Hydrodynamic Drag of *O. niloticus* and *C. batrachus*

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Abstract

The effect of fish physiology on hydrodynamics is investigated by comparing the drag coefficients of *Oreochromis niloticus*, which is characterized by a flat body with scales, and *Clarias batrachus*, which is characterized by a long, rounded body with smooth skin. The fish were towed horizontally through water using a pulley system, and their velocity was tracked. Reynolds numbers were calculated to identify the flow regime. Drag coefficients of *O. niloticus* and *C. batrachus* were measured as 0.060 ± 0.007 and 0.042 ± 0.006, respectively, with Reynolds numbers of 1.79×10^5 and 2.23×10^5. The results indicate that the round, scaleless body of the catfish generates less drag compared to the flat, scaled body of the tilapia.

Keywords: *Clarias batrachus, Oreochromis niloticus,* Drag Coefficient, Reynolds Number, Turbulent Flow

I. INTRODUCTION

Hydrodynamic forces, such as drag, play a central role in determining the motion of fish. Drag arises from the interaction between the fish's body and the surrounding fluid and is influenced by both flow conditions and morphological characteristics, such as body shape, surface texture, and cross-sectional area. Understanding how physiological differences among fish species affect hydrodynamic drag is therefore important not only for biological and ecological studies but also for applications in bio-inspired engineering and fluid dynamics.

Previous studies have examined drag in aquatic animals and bio-inspired systems using towing tests, coasting experiments, and CFD simulations. Tandler et al utilized coasting experiments on bluegill sunfish (*Lepomis macrochirus*) to estimate drag by measuring the deceleration of live fish after active swimming.[1] They found that live fish produced less drag than passively towed dead fish, suggesting that body posture and muscle activity can influence drag measurements. Their research also provides additional information, comparing dead sunfish with high and low rigidity, suggesting that stiffness increases the coefficient. On average, the drag coefficient is approximated to be 0.0154 ± 0.0070 (mean ± SD) at a Reynolds number of 41,000 ± 14,000.

Alexander investigated how different reference areas, such as total surface area or maximum cross-sectional area, affect the calculated drag coefficient of swimming animals.[2] The study showed that the choice of reference area can significantly change the resulting drag coefficient, emphasizing the need for consistent reporting when comparing drag measurements across different studies.

In addition to biological experiments, computational methods have also been used to study hydrodynamic drag in aquatic bodies. A CFD study by Muratoğlu modeled a shark-body hydrofoil using ANSYS, an engineering simulation software with a multiple turbulence model, to analyze lift, drag, and pressure distribution under steady flow conditions.[3] The simulations showed that the shark-like streamlined flow (small attack angle) reduced drag by limiting flow separation along the body surface and can be useful for biomimetic underwater vehicle design. This further confirms that body morphology, surface properties, measurement methods, and reference area play a role.

Current research in this field largely focuses on high-performance swimmers, numerical models, or engineered systems, while direct experimental comparisons between fish species with contrasting morphologies under identical towing conditions

Figure 1: Nile tilapia (*Oreochromis niloticus*) and catfish (*Clarias batrachus)* were used in the experiment.

remain limited. This study investigates how differences in fish physiology affect hydrodynamics by comparing the drag coefficients of Nile tilapia (*Oreochromis niloticus*), which have a flat body and scales, and catfish (*Clarias batrachus)*, which have a long, round body with smooth skin covered with mucus (Figure 1).

II. METHODS

Apparatus and Procedure

The testing was conducted in a 1.5 m long water tank, allowing horizontal towing of the fish at a constant depth, as shown in Figure 2. A pulley-based towing system was mounted at one end of the tank. A fishing line was routed through three low-friction pulleys, with one end attached to a hanging mass and the other hooked to a fish. A

