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DEVELOPMENT OF AN AUTONOMOUS ROBOT FISH TO STUDY SWIM PATTERN HYDRODYNAMICS

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Abstract. *The Ambiental impact of fishes on the presence of hydrokinetic turbines in rivers is an actual concern where there is a lack of collision risk descriptions in the literature. In this way, this works proposed a methodology to study the fish swimming on the boundaries of axial hydrokinetics turbines based on an experimental approach. An autonomous robot fish was developed to replicate the Astyanax fish, also known as Lambari, a usual species found in Brazil. The fish concept was manufactured employing 3D printing. The oscillating movement was made by one servomotor, placed inside the model, where it was controlled by a sinusoidal wave get from a mathematical model established on real swimming experiments. The main objective was to validate the hydrodynamics parameters, drag and pressure coefficient, of swimming inside the water tunnel and compare them with numerical data. We present results for the fish swimming with and without the one hydrokinetic turbine. The discussion about the proper parameters to precise the collision risk on axial hydrokinetics turbines.*

Keywords: *autonomous, robot, fish swimming, hydrokinetic turbine.*

1. INTRODUCTION

Hydrokinetic turbines are still a theme of theoretical and experimental research (the vast majority of turbines are in the pre-commercial stage), studies on related environmental impacts are in the same situation. As few installations are operating in the world, there are few environmental impact studies of hydrokinetic turbines (Laws and Epps, 2016). Hydrokinetic turbines have lower environmental impacts than conventional hydroelectric turbines. Even so, it is considered that this technology can generate negative environmental effects such as changes in current and waves, changes in the habitats of organisms, sediment suspension, noise, generation of electromagnetic fields, toxicity (paints, lubricants, etc.), interference with animal movements, and finally collision of aquatic organisms with the turbine rotor blades (U.S. Department of Energy, 2009). Many species of fish move or migrate over long distances across rivers and oceans and can cross with hydrokinetic turbines. Studies on the collision and striking of fish with the moving parts of the turbine show that the severity of such a collision depends on the swimming ability of the fish, the speed of the current, and the characteristics of the blade (number, profile, length, thickness, spacing, and rotation) (Wilson *et al.*, 2007; U.S. Department of Energy, 2009). It should be noted that most studies on fish interaction and hydrokinetic turbines originate from the study of conventional hydroelectric turbines. There are few specific environmental impact studies focused on fish and hydrokinetic turbines. It is also noted that many works on fish collisions with hydrokinetic turbines have been carried out in the field (Nederland Maritiem Land, 2016; Fraser *et al.*, 2018; Williamson *et al.*, 2019). Studying fish swims in disturbed flows is an emerging topic. Thus, the proposed work investigates the fish swimming flow under disturbed and undisturbed flow conditions inside the tunnel water using autonomous robot fish. The species considered was the lambari (*Astyanax bimaculatus*) for his carangiform kinematics, the geometrical model was already constructed in previous work (Macias *et al*., 2020) and is a native species from Brazil.

2. TUNNEL WATER

Water tank or tunnel tests offer an alternative approach to obtain data on the interactions between turbines and fish, with the advantage of allowing fundamental responses to be observed (Yoshida *et al*., 2020). Many works use water tunnels to observe possible impacts between fish and turbines, but in this work, the main objective is to study the aerodynamics of the Lambari.

The present experimental study was carried out at the Energy and Environment Laboratory of the Mechanical Engineering Department of the University of Brasília. A series of dynamic tests of the fish model used an Armfield model HAN 5 closed-circuit water tunnel, 2750 mm high, 4900 mm long, and 1100 mm wide, powered with a 5500 W motor/pump assembly (Figure 1). Table 1 introduces the part details shown in Figure 1.

