et al., 2017) resulted in a clearly identifiable thermal perturbation in the main thermocline.

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**Findings and Conclusions**

Our investigation focused on the wake dynamics and detection potential in relation to the characteristics of (i) the submersible itself—its speed, depth, and size, and (ii) the ambient fluid, including thermal and haline stratification, planetary rotation and levels of background turbulence. These results will assist the Navy in the identification of detection vulnerabilities and affect the tactics of undersea warfare by narrowing the submarine search areas. The essential findings were reported in Radko and Lewis (2019) and Danieletto et al.,(2019).

The research component reported in Radko and Lewis (2019), attempted to quantify the decay rates of stratified wakes in active oceanic environments, characterized by the presence of intermittent turbulence and double-diffusive convection. Of particular interest was the possibility of utilizing standard oceanographic microstructure measurements as a means of wake identification and analysis. The investigation was based on a series of direct numerical simulations of wakes produced by a sphere uniformly propagating in stratified two-component fluids. We examined and compared the evolution of wakes in fluid systems that are (i) initially quiescent, (ii) double-diffusively unstable, and (iii) contain preexisting turbulence. The overall conclusion from our study is that the measurement of microscale signatures of turbulent wakes could represent a viable method for hydrodynamic detection of propagating submersibles.

The study of Danieletto et al., (2019) was focused on drag evaluation and prediction, which are integral to maximizing the efficiency of nautical vehicles and limiting their hydrodynamic signatures. One source of drag that remains poorly understood, yet has significant effects for vessels traversing stratified waters, is the dead-water phenomenon. It represents the dramatic increase in drag associated with internal waves created by the body itself. This phenomenon has been studied in the literature for surface and submerged vessels separately, but little attention has been given to directly comparing the two. Our research investigated the dead-water effects by comparing laboratory outcomes for both submerged and surface body experiments in stratified and unstratified fluids. By comparing the drag coefficient measured in each case, we found that the stratified contribution to the drag coefficient is comparable for surface and submerged bodies. The change in the drag coefficient caused by stratification is always positive in these experiments, but is much larger for speeds lower than the maximum phase speed of the system. This implies that the dead water modification to the drag coefficient does not depend on the location of the body, which is an important consideration in determining the depth of maximum efficiency for vessel transport.

In the course of this project, four Navy students (CRD Lewis, LCDR Dougherty, LT Kramer, LT Zimny) performed their thesis research on hydrodynamically-based detection, concurrently learning techniques of high-performance computing.

## Recommendations for Further Research

Our present investigation stimulated several promising ideas for follow-up projects. These ideas are currently pursued by the thesis students supervised by the PI and Co-PI. LCDR Dougherty is performing a series of numerical simulations of submarine wakes in an active field of internal waves, and these simulations will be used to assess the prospects of satellite-based detection for a given depth and speed of a submersible. LT Kramer is exploring the ramifications of submarine maneuvering for wake detection, and LT Zimny currently works on the development and use of artificial intelligence and machine-learning techniques for the identification of late wakes.

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