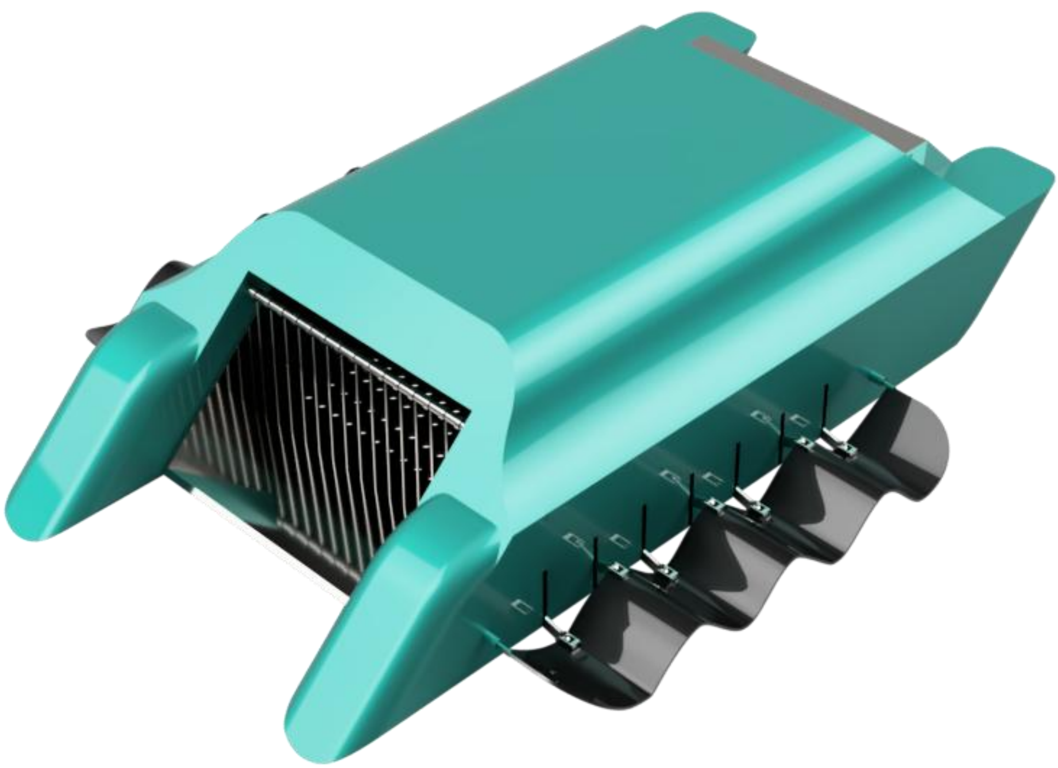
Unmanned Surface Vehicle (USV) for Waste Collection

Proposed Solution:

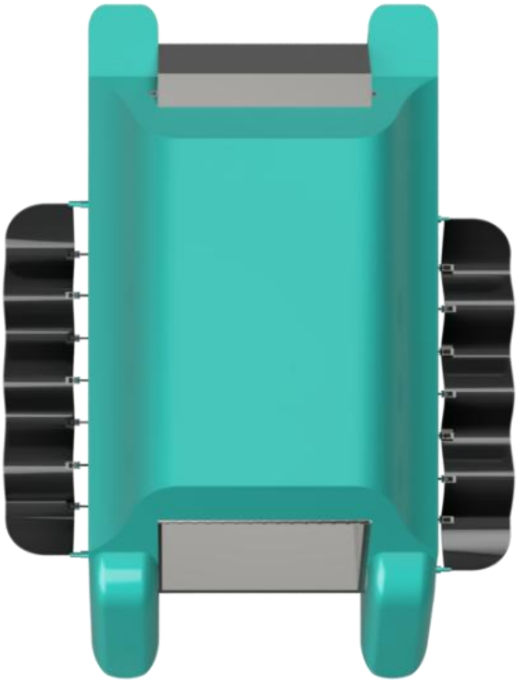
Bio-inspired USV that efficiently collects surface waste from water bodies. The USV features biomimetic fin-based propulsion for agility and energy efficiency, allowing it to navigate smoothly through water with minimal disturbance. It incorporates a dual navigation system: manual control via a radio transmitter for primary navigation and autonomous mode using Pixhawk flight controller and Raspberrypi for more complex, pre-programmed waste collection routes. The primary mission is to aid in environmental clean-up efforts by collecting floating waste on water surfaces, such as plastic debris, leaves, and other pollutants.