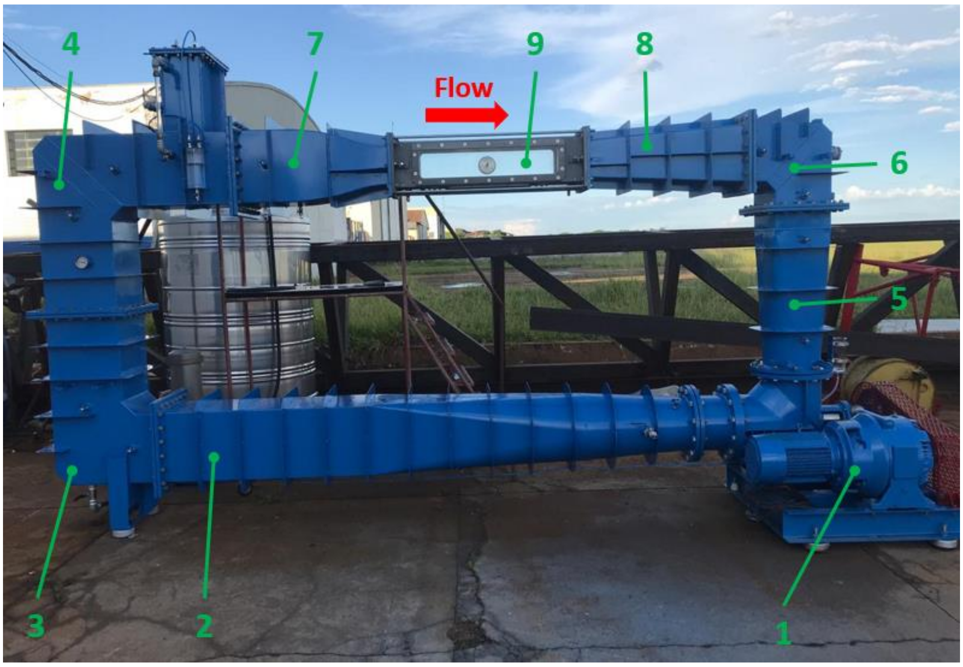

Figure 1. Water tunnel.

Table 1. Description of the main parts of the water tunnel.

Items	Description
1	Main motor-pump set with mechanical speed variator
2	Base tube
3	Lower left curved section
4	Upper right curved section
5	Left vertical section
6	Top left curved section
7	Test section inlet nozzle
8	Test section output diffuser
9	Testing section

3. DESIGN OF THE ROBOT FISH

From the 3D model of the lambari created by Macias *et al.* in 2020 (Figure 2), an adequate scale was defined for the water tunnel (Figure 3) to be used for the hydrodynamic behavior tests. It was necessary to increase the size of the fish to adapt to the tunnel section and the dimensions of the observation window (Figure 3 b and c). Fish body length measured 296 mm. The final result of this first stage is illustrated in Figure 4, where a maximum blocking factor of less than 10% was considered. Comparing the largest section of the fish with that of the tunnel, this blocking factor did not exceed 3% and the size of the fish is in accordance with the dimensions of the window.

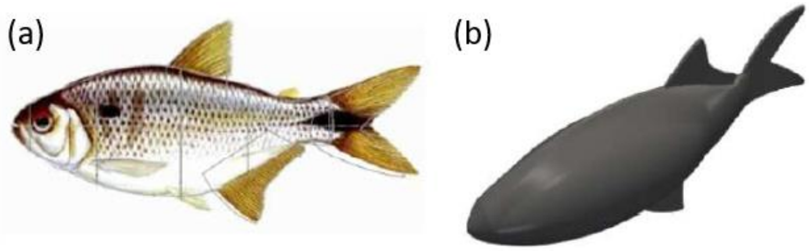

Figure 2. Lambari fish (a) and 3D reconstruction (b), (Macias *et al*., 2020).

