FIRE BALEEN CleanCurrent: UAV Design For Microplastic Collection in Water Systems

SAINT LOUIS UNIVERSITY
SCHOOL OF SCIENCE AND ENGINEERING

Saint Louis University School of Science and Engineering

Ava Alton, B.S. Aerospace Engineering Minor Anthropology, Juhyeong Seon, B.S. Aerospace Engineering

Research Question: How can an autonomous underwater vehicle structure be optimized to maintain a constant internal flow velocity of 0.5 m/s through a 15° inclined baleen filtration array while minimizing hydrodynamic drag?

Design Goal: To engineer a low drag hull geometry with integrated inlet/outlet channels that facilitate passive water filtration, effectively balancing structural integrity with fluid dynamics.

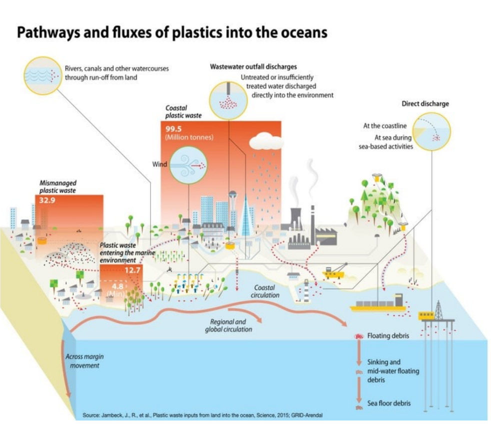
Key Finding: CFD simulations confirmed that the proposed hull geometry achieved the target internal flow rate at 0.5 m/s, successfully optimizing the trade-off between filtration throughput and parasitic drag.

Missouri Space Grant

Abstract

Microplastic pollution requires efficient, autonomous recovery solutions. This study investigates the design and optimization of an autonomous underwater vehicle structure capable of maintaining a target internal flow velocity of 0.5 m/s, the optimal threshold for baleen-inspired microplastic filtration. Using Onshape, a hull geometry was developed featuring a 15° inclined filtration array. Computational Fluid Dynamics was performed to characterize the system's hydrodynamic performance, specifically analyzing the relationship between UAV forward velocity, internal flow throughput, and parasitic drag. Results demonstrate that the optimized hull geometry effectively sustains target filtration parameters, providing a scalable model for low-drag, high-efficiency autonomous environmental remediation.

Introduction

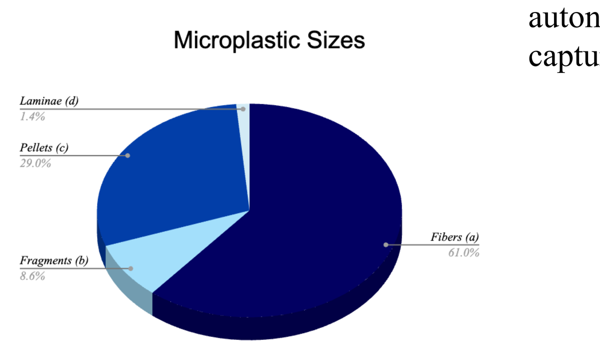


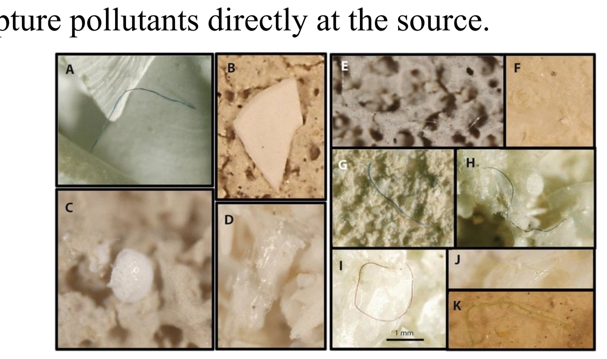
Leading Locations of Microplastic Pollution

- Urban Runoff and Drainage Networks
- Riverine and Estuarine Conduits
- Stagnant and Low-Flow Shorelines
- Industrial and Wastewater Effluent

St. Louis Leading Locations

- Stormwater detention basins and drainage outfalls throughout the St. Louis metro area function as high-concentration accumulation zones for microplastic debris.
- These low-flow environments provide ideal operational conditions for deploying autonomous, low-drag UAVs to intercept and capture pollutants directly at the source.