Conceptual Design Approach:

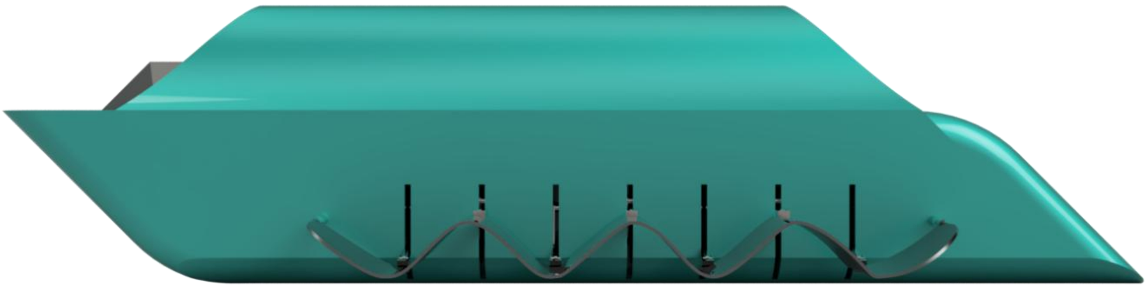
3D Model / Design:



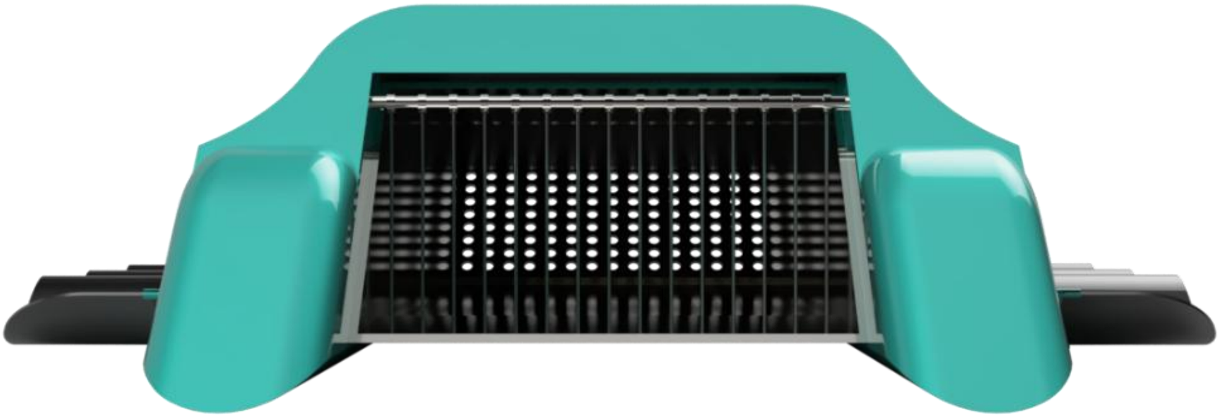
a) Isometric View



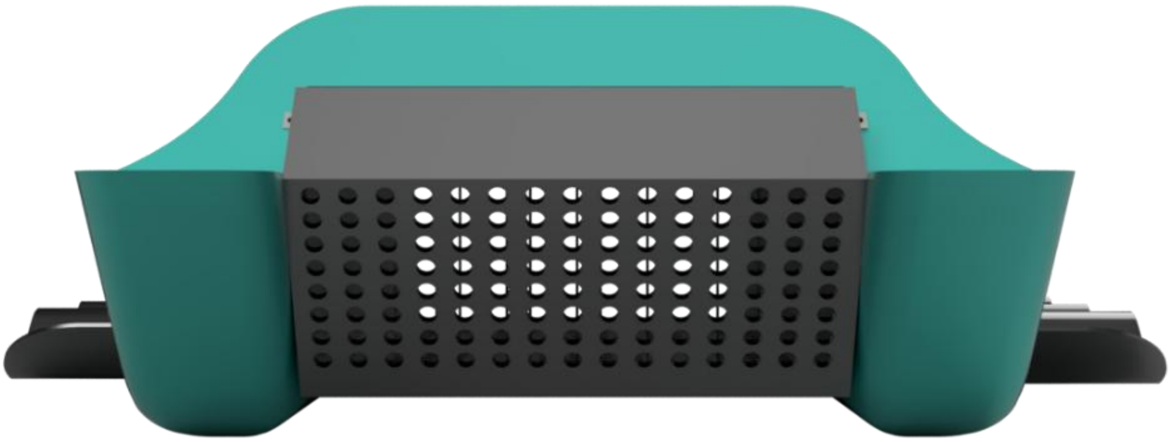
b) Top View



c) Side View

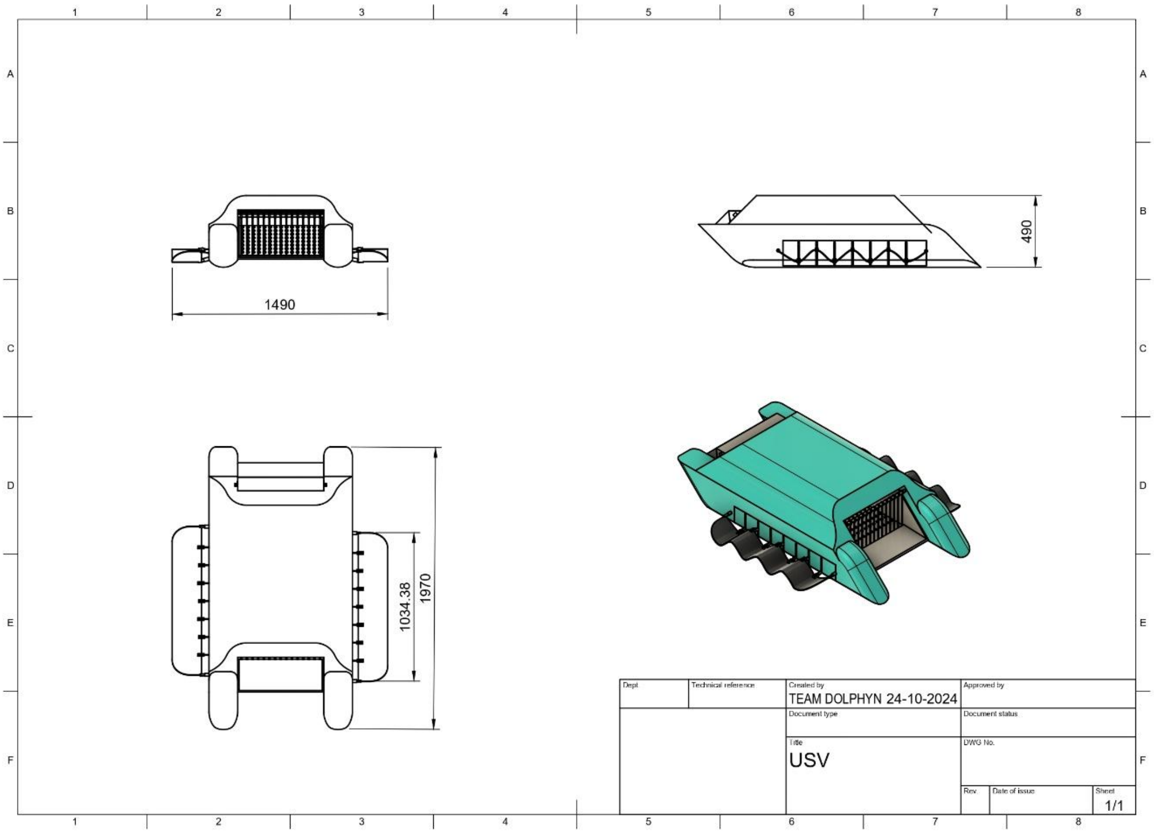


d) Front View



e) Back View

2D Draft:



Technical Requirements and Specifications:

Functional Requirements:

1. **Primary Navigation via Radio Transmitter:** Allows for direct, manual control by the operator to navigate around large or concentrated waste areas.
2. **Autonomous Navigation using Pixhawk:** Capable of self-guided routes to follow predetermined paths along water surfaces for routine waste collection.
3. **Waste Collection Mechanism:** Equipped with a front-mounted One-Way Mechanical Barrier collection system that captures and stores floating debris.
4. **Bio-Inspired Undulating Fin from knife fish:** Designed for energy-efficient, low-disturbance movement, particularly beneficial in sensitive or ecologically significant areas.
5. **Obstacle Avoidance:** Equipped with Camera to detect and avoid obstacles such as rocks, buoys, or other vessels.

Navigation and Control System:

- In **manual mode** Pixhawk receives input from the radio transmitter, enabling direct control.
- In **autonomous mode,** Pixhawk manages movement based on GPS waypoints and real-time IMU adjustments, providing stability and autonomous navigation for waste collection.

1. Waste Collection System:

- **One-Way Mechanical Barrier:** Positioned at the front of the USV, this system includes a rake system that collects up floating debris as the USV moves through the water. The collected waste is stored in a detachable bin or basket located at the back of the USV for easy removal and disposal.
- **Mesh Filter:** A mesh filter integrated into the collection system ensures that only debris and waste are collected, allowing water to flow through and reducing drag on the vehicle.