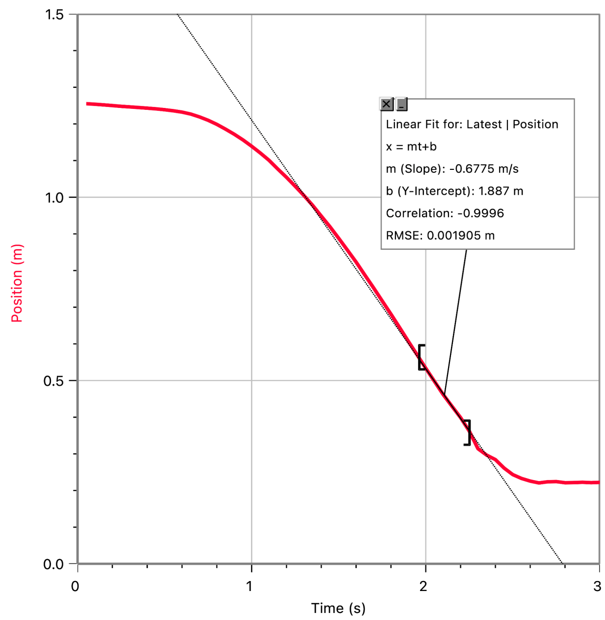

Figure 3: Displacement-Time Graph Showing Determination of Terminal Velocity

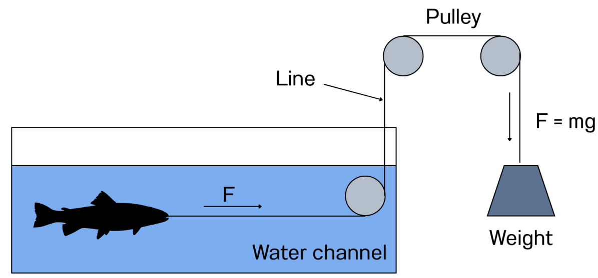

Figure 2: Diagram of Apparatus

motion detection sensor was placed beneath the hanging mass.

Five different towing forces were applied by using masses ranging from 25 g to 110 g. Three initial tilapia specimens were tested using masses ranging from 30g to 110g, while subsequent tilapia and the catfish were tested using masses ranging from 25g to 45g. For each mass, five trials were conducted for three individual catfish and five individual tilapias. In each trial, the hanging mass was released from rest, pulling the fish horizontally through the water until a steady velocity was reached.

Velocity Measurement and Data Analysis

Displacement–time data were recorded for all trials. A region of the displacement–time graph corresponding to constant velocity was selected to determine the terminal velocity for each trial, as shown in Figure 3. The total wetted surface area of the two fish species was estimated using ImageJ. Photos of the fish were taken from the top and sides, with a ruler scale for calibration. For *Oreochromis niloticus* since the body is relatively flat, the side view area obtained from ImageJ (Figure 4) was multiplied by two to approximate the total surface area. Due to the rounded body of *Clarias batrachus*, both the top and side view areas were measured and combined, then multiplied by 2 to estimate its total wetted surface area.

Drag force was then plotted against the square of terminal velocity. The drag coefficient (C_D) was calculated from the drag force (D) acting on the masses, the fluid density (p), the estimated surface

Figure 4: Projected area measurement of Nile tilapia using ImageJ.

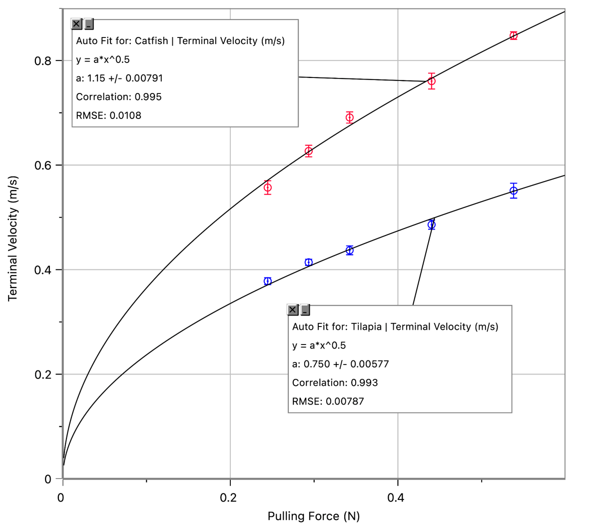

Figure 5: Terminal Velocity vs Pulling Force with Square-Root Fit from an example tilapia and catfish

area (S) of the fish, and their terminal velocity (v), according to the equation:[4]

$$C_D = \frac{2D}{\rho v^2 S} \quad (1)$$

Reynolds numbers were also determined by inputting measured terminal velocities and characteristic fish dimensions into an online Reynolds number calculator.[5]

III. RESULTS AND DISCUSSION

The results showed that terminal velocity increased as the applied pulling force increased for both *O. niloticus* and *C. batrachus*. In both species, the increase in terminal velocity followed a square-root relationship with pulling force, as shown in Figure 5. At comparable pulling forces, *C. batrachus* generally reached higher terminal velocities than *O. niloticus*, suggesting that the catfish experienced lower hydrodynamic resistance during towing. Tilapia specimens were tested over a wider range of pulling forces (30–110 g) than the catfish (25–45 g). The lower-force tilapia measurements followed the same linear drag force–velocity^2 relationship as the higher-force measurements, with no noticeable change in slope. This indicates that the calculated drag coefficient was independent of the applied pulling force within the range tested, supporting the use of data from the full force range in the final analysis.