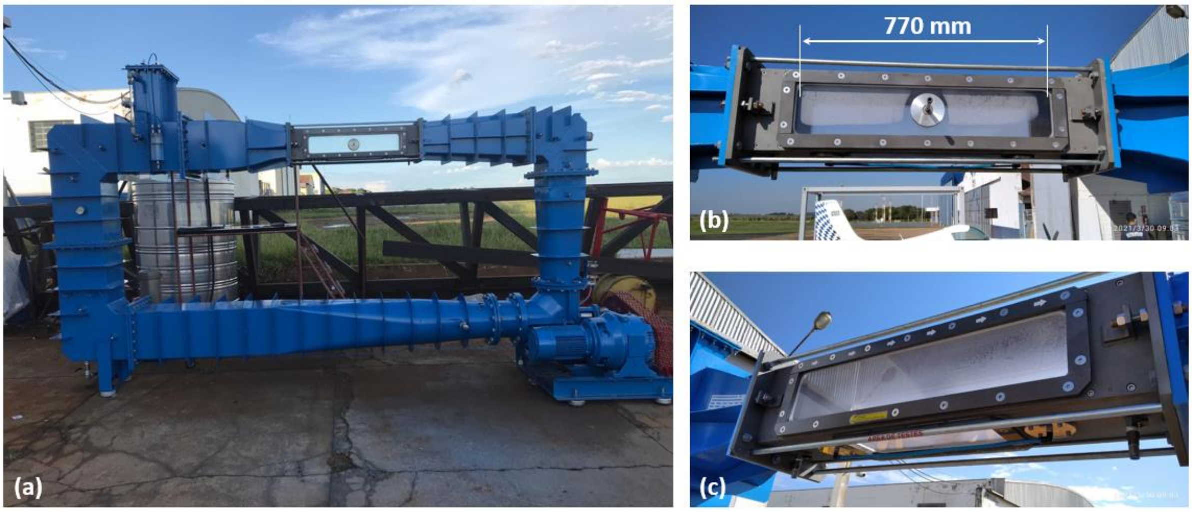

Figure 3. Water tunnel (a) and details from the test section (b) and (c).

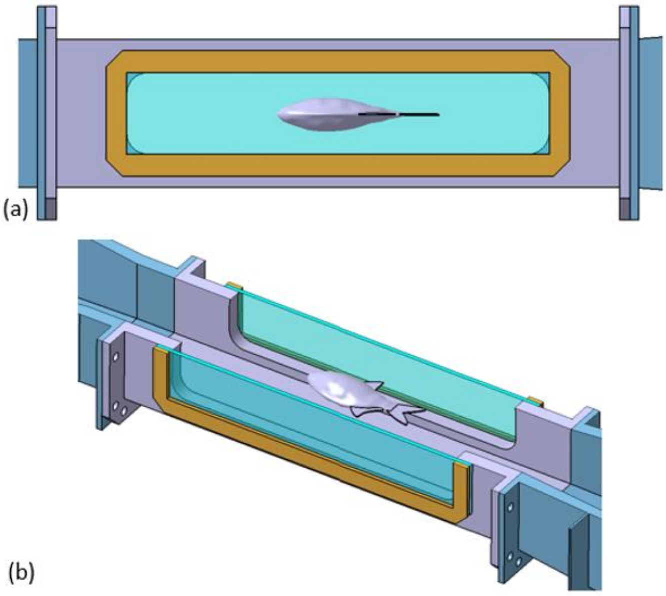

Figure 4. Front view of the water tunnel observation window (a) and isometric view with longitudinal section of the observation section (b).

A mechatronic fish was then projected from the 3D model defined in the first stage. The purpose is to reproduce Lambari's swimming profile in a simple way. It was inspired by the tuna model (Zhu *et al*., 2019). The Tunabot has a rigid part, the head, and the tail moves through a servomotor inserted in the head. The Lambari robot also consists of two parts: the head and the active body and tail as shown in Figure 5(b). The head is equipped with a servomotor (Micro SG90 Servo Motor 9G for Arduino), 1/4 "NPT hole for connection with the water tunnel and a pressure tube (Figure 6). Movement is produced by rotating the servomotor accoupled to an elbowed shaft trapped inside an oblong hole. The servomotor can reproduce the fish's swimming frequency, thus reaching the lambari's swimming speed of 2.5 m/s. The active tail is composed of five vertebras inspired by the work of Zhong and Du in 2016 as shown in Figure 5, and driven by a flexible silicone skin with dorsal and anal fins and caudal peduncle (Figure 6).

