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# HYDRODYNAMICS OF ROBOT FISH

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***Abstract:*** *For studying the motion of a robot fish we calculate the jump of pressure over a flexible hydrofoil performing oscillatory or undulatory motions. For a certain class of motions we find that if the frequency of the motion surpasses a critical value there appears the thrust.*
***Keywords.:*** *flexible hydrofoil,integral equation,numerical solution, thrust.*

## 1. INTRODUCTION

The wide interest shown to robot fishes has many reasons. The use of fish robot for ship propulsion will help prevent shoreline erosion and the undermining of submarine installations caused by ships screw. The soft drive action of the robot fish also prevents the churning of the watercourse and sea beds and its effects on marine aquatic plants and animal populations. We present below two pictures taken from the internet. The first picture is the picture of the robot fish created at the University of Essex, in order to detect the pollution in water.

**Figure 1:** Robot fish created at the Essex University**.**

The second picture presents the skeleton of a robot fish created at the Technical University of Darmstadt.

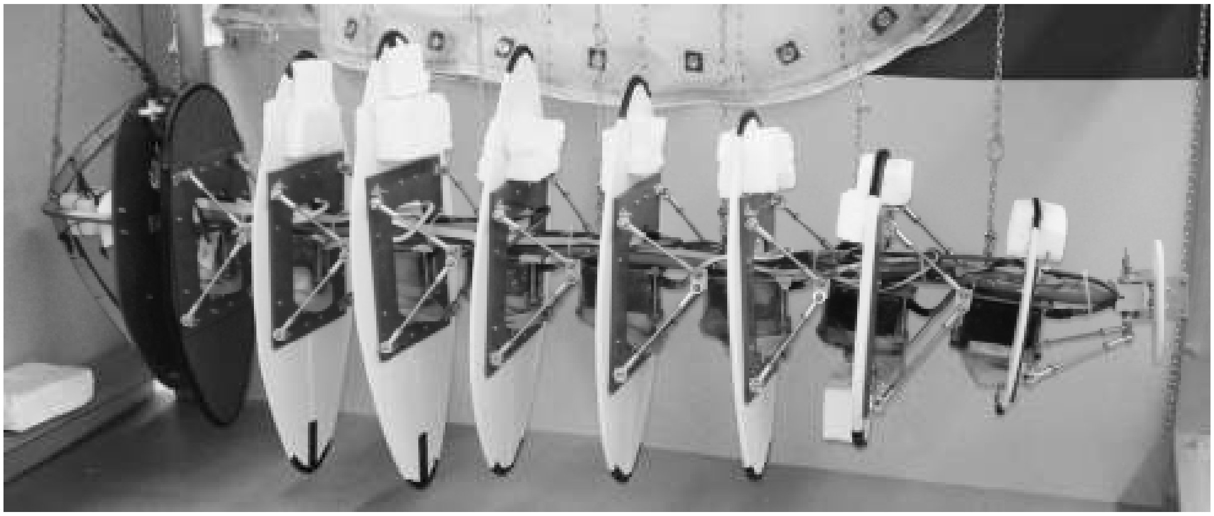

**Figure 2:** Skeleton of a robot fish constructed at TU Darmstadt**.**

The kinematics and hydrodynamics of the robotic fish is investigated in many papers. For example in [4] one presents theoretical and experimental results concerning the kinematics and hydrodynamics of the robot fish in a simulator. In the present paper we calculate the hydrodynamic coefficients for a robot fish which is considered a flexible hydrofoil subjected to oscillatory or undulatory motions. For certain motions we put into evidence the average thrust which causes the translation motion of the hydrofoil.

## 2. THE INTEGRAL EQUATION FOR THE JUMP OF THE PRESSURE

Let us consider a flexible hydrofoil whose equation (in dimensionless coordinates) is

$$z = h(x, y)\exp(i\omega t) \tag{1}$$

As it is shown in [1], [2], [3] the equation for the jump of the pressure over the hydrofoil is in dimensionless variables

$$\frac{-\varpi}{4\pi}\iint_D^* f(\xi,\eta)\exp(-i\omega x_0)\left(\int_{-\infty}^{x_0}\frac{\exp(i\omega s)}{\left(s^2+\varpi^2 y_0^2\right)}ds\right)d\xi d\eta = \frac{\partial h(x,y)}{\partial x} + i\omega h(x,y) \tag{2}$$

where *D* is the projection of the hydrofoil onto the *Oxy* – plane, *f* is the jump of the pressure, $\varpi$ is the aspect ratio and $x_0 = x - \xi, y_0 = y - \eta.$ The asterisk indicates the finite part in the Hadamard sense of the integral.