2. Propulsion System: Biomimetic Fin Design:

Inspired by the efficient movement of marine animals, the fin-based propulsion system enhances maneuverability and minimizes disturbances in the water. The fins:

- Operate with **oscillating movement**, mimicking natural swimming, which reduces energy usage and maintains a quiet presence, avoiding excessive disruption to aquatic life.
- Provide **versatile maneuverability**, especially beneficial for navigating around obstacles or reaching confined spaces where waste tends to accumulate.

3. Pixhawk 2.4.8 for Autonomous Stability and Control:

- IMU (Inertial Measurement Unit): Provides stability control by tracking roll, pitch, and yaw, essential for steady movement and accurate waste collection.
- GPS Module: Enables precise navigation for autonomous operations, allowing the USV to follow defined paths or return to base when necessary.

4. **1080p HD Camera:**

- Integrated camera captures surface images for **obstacle detection** and **visual navigation** using YOLO v7 algorithms.

5. **Raspberry Pi as Companion Computer:**

- The **Raspberry Pi** serves as the companion computer, handling image processing (YOLO v7), sensor data integration, and supporting autonomous navigation alongside the Pixhawk controller.

6. **Waste Bin Full Detection:**

- An **IR sensor** detects when the waste bin is full, triggering the USV to return to the home position for unloading.

7. **Home Position for Waste Unloading:**

- The USV autonomously returns to a pre-programmed home position using Pixhawk and GPS waypoints for waste unloading.

Hull Design and Structural Integrity

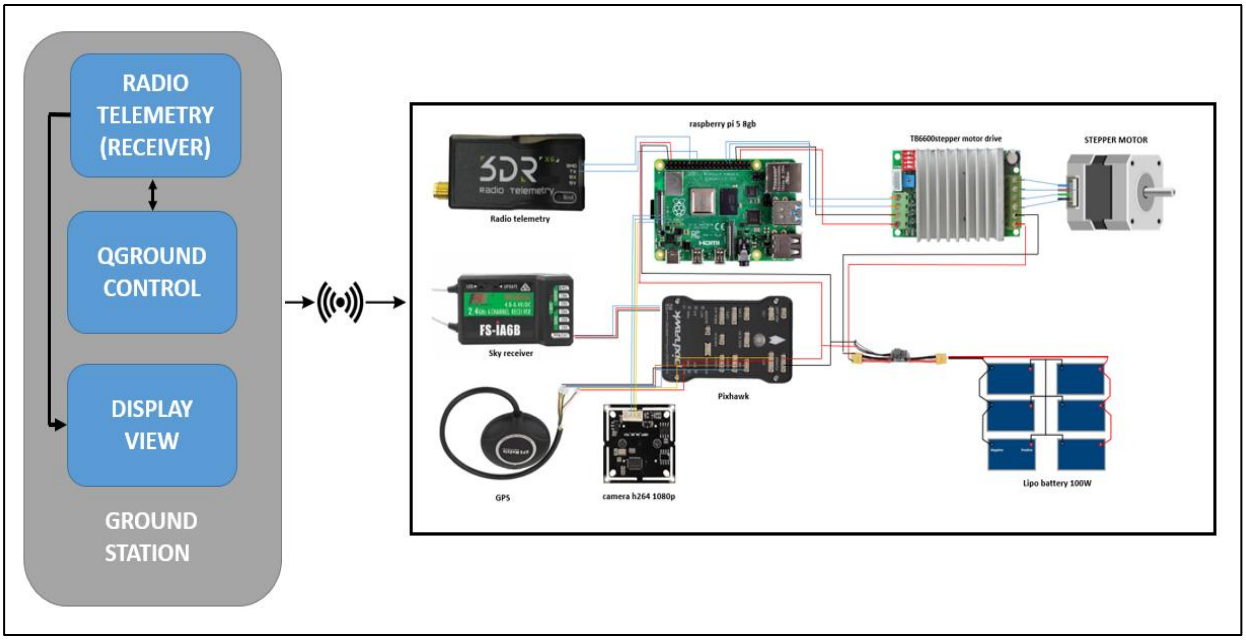
The hull is designed to ensure:

- **Stability and Buoyancy:** Lightweight, corrosion-resistant materials are used for the hull to prevent rusting and degradation over time.
- **Waterproof Compartment for Electronics:** The Pixhawk, raspberry pi 4, GPS module and other control electronics are secured in a waterproof compartment using acrylic pipe enclosed by resin, ensuring safety and durability in aquatic environments.
- **Waste Collection Payload:** The USV's waste tank capacity is **25.97 liters** (2.597×10^7 mm^3), providing sufficient space for surface debris collection during extended operations without frequent unloading.