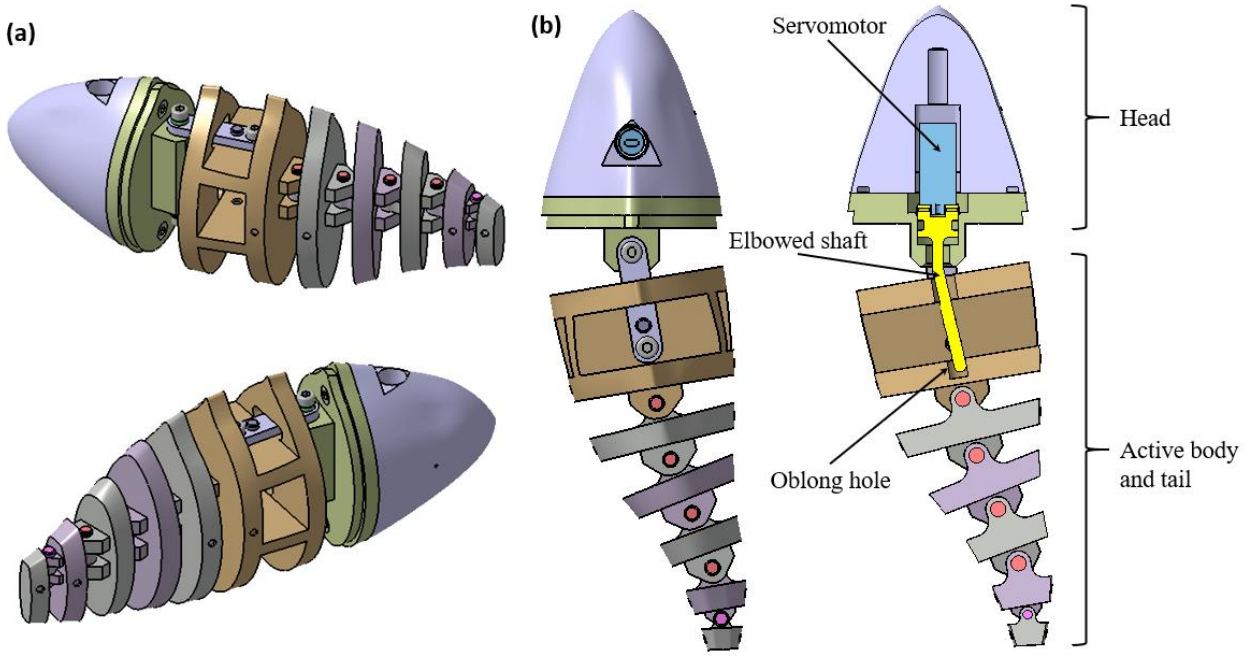

Figure 5. Isometrics views (a) and top view and longitudinal section of the lambari robot (b).