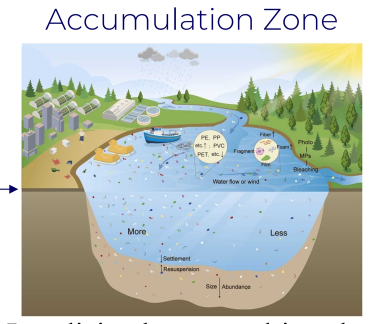
The Study Site

Spanish Lake is the primary location in this runoff, making it a critical hub for collecting microplastic pollution.

The Source

Outfalls serve as primary transport pathways, efficiently flushing microplastic debris from urban surfaces into the aquatic system.

Accumulation Zone



Localizing hotspots, driven by water flow and sediment dynamics, serves as our primary target for effective pollutant interception.

Methodology

Baleen-Inspired Filtration System

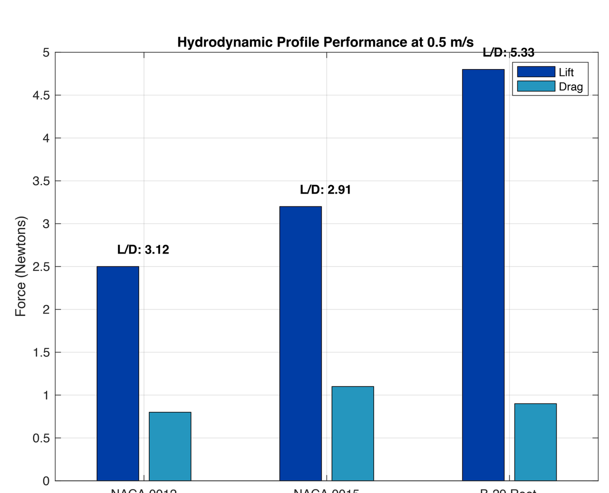
- Biomimetic of the feeding mechanism of Baleen whales utilizes a high surface area to trap prey.
- 2mm mesh is oriented to capture microplastics while minimizing hydrodynamic backpressure.
- Leveraging UAV'S forward velocity, filter functions as a passive collector, eliminating the need for pumps and extending the mission lifespan.

Hydrodynamic Body Optimization

- Analysis of three airfoil profiles for optimal geometry required to minimize energy consumption during the mission.
- Selection of the B-29 Root profile.
- B-29 Root design achieved the highest Lift- to-drag ratio, extending range, and improving stable low-flow maneuverability in restricted channels.

Sensors

- *GPS*
- *Inertial Measurement Unit*
- *Ultrasonic Transducer*
- *Camera*



Results

CFD Result

- Four CFD simulations were conducted using the SST k-OMG turbulence model at inlet velocities of 0.5 m/s, 1.0 m/s, 1.5 m/s, and 2.0 m/s.
- Each Simulation was run for 2000 iterations.
- All velocity profiles show a consistent trend:
  - Velocity increases at the first two points
  - Velocity remains approximately constant across the next three points
  - Velocity decreases exponentially over the final three points
- This behavior indicates that the internal filter causes a conversion of kinetic energy into pressure loss.
- As a result, the flow experiences a gradual reduction in velocity downstream of the filter