Software stacks:

- **Autodesk Fusion 360**: Used for designing the USV components (hull, waste collection system, propulsion), including part modeling and assemblies.
- **ANSYS 2024 R1**: Analyzes structural integrity and hydrodynamics, simulating stress, strain, and fluid flow to ensure durability and efficiency.
- **QGroundControl**: Provides mission planning, waypoint navigation, and real-time telemetry for precise monitoring and control of the USV.
- **ROS 2**: Manages sensor integration (GPS, IMU, ultrasonic), processing data for autonomous navigation and obstacle avoidance.
- **Gazebo**: Simulates USV dynamics, navigation, and waste collection in 3D for design validation and optimization before deployment.
- **YOLO v7:** Processes visual input from the camera for real-time obstacle detection and navigation assistance.

Electronic circuit Design:



Theoretical Calculations:

1

Thrust Force Formula:

$$F_t = \frac{1}{2} \rho A v^2 C_t$$

ρ - Density of the fluid [kg/m^3]

A - Effective area of the Surface [m^2] → Undulating Fins

V - Velocity of the fluid [m/s]

C_t = Thrust Co-efficient [No dimension]

$$F_t = \frac{1}{2} \rho A v^2 C_t$$

$$F_t = \frac{1}{2} \times 1000 \times 0.248 \times (1.5)^2 \times 1.5$$

$$F_t = 418.5\ N \Rightarrow F_t = 418.5 \times 2 \Rightarrow \boxed{F_t = 837\ N}$$

Here we have used Undulating propulsion system on both sides. The above calculation for one of the Undulating fin. For Both we had multiplied by two.

Drag force:

$$F_d = \frac{1}{2} \rho A v^2 C_d$$

ρ - Density of the fluid [kg/m^3]

A - Effective area of the Surface [m^2] → Submerged Faces

V - Velocity of the fluid [m/s]

C_d - Drag Co-efficient [No dimension]

2

$$F_d = \frac{1}{2} \rho A V^2 C_d$$

$$= \frac{1}{2} \times 1000 \times 1.683 \times 0.04 \times 0.8$$

$$F_d = 26.928 \times 2$$

$$\boxed{F_d = 53.856\ N}$$

By Considering the both Undulating fins we had multiplied by two.

Total Velocity:

$$V = \sqrt{\frac{2F_t}{\rho A C_t}}$$

F & F_t = Thrust force [N] and Thrust co-efficient.

ρ - Density of the fluid [kg/m^3].

A - Area of the Undulating fin.

C_t - Co-efficient of the thrust.

$$V = \sqrt{\frac{2F_t}{\rho A C_t}}$$

$$V = \sqrt{\frac{2 \times 837}{1000 \times 0.248 \times 1.5}}$$

$$\boxed{V = 2.121\ m/s}$$

3

Relation between Motor RPM:

$$V = 2\pi f A$$

f - Frequency of oscillation [in Hz]

A - Area of the Undulating Fin.

$$V = 2\pi f A$$

Rewriting,

$$f = \frac{V}{2\pi A}$$

$$f = \frac{2.121}{2 \times 3.14 \times 0.248}$$

$$\boxed{f = 1.36\ Hz}$$

Converting Oscillation into RPM:

$$RPM = f \times 60$$

$$RPM = 1.36 \times 60$$

$$\boxed{RPM = 81.6}$$

Buoyancy formula:

$$B = \rho \times V \times g$$

g - Specific gravity

ρ - density of the fluid [kg/m^3]

V - Volume of the USV

4

$$B = \rho V g$$

$$B = 1000 \times 0.301 \times 9.81$$

$$B = 2952.81\ N$$

Converting N into kg

$$\boxed{B = 301\ kg}$$

Torque Calculation:

$$\tau = r \times F_t \times \sin\theta$$

F_t - Average thrust produced

r - Distance from the pivot point of the center of the fin or where the force applied

