College of Engineering and Computer Science
Office of the Dean
777 Glades Road, EE96, Room 308
Boca Raton, FL 33431
561.297.3400

Announces the Ph.D. Dissertation Defense of

Mackenzie Smith

for the degree of Doctor of Philosophy (Ph.D.)

Hydrodynamics of Ocellate River Stingrays and Applications Towards Benthic Underwater Vehicles

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Zoom Link: https://fau-edu.zoom.us/j/83041743902?pwd=r6AKuGOtcqdDgbLL0JCFHACOYF8HQr.1

DEPARTMENT: Ocean and Mechanical Engineering

ADVISOR:
Oscar Curet, Ph.D.

PH.D. SUPERVISORY COMMITTEE:
Marianne Porter, Ph.D.
Manhar Dhanak, Ph.D.
Siddhartha Verma, Ph.D.

ABSTRACT OF DISSERTATION
While the undulatory movement of benthic stingrays has been studied, few studies have examined the fluid dynamics of flat pectoral fin movement utilized as niche gliding locomotion near the ground or for station-keeping in the presence of incoming flow. In this work, we studied the hydrodynamic performance of the ocellate river stingray (Potamotrygon motoro) as a function of distance from the ground for different body sizes. Three stingray specimens of three different sizes were scanned (disproportional models), and two additional models were created by scaling the medium model 25\% larger and smaller (scaled models). These models replicated the dorsoventral body structure of the ocellate river stingray, which resembled a hydrofoil. The 3D-printed models were tested in a recirculating flume to measure drag and lift forces at distances of 0.1 cm to 18 cm from the ground (approximately 0.007 to 1.33 body lengths, respectively). Each force was measured at two water flume flow speeds, 12 cm/s and 18.5 cm/s. In addition, particle image velocimetry (PIV) was conducted to measure the flow field around the models' head at mid-plane at three different heights above the ground. Force results showed a significantly higher lift-to-drag ratio when the model was closest to the substrate, which rapidly decreased with height above the ground. Lift patterns were consistent across all models, with a steep increase at 0.1 cm above the ground, then a sharp decrease at 2 cm, and finally a slight second increase before decreasing towards negative lift at approximately 16-18 cm. Drag increased directly with surface area as flow speed increased. Scaled models showed a steady, clear increase in drag and lift with size, whereas lift showed a disproportionate relationship with size. There were slight differences in lift and drag between allometric and isometric models, suggesting morphological differences with growth. The drag coefficient increased exponentially up to 2 cm distance from the ground, then plateaued for the remaining heights, despite the three-part variation in the lift coefficient. PIV results showed strong interaction with the ground at 0.1 cm above the ground, with a decrease in flow speed around the stingray body. Additionally, a deflection of flow in the upward direction was observed in the transitioning area from the front to the dorsal side of the body (as shown in the velocity field in the vertical direction). Further analysis of the fluid dynamics investigated the velocity magnitude, vorticity, and the velocity field in the x- and y- directions. The pressure field showed a change from high to low pressure as the flow traveled from the front to the back of the dorsal side of the model. The PIV and pressure field results verify fast flow at the front of the model and slower flow over of the body. An application of the stingray hydrodynamic results was implemented on a benthic walking underwater robot to improve walking contact with the ground. Results showed an increase in negative lift, which aided the robots' walking ability in the benthic environment and improved energy efficiency.

Further work on this topic could help robotic systems navigate the underwater environment safely and efficiently. While factors such as allometric growth between males and females and juvenile stingray hydrodynamics with ground effect were examined in this research, the addition of adult models could provide more insight. This research provides more details on the hydrodynamic properties of the ocellate river stingray.

BIOGRAPHICAL SKETCH
Born in Longwood, FL
B.S., Biological Sciences, Florida Atlantic University
Certificate of Environmental Sciences, Florida Atlantic University
B.S., Ocean Engineering, Florida Atlantic University
Certificate of Underwater Acoustics, Florida Atlantic University
M.S., Ocean Engineering, Florida Atlantic University
Ph.D., Ocean Engineering, Florida Atlantic University

CONCERNING PERIOD OF PREPARATION
& QUALIFYING EXAMINATION

Time in Preparation: 2022 - 2026

Qualifying Examination Passed: Spring 2024

Published Papers:

Brown, N., Briggs, T. R., Smith, M., & Kajiura, S. (2026). Effect of Beach Nourishment–Driven Turbidity on Water Quality and Blacktip Shark Aggregations. Journal of Coastal Research, 1(aop).