The calculated Reynolds number for the Nile tilapia ranged from 1.1×10^5 to 2.6×10^5, while those for the catfish ranged from 1.5×10^5 to 3.2×10^5, both well above the turbulent transition

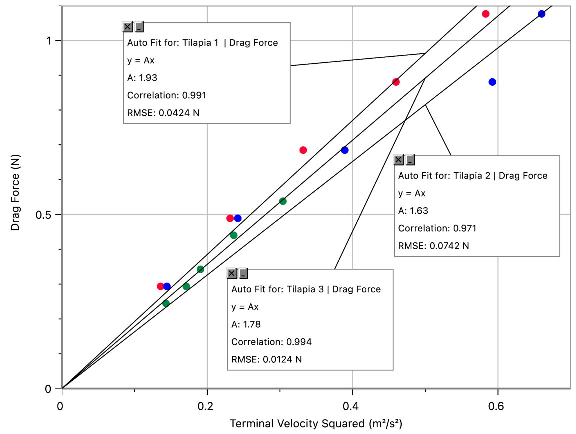

Figure 6: Drag Force vs Terminal Velocity Squared for tilapia.

threshold of approximately 4×10^3, confirming turbulent flow across all trials. As turbulent flow produces drag forces proportional to the square of the velocity, this supports the relationship observed in Figure 5.

Figure 6 shows an approximately linear relationship between drag force and terminal velocity squared for the tilapia specimens shown, consistent with the expected quadratic drag model under turbulent flow conditions. The three specimens presented here (Tilapia 1, 2, and 3) were selected from the five tested to display the full range of results obtained. These results support the suitability of the use of equation 1 in the analysis. The fitted slopes for the specimen shown were relatively similar, ranging from 1.63 to 1.93, suggesting generally consistent hydrodynamic behavior across the specimens tested, though the scatter about each fit varied.

Figure 7 demonstrates that the relationship between drag force and terminal velocity squared

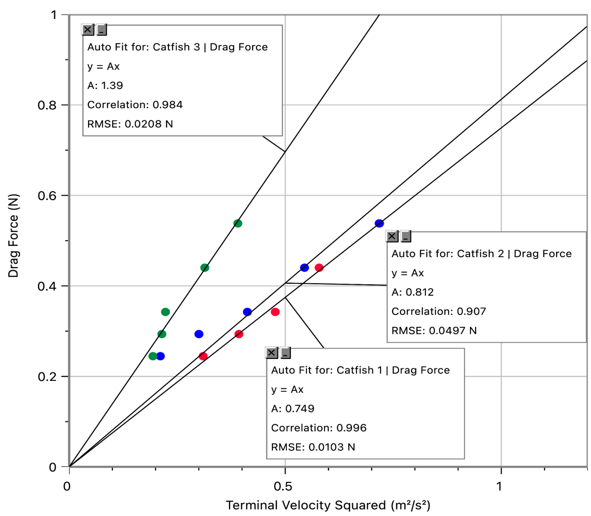

Figure 7: Drag Force vs Terminal Velocity Squared for catfish

O. niloticus (tilapia)				
Specimen	Length ±0.002 (m)	Height ±0.002 (m)	Surface Area ±0.006 (m^2)	Drag Coefficient ±0.007 (Cd)
Tilapia 1	0.306	0.130	0.025	0.066
Tilapia 2	0.322	0.132	0.029	0.063
Tilapia 3	0.339	0.137	0.032	0.055
Tilapia 4	0.353	0.146	0.035	0.058
Tilapia 5*	0.333	0.129	0.031	0.120

Table 1: Measured drag coefficients and morphological dimensions of *O. niloticus* specimens. *Tilapia 5 was noticeably stiff when tested.

C. batrachus (catfish)				
Specimen	Length ±0.002 (m)	Height ±0.002 (m)	Surface Area ±0.006 (m^2)	Drag Coefficient ±0.006 (C_d)
Catfish 1	0.334	0.058	0.047	0.039
Catfish 2	0.375	0.058	0.048	0.032
Catfish 3	0.381	0.059	0.051	0.054

Table 2: Measured drag coefficients and morphological dimensions of *C. batrachus* specimens.

remained approximately linear for all three catfish specimens, as it did for the tilapia. This supports the validity of the quadratic drag model within the tested velocity range. The quadratic drag relationship remained consistent despite some variation in the slope which indicates small variability in the hydrodynamic behavior among the catfish tested.

Table 1 shows the physical dimensions, surface area and calculated drag coefficient of the tilapia. No clear relationship was observed between drag coefficient and any single morphological parameter. For example, Tilapia 1 possessed the smallest measured surface area but exhibited a higher drag coefficient than Tilapia 3 and Tilapia 4, both of which had larger surface areas. Similarly, differences in width and length alone did not consistently correlate with drag coefficient values. These observations suggest that factors beyond overall body dimensions influenced the results. However, this conclusion should be interpreted with caution, as only four representative tilapia were included in the final analysis and these covered a relatively narrow range of body sizes. This limited sample size and size range limit the ability to identify a relationship between morphology and drag coefficient. Further research using a larger number of specimens spanning a wider range of body sizes would provide greater confidence in determining a relationship.