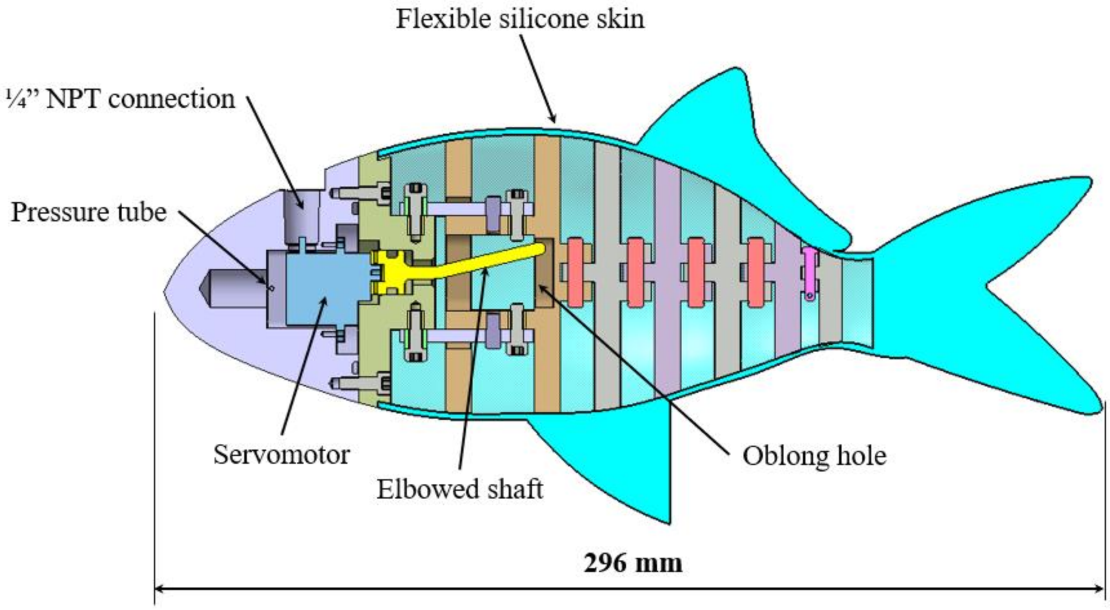

Figure 6. Longitudinal section of the lambari robot.

The head, the body, and internal support structures were 3D-printed in polylactic Acid (PLA) at the *Laboratório Aberto de Brasília* (LAB), University of Brasília. This material is one of the most environmentally-friendly 3D printing materials which is in total adequacy for this research. The parts that were being assembled by screws were be fitted with M4 brass inserts, a technology widely used in 3D printing for its low cost and ease of installation. The tightness of the servomotor was guaranteed using O-rings. Using the previously specified geometry for the flexible silicone skin, two symmetrical molds were designed and 3D-printed. Figure 7 shows both sides of the flexible skin´s 3D-printed mold. Once the mold was printed it was clamped and the liquid silicone was poured in. The result is shown in Figure 8. The thickness of the skin was 2 mm.

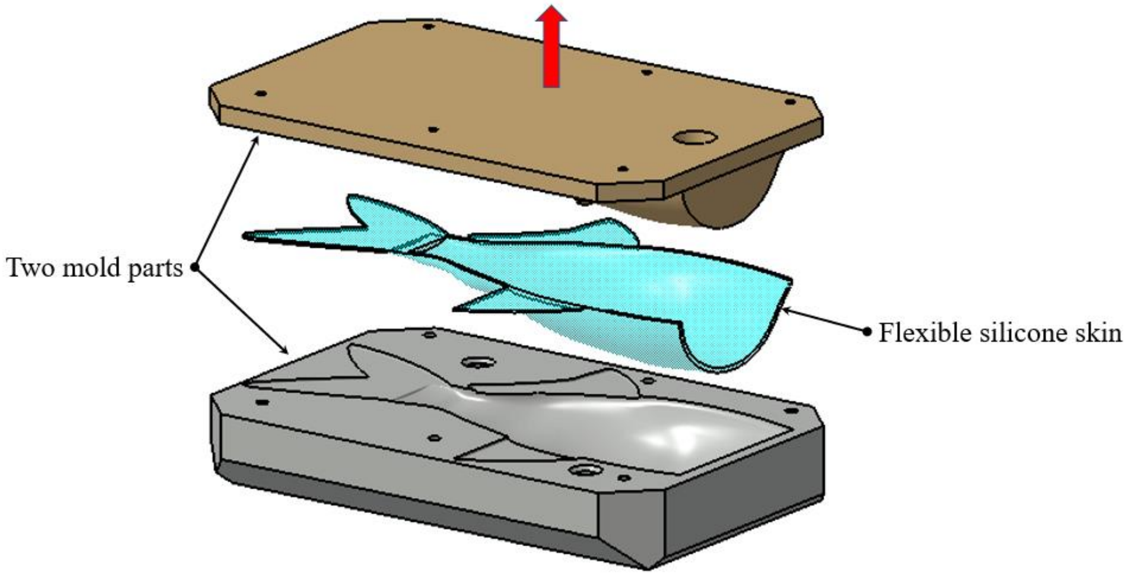

Figure 7. Mold for symmetrical flexible silicone skin.