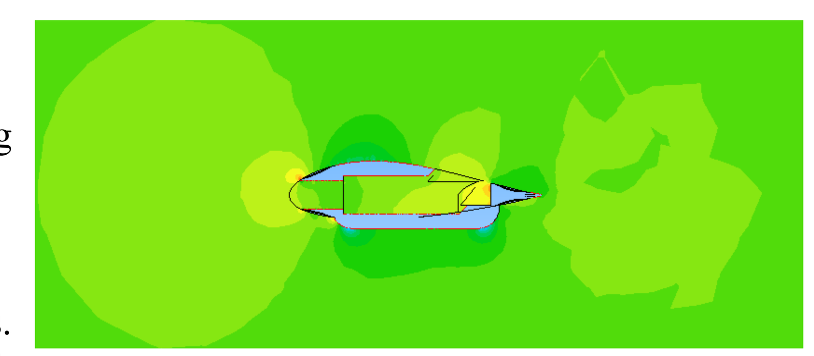


Figure 1: Pressure Plane With V = 0.5 m/s

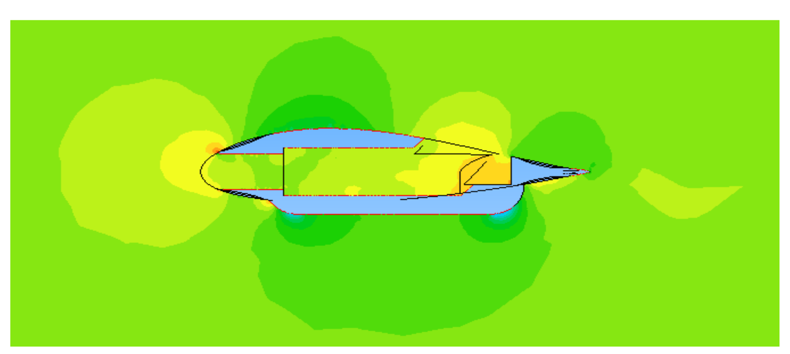


Figure 2: Pressure Plane With V = 1 m/s

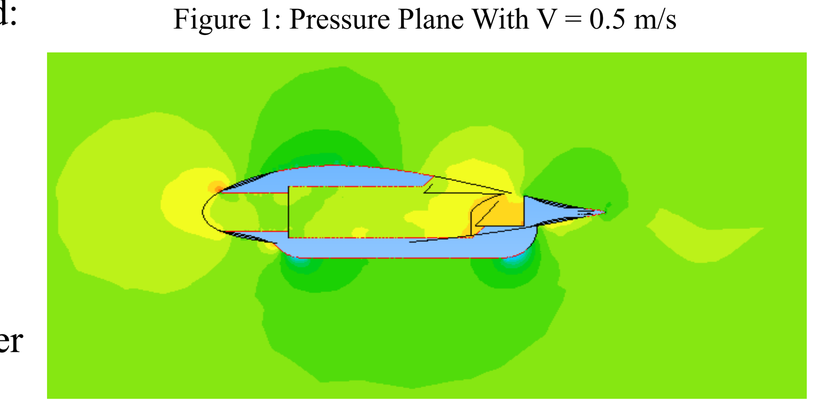