The *2D* integral equation is singular. In order to put into evidence the kind of the singularity of the kernel we shall split it into several kernels

$$K(x, y;\xi,\eta) = K_1(x, y;\xi,\eta) + \ldots + K_8(x, y;\xi,\eta), \tag{3}$$

where

$$K_1(x, y;\xi,\eta) = \frac{1}{\varpi^2 y_0^2}\left(\frac{x_0}{\sqrt{x_0^2+\varpi^2 y_0^2}} - \frac{x_0}{|x_0|}\right), \tag{4}$$

$$K_2(x, y;\xi,\eta) = \frac{1}{\varpi^2 y_0^2}\left(1 + \frac{x_0}{|x_0|}\right), \tag{5}$$

$$K_3(x, y;\xi,\eta) = \frac{-i\omega}{\sqrt{x_0^2+\varpi^2 y_0^2}}, \tag{6}$$

$$K_4(x, y;\xi,\eta) = -\frac{\omega^2}{2}\frac{x_0}{|x_0|}\ln\left(|x_0| + \sqrt{x_0^2+\varpi^2 y_0^2}\right), \tag{7}$$

$$K_5(x, y;\xi,\eta) = \frac{\omega^2}{2}\ln(\varpi|x_0|)\left(1 + \frac{x_0}{|x_0|}\right), \tag{8}$$

$$K_6(x,y;\xi,\eta)=\frac{\omega^2 x_0}{\sqrt{x_0^2+\varpi^2 y_0^2}}, \tag{9}$$

$$K_7(x,y;\xi,\eta)=\frac{\omega}{\varpi|y_0|}K_1(\omega\varpi|y_0|)-\frac{1}{\varpi^2 y_0^2}-\frac{\omega^2}{2}\ln\frac{\omega\varpi|y_0|}{2}$$
$$+\frac{i\pi\omega^2}{2\varpi|y_0|}\left(I_1(\omega\varpi|y_0|)-L_{-1}(\omega\varpi|y_0|)+\frac{2}{\pi}\right)+\frac{\omega^2}{2}\ln\frac{\varpi}{2}, \tag{10}$$

$$K_8(x,y;\xi,\eta)=\int_0^{x_0}\frac{\exp(i\omega s)-1-i\omega s+\omega^2 s^2/2}{\left(s^2+\varpi^2 y_0^2\right)^{3/2}}ds. \tag{11}$$