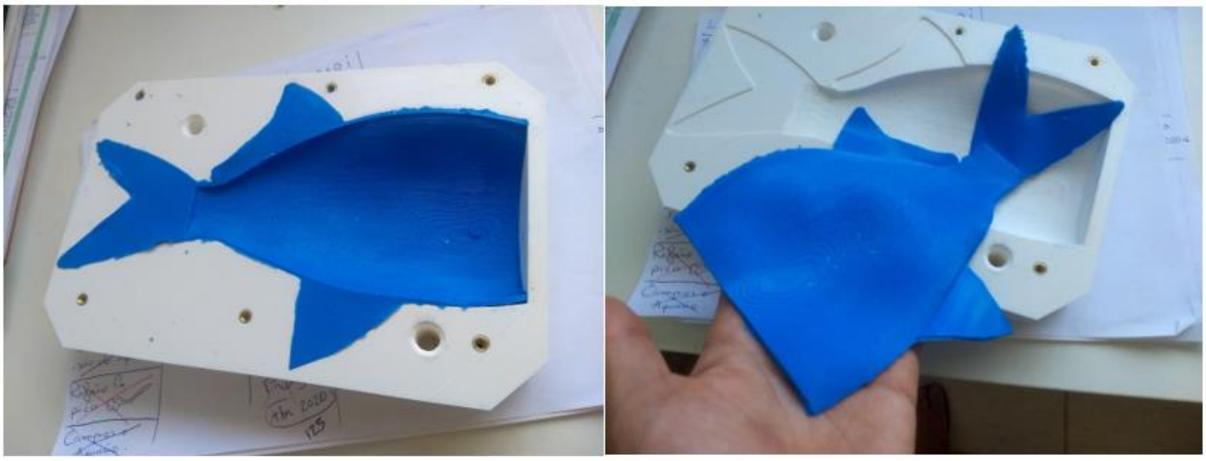

Figure 8. Flexible silicone skin after molding.

Flowing the original project, the final product after the 3d print was shown in Figure 9.

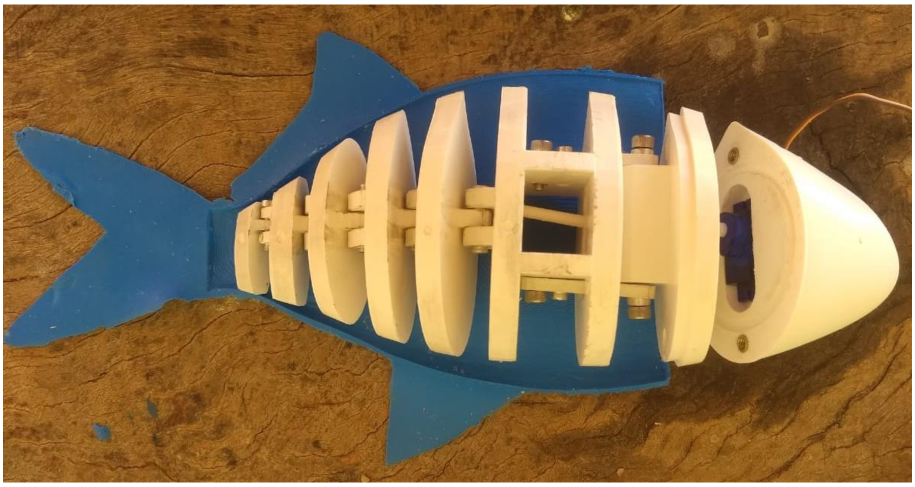

Figure 9 - Final Fish structure

A major focus of this work was the development of a Lambari robot that can simulate the swinging of the real one. The proposed device showed thar it was possible to archive this goal with the final assemble. Appling a senoidal signal on the servormotor the motion was very similar.

4. ACKNOWLEDGEMENTS

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6. RESPONSIBILITY NOTICE

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