It should be noted that Tilapia 5 displayed a substantially higher drag coefficient (0.120) than the other specimens, whose values ranged only from 0.055 to 0.066. Due to time constraints, tilapia 5 had a longer interval between death and testing, and appeared significantly stiffer than the other fish during testing. The body also appeared less flexible during towing. Since the experiment aimed to represent the fish's natural passive swimming form, unusually stiff specimens would be considered less representative. Therefore, Tilapia 5 was treated as an anomalous result and excluded from the calculation of the average drag coefficient. Excluding this specimen, the remaining tilapia exhibited drag coefficients between 0.0551 and 0.0658, with an average value of approximately 0.060 ± 0.007.

Table 2 shows that the drag coefficients of the three catfish specimens ranged from 0.0317 to 0.0542, with an average value of approximately 0.042 ±0.006. The relatively low average drag coefficient suggests that the catfish experiences lower resistance during passive motion through water, compared to the tilapia. The surface area, width, and length values indicate that all the specimens vary in size and dimensions, yet, like the tilapia, there is no clear correlation between morphology and drag. Interestingly, catfish 1 and 2 had very similar surface areas but still showed a significant difference in drag coefficient, indicating that, like the tilapia, factors beyond overall body dimensions also influenced the results. However, no clear reason for this difference could be identified from the measurements collected in this investigation.

The results indicate that the catfish exhibited a substantially lower drag coefficient than the Nile tilapia under passive towing conditions, despite the common assumption that Tilapia possess a more streamlined body form. One possible explanation for this difference is the difference in skin texture and mucus coverage observed on the skin surfaces of the two species. The catfish appeared to have a thicker mucus layer compared to the Tilapia. Mucus reduces drag by decreasing the velocity gradient near the skin surface, thereby lowering shear stress at the fluid–body interface.[6] Moreover, epidermal mucus is also shown to reduce frictional drag compared to smooth or scaled surfaces without mucus, with reductions generally approaching 50%.[7] Therefore, the greater mucus coverage observed on the catfish likely reduced the velocity gradient along the body surface more effectively than in the Tilapia, resulting in a lower overall drag coefficient for the catfish.

Because both species were tested after death, the measured drag coefficients reflect passive hydrodynamic behavior rather than the conditions experienced during active swimming. Previous coasting experiments on bluegill sunfish showed that live fish generate less drag than dead, passively towed fish, demonstrating that muscle tone and fin control can significantly influence drag.[1] In this study, those active mechanisms were absent in both the catfish and tilapia, so the comparison depends primarily on passive characteristics such as body shape and surface properties.

Because both fish were tested in a passive state after death, their drag coefficients can be directly compared to studies of rigid solid bodies. Li and Zhou found that elongated ellipsoids delayed flow separation but exhibited higher drag coefficients than flattened ellipsoids under the same flow conditions.[8] Furthermore, Zhan et al. compared the gliding performance of a flattened manta ray, a fusiform killer whale, and a highly streamlined swordfish using rigid, smooth-surfaced three-dimensional models rather than live animals.[9] They found that form drag was highest in the flattened manta ray, intermediate in the killer whale, and lowest in the swordfish. Based on body shape alone, the catfish, with its more rounded, elongated form, would therefore be expected to produce greater drag than the tilapia. However, the present experiment found the opposite trend: the catfish had a lower drag coefficient. This suggests that the mucus layer and skin characteristics of the catfish played a significant role in reducing its drag coefficient.

Despite the clear trends observed in this study, several methodological limitations may affect the reliability of the measured drag coefficients. Variations in specimen size, orientation, and mucus coverage between individual fish may also have contributed to inconsistencies in the measured drag coefficients. Future research could test this hypothesis by removing the mucus layer from catfish and comparing the resulting drag coefficient with that of untreated specimens. Additional studies could also compare scaled and scaleless fish species with similar body shapes to isolate the effect of skin texture and mucus coverage on drag.

IV. CONCLUSION

It was shown that drag force is proportional to the square of velocity for both Nile tilapia (*O. niloticus*) and catfish (*C. batrachus)* when towed passively through water. It was further shown that the catfish, which have a long rounded body with smooth skin, exhibited a lower average drag coefficient (0.042 ± 0.006) than the Nile tilapia, which have a flat body and scales (0.060 ± 0.007). These findings suggest that differences in body shape and surface characteristics, particularly the catfish's round body, scale-less skin, and mucus contribute to reduced hydrodynamic drag.

V. REFERENCES

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