Figure 3: Pressure Plane With V = 1.5 m/s

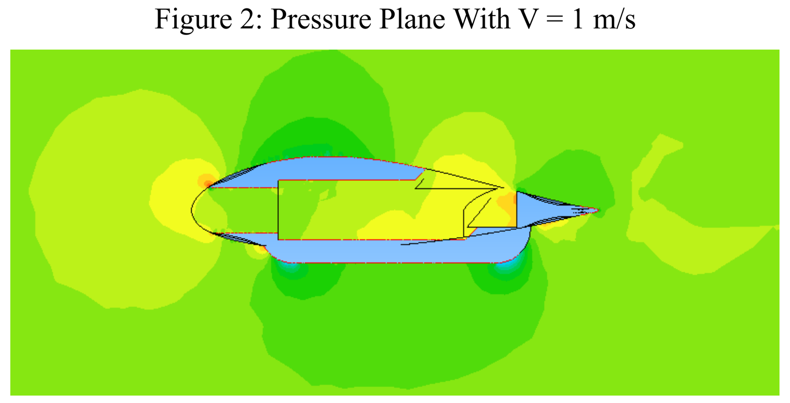
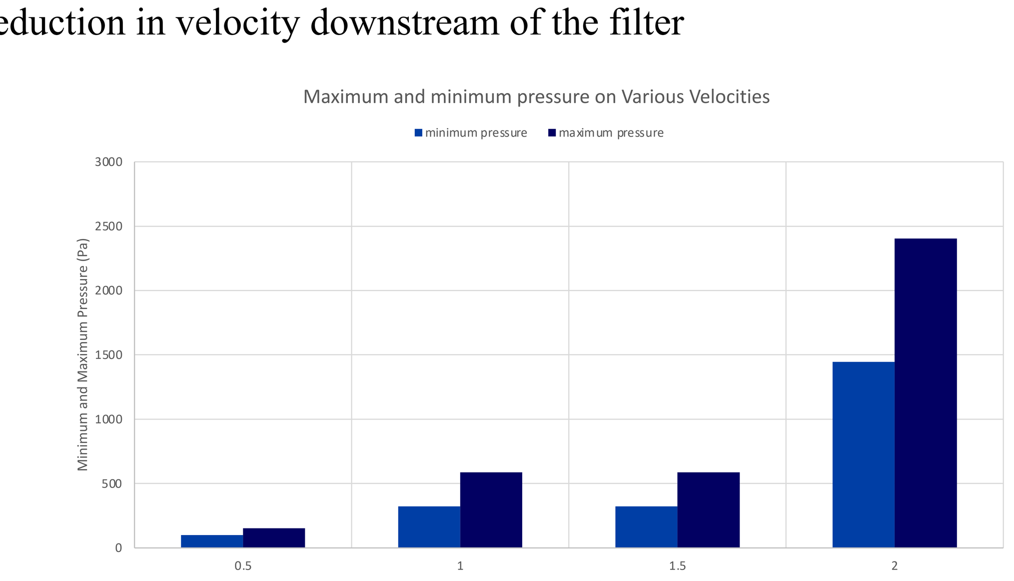
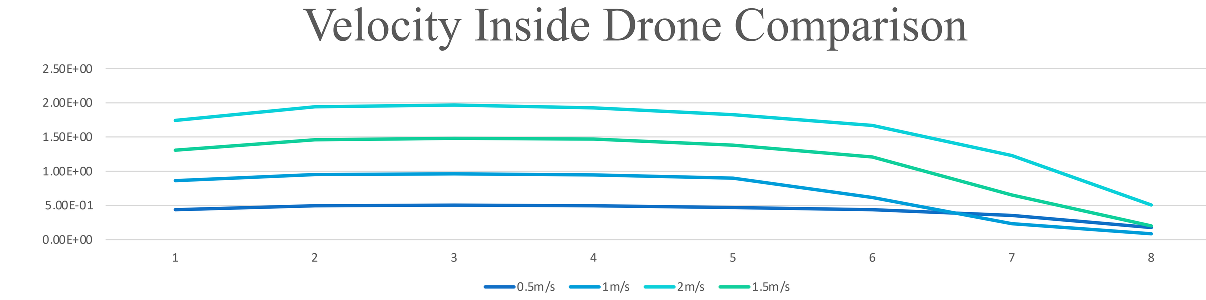
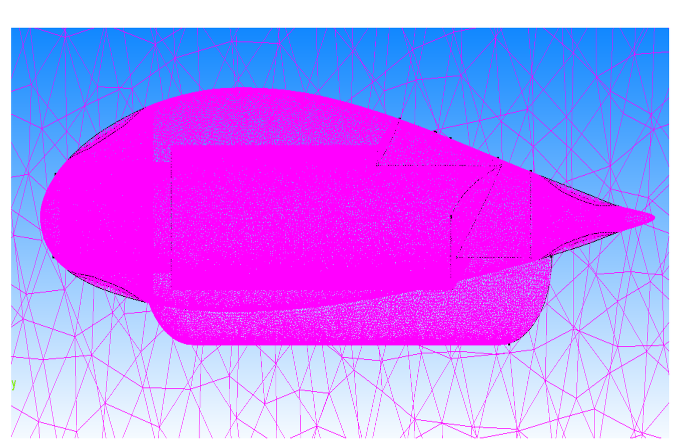