θ - Angle between the direction of force and the lever arm

$$\tau = r \times F_t \times \sin\theta$$

$$\tau = 0.17 \times 337 \times \sin[83^\circ]$$

$$\boxed{\tau = 5.2\ Nm}$$

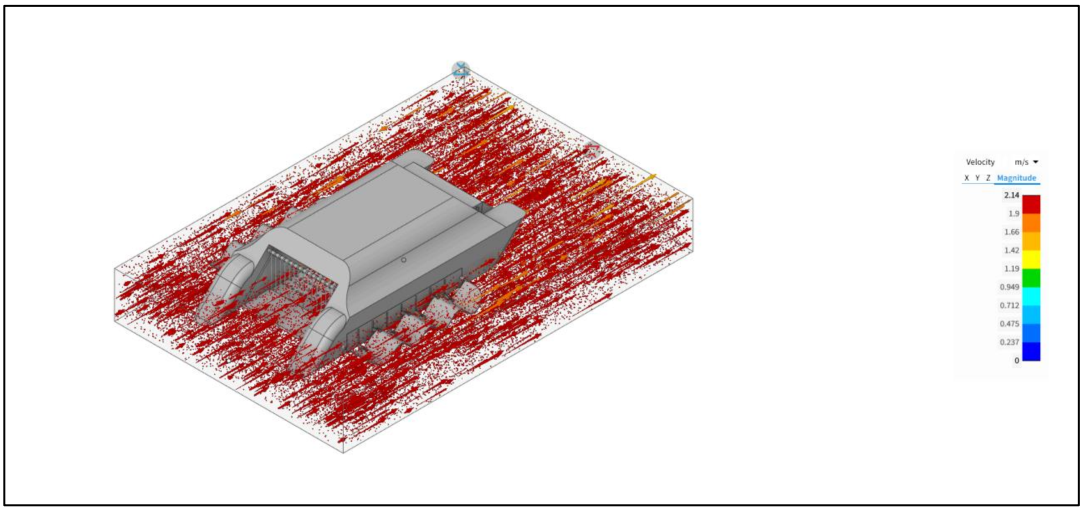
Power Calculation:

S.NO	COMPONENTS	POWER (W)	AMPERE (A)
1	STEPPER MOTOR	69	6
2	PIXHAWK	8.5	1.7
3	RASPBERRY PI 5	8	1.6
4	GPS	0.5	0.03
5	CAMERA	1.7	0.3
6	OTHERS	1.3	0.37
TOTAL		89	10

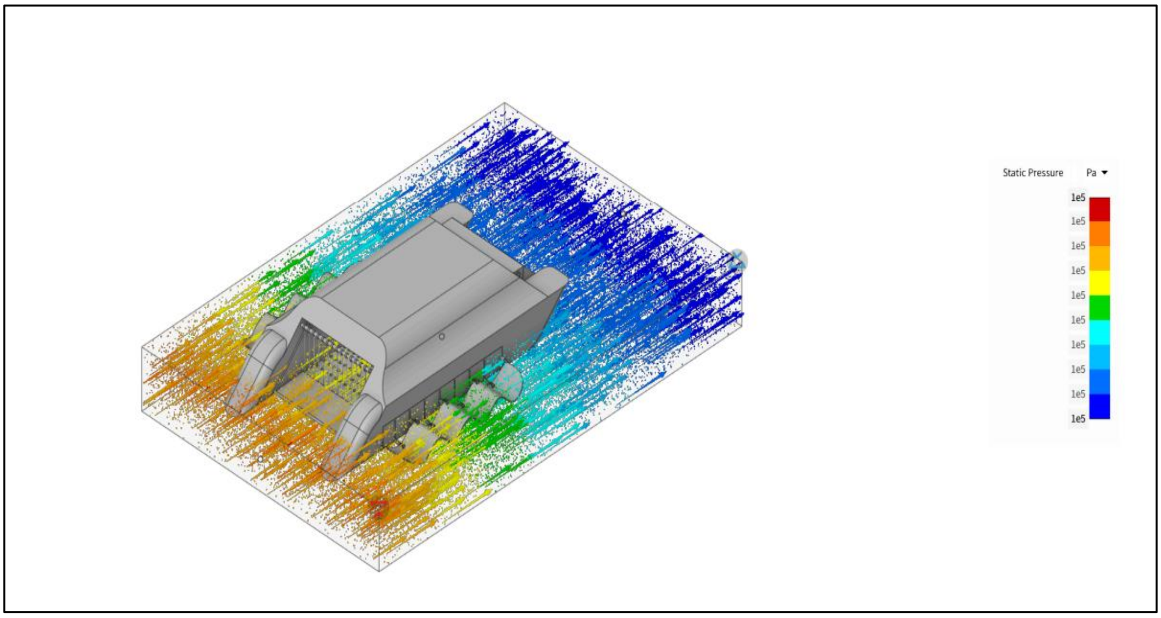
Preliminary Analysis and Simulations:

Hydrodynamic and Structural Analysis:

