

## Abstract

The deployment of Autonomous Underwater Vehicles (AUVs) in coordinated missions has grown significantly, covering applications such as environmental monitoring, defense operations, and industrial inspections. A key challenge in such missions lies in ensuring hydrodynamic efficiency and reliable collision avoidance, as conventional sensor-based strategies are often limited by underwater visibility and acoustic interference. Furthermore, these approaches typically overlook the influence of inter-vehicle hydrodynamic interactions, which strongly affect stability and energy consumption in swarm operations.

This thesis addresses these challenges by integrating Computational Fluid Dynamics (CFD) simulations with machine learning models to develop a comprehensive framework for hydrodynamic optimization and proactive collision avoidance. The study is organized into three parts. First, a systematic CFD investigation of series formations explores the effects of velocity and spacing on drag distribution and provides data for surrogate model development. Second, symmetric V-formations are analyzed to examine drag, lift, and moments, with optimization applied to identify stable and energy-efficient swarm geometries. Finally, building on these hydrodynamic insights, a dynamic collision avoidance framework is developed by training machine learning models on CFD-derived datasets, enabling predictive force and moment estimation for anticipatory trajectory corrections.

All simulations employed an AUV model of characteristic length 1.075 m, which served as the reference scale for all spacing and formation analyses. Experimental validation in a circulating water tunnel further supported the numerical results, demonstrating good agreement in observed wake interactions and flow patterns.

This work contributes a scalable and physics-informed approach for multi-AUV swarm operations by bridging hydrodynamic modeling, optimization, and real-time collision avoidance. The framework lays the groundwork for enhancing the efficiency, safety, and adaptability of autonomous underwater systems in complex marine environments.

**Keywords:** Autonomous Underwater Vehicles, Collision Avoidance, Computational Fluid Dynamics, Machine Learning, Random Forest Regression, Hydrodynamic Forces, MultiVehicle Coordination