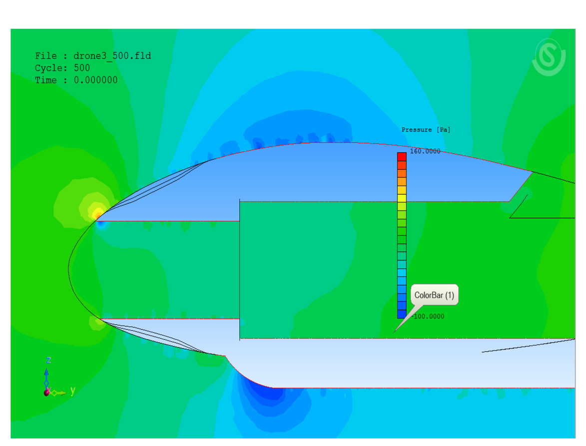
Figure 4: Pressure Plane With V = 2 m/s



Velocity Inside Drone Comparison







Pressure Distribution

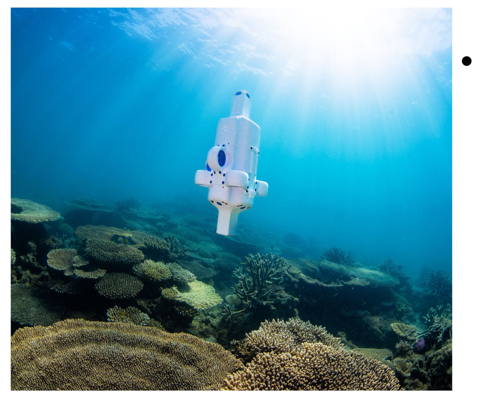
- Pressure contours show a physically consistent distribution across the control volume in water.
- High-pressure regions appear at the front and inlet-facing surfaces due to flow stagnation.
- Low-pressure regions develop along the sides and downstream as the flow accelerates and separates
- Pressure gradient is consistent with expected hydrodynamic behavior and contributes to the overall drag characteristics of the drone.
- Simulation did not fully converge to a steady-state solution, resulting in minor irregularities in the contours
- While this limits quantitative accuracy, the overall pressure trends remain valid and provide meaningful insight into the drone's hydrodynamic performance.

Conclusion

- By successfully integrating baleen-inspired filtration mechanics into a low-drag system, it demonstrates that passive debris capture is a viable, energy-efficient alternative to power-intensive methods.
- The proposed integration fleet-based deployment provides a robust framework for large-scale watershed restoration, capable of transitioning from localized testing in Spanish Lake to widespread urban waterway mitigation.
- *Project Baleen* stands at the intersection of environmental stewardship and advanced robotics; its development not only addresses immediate microplastic pollution but also serves as a proof of concept for autonomous resource filtration systems in diverse aquatic environments, with potential future extraterrestrial applications.

Future Work

- Conducting comprehensive field trials at Spanish Lake to establish real-world performance baselines.
- Analyzing battery lifecycle and collection-per-watt efficiency to optimize runtime versus debris capture throughput.
- Using field data to refine the filtration module's geometry, ensuring maximum microplastic retention in variable flow conditions.
- Implementing advanced pathfinding algorithms to transition from operator-controlled navigation to full, swarm-capable autonomy.
- Developing automated docking and recharging stations to enable persistent, long-term operation.
- Scaling the system into a multi-unit swarm capable of patrolling and cleaning larger watershed areas simultaneously.



- Implementing computer vision-based debris quantification to monitor filter capacity in real-time, enabling fully autonomous mission termination and return-to-home sequencing once maximum storage volume is reached.

Acknowledgements

The development of the Project Baleen system was made possible through the support and guidance of Dr. Potvin. We are also deeply appreciative of the Saint Louis University School of Science and Engineering for providing the funding necessary to design, prototype, and test the system. Finally, we thank the Missouri Space Grant Consortium for funding our summer research, enabling us to explore the potential of this technology for implementation not only here on Earth, but also on extraterrestrial ocean worlds.