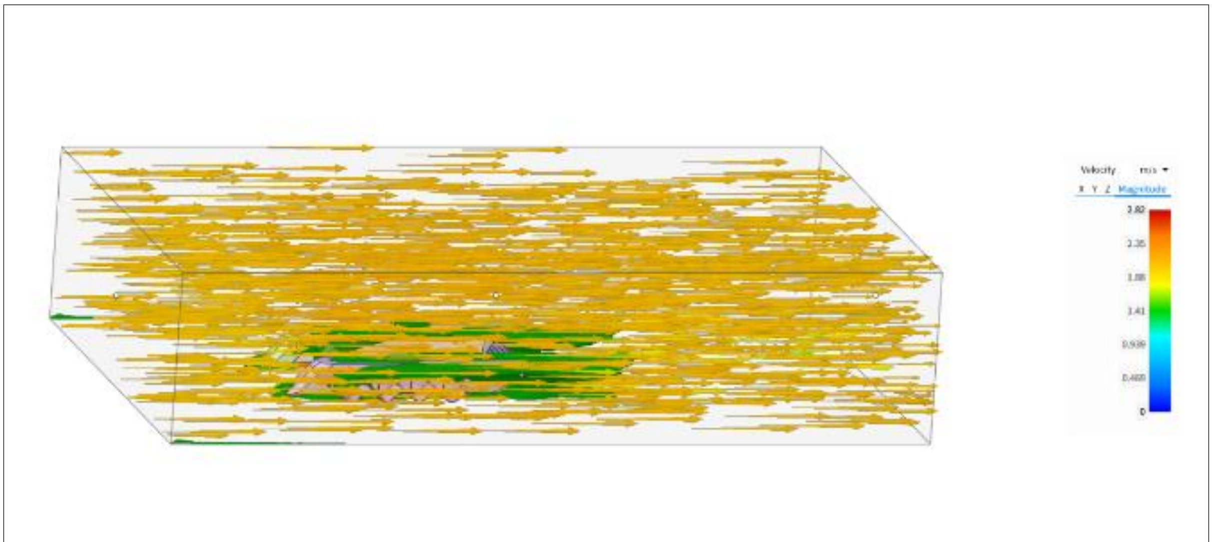
- **Drag Coefficient Testing:** Computational Fluid Dynamics (CFD) simulations confirmed that the hull and fin designs minimize water resistance, optimizing speed and efficiency for waste collection.
- **Finite Element Analysis (FEA):** Ensured the hull's durability under potential forces from wave impact and collected debris.



a) Velocity Flow



b) Static Pressure Flow



c) Drag Force

Source: **Ansys report**

Project Tentative Budget:

S.No	MATERIAL	QUANTITY	COST (INR)
1	Pixhawk kit	1	₹ 14,231.00
2	Raspberry Pi	1	₹ 7,917.00
3	GPS Module Ublox NEO	1	₹ 1,302.00
4	Pixhawk Power Module	1	₹ 486.00
5	Camera H-264 (1080p)	1	₹ 4,400.00
6	Raspberry Pi 4 model B - 8 GB RAM	1	₹ 7,200.00
7	Raspberry Pi 4 model B - Heat Sink	1	₹ 150.00
8	NEMA17 4.4Kgcm Stepper Motor	1	₹ 439.00
9	Battery 11.1 v 10000mAH	1	₹ 9,000.00
10	water proofing sheet	1	₹ 1,679.00
11	Acrylic Round Tube	1	₹ 1,249.00
12	22AWG Extension Copper Cable Wire	1 roll	₹ 660.00
13	power switch	1	₹ 210.00
14	GLASS FUSE	10	₹ 110.00
15	PPM Encoder	1	₹ 1,900.00
16	Radio Transmitter	1	₹ 6,399.00
17	Ultra Sonic sensor	1	₹ 499.00
18	EPDM Rubber Sheet	1 roll	₹ 1,500.00
19	Poly Carbonate sheets (8*4) feet	2	₹ 20,000.00
20	laser cutting material (ss) 5mm thickness	-	₹ 10,876.00
21	(ss) 304 sq pipe 18*18*1.5	1	₹ 6,200.00
22	MISCELLANEOUS COST	-	₹ 30,000.00
TOTAL			₹ 1,26,407.00