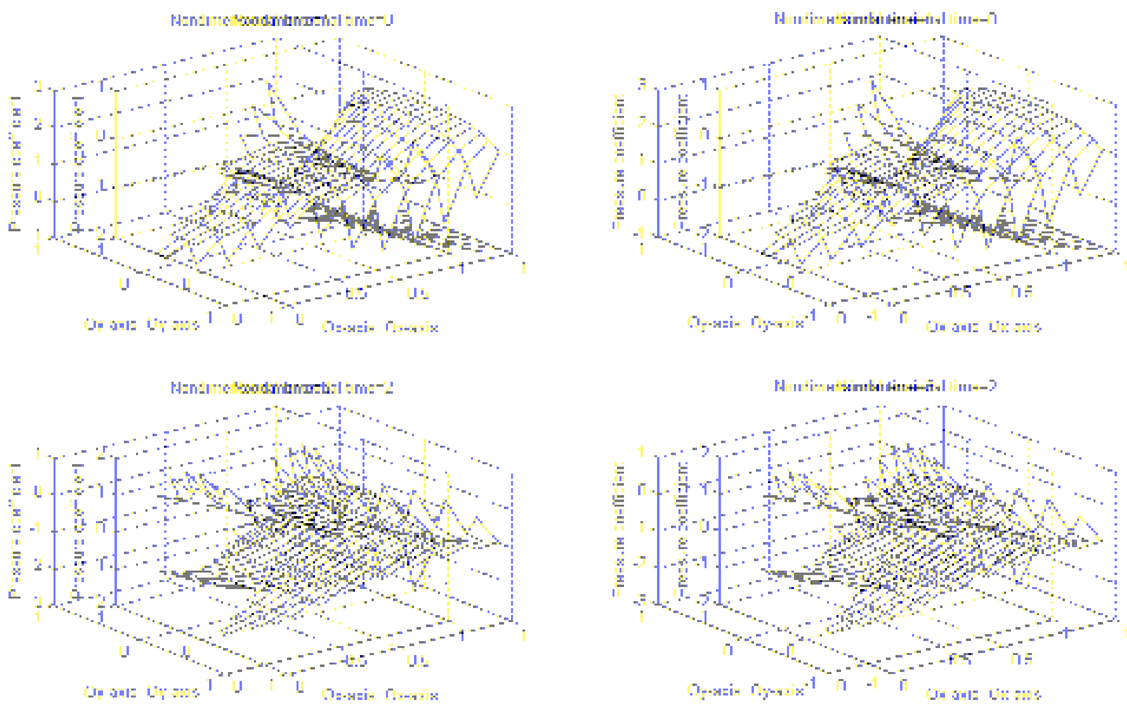

**Figure 3:** Pressure coefficient over a flexible hydrofoil**.**

For these kernels one provides in [2] adequate quadrature formulas in order to discretize and solve the integral equation. In figure 3 we present the pressure coefficient $f/\alpha$ over the undulatory delta hydrofoil having the equation $h(x,y)=\alpha\exp(i\omega_1 x)$ at various moments. We considered $\omega=\pi/4, \omega_1=-\pi$.

## 2. CALCULATION OF THE THRUST

The pressure coefficient is

$$C_p(x,y,t)=\mathrm{Re}[f(x,y)\exp(i\omega t)]/\alpha. \tag{12}$$

We calculate numerically the drag coefficient

$$C_D=-2\int\int_D n_x C_p(x,y,t)dxdy \tag{13}$$

and the average drag coefficient

$$\underline{C}_D=\frac{1}{T}\int_0^T C_D(t)dt, T=\frac{2\pi}{\omega}. \tag{14}$$

In figure 4 we present the average drag coefficient versus the reduced frequency $\omega$. We notice that starting from a certain value of the reduced frequency the average drag coefficient becomes negative i.e. it appears a propulsive force (thrust).

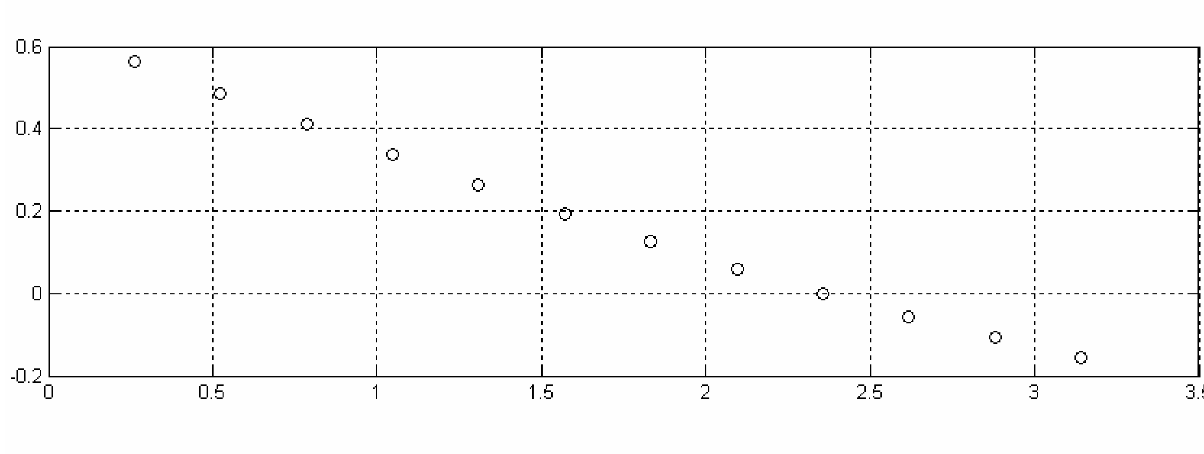


**Figure 4:** Average drag coefficient against reduced frequency**.**

## 3. CONCLUSION

The undulatory or oscillatory motion of a flexible hydrofoil in a fluid may determine a thrust force. In this paper we presented a method to calculate the thrust force by solving an integral equation which appears in the hydrodynamics of non-viscous fluids. This approach is a simplified one because one has to take also into account the viscous drag and other hydrodynamical effects. For a complete study of the motion of a robot fish one has also to take into account the motion control, the autonomous navigation and other aspects of the interaction between the robot fish and the water.

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