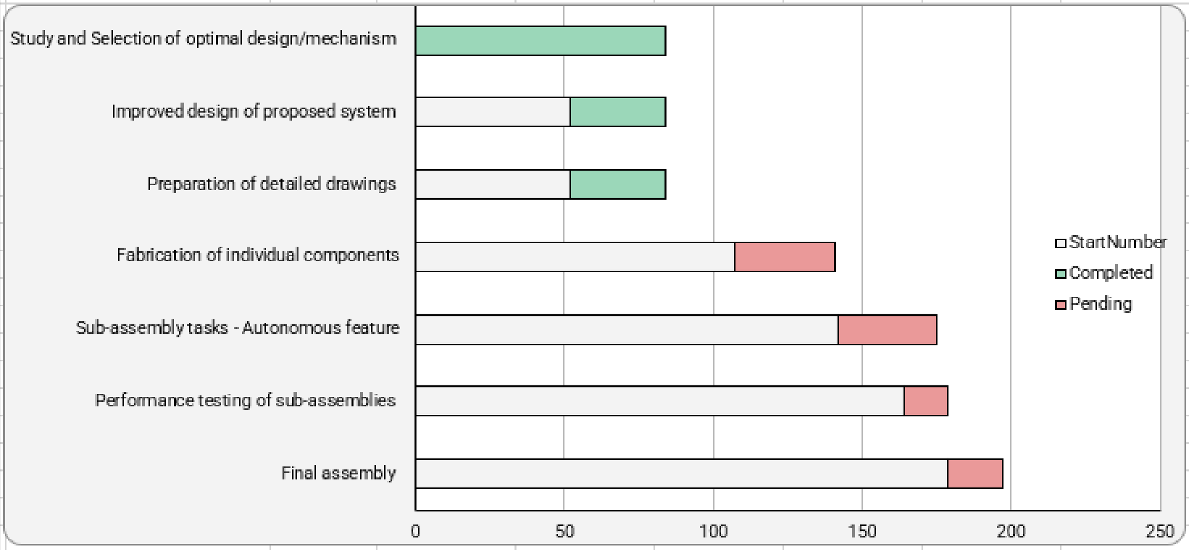
- **Production Cost**: ₹1,26,407 per unit.
- **Operational Expenses**: ₹85,000 - ₹100,000/month.
- **Revenue**: Sales, subscriptions, data analytics, recycling partnerships.
- **Expansion**: Pilot phase, regional expansion, nationwide growth.
- **Funding**: ₹50-70 lakh.

SOURCE: Business Model Canvas

Project Timeline:

Task	Start Date	End Date	Progress	StartNumber	Total Days	Completed	Pending
Study and Selection of optimal design/mechanism	16-08-2024	07-11-2024	100%	0	84	84	0
Improved design of proposed system	07-10-2024	07-11-2024	100%	52	32	32	0
Preparation of detailed drawings	07-10-2024	07-11-2024	100%	52	32	32	0
Fabrication of individual components	01-12-2024	03-01-2025	0%	107	34	0	34
Sub-assembly tasks - Autonomous feature	05-01-2025	06-02-2025	0%	142	33	0	33
Performance testing of sub-assemblies	27-01-2025	10-02-2025	0%	164	15	0	15
Final assembly	11-02-2025	28-02-2025	0%	179	18	0	18
Overall Status	**8-16-2024**	**2-28-2025**	**37.50%**	**Completed**		**Pending**	

Gnatt Chart



Team Expertise:

Technical Skill Matrix							
Team member Names	List of skills Sets						
	3D Modeling	Mechancial Fabrication	Embedded System	Programming	Electrical / Circuit Design	ROS2	ML/AI
HARISHINI J	Rookie	Not Applicable	Master	Master	Pro	Rookie	Rookie
ABINESH T	Pro	Pro	Rookie	Master	Not Applicable	Novice	Not Applicable
SUMEETH KUMAR	Not Applicable	Not Applicable	Pro	Pro	Pro	Pro	Master
AROCKIA SUBHIKSHA C	Not Applicable	Not Applicable	Master	Master	Pro	Rookie	Not Applicable
HARIHARAN K	Pro	Pro	Rookie	Novice	Rookie	Not Applicable	Not Applicable
GOWTHAM C	Rookie	Rookie	Novice	Novice	Pro	Rookie	Not Applicable
SRIDHARSHAN P	Pro	Novice	Not Applicable	Novice	Rookie	Not Applicable	Not Applicable
RAHUL SRINIVAS P	Master	Novice	Not Applicable	Novice	Rookie	Not Applicable	Not Applicable
SRIDHARAN I	Not Applicable	Rookie	Not Applicable	Pro	Rookie	Not Applicable	Novice
SACHINDEEPAK C	Not Applicable	Rookie	Not Applicable	Pro	Rookie	Not Applicable	Master