The Benefits of Fish Schooling In-Phase for Developing a New Bio-Inspired Propulsion System

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TECHNION AUTONOMOUS SYSTEM PROGRAM

ABSTRACT

The goal of this project is to examine the benefits of two foils in an efficient propulsion system through water that emulates the movement of fins in a fish school [1]. We used two aluminum foils that underwent horizontal and angular oscillations called heaving and pitching. We then compared the efficiency when one foil oscillated alone to when two travelled together in phase, remaining parallel at all times. Using two foils gives a more accurate representation of the movement in a fish school [2]. This is an interesting and ground-breaking project because the delineation of fin movement into its heaving and pitching components may show why fish are so efficient at propulsion [3].

'FISH'YCS©

Basic knowledge of hydrodynamics:

What are the types of motions exhibited by the foils?
Heaving: Side to side motion of the foils.
Pitching: Up and down motion of the foils (also known as θ) [Figure 1].

What does 'In Phase' and 'Out of Phase' mean?
In phase is when the foils oscillate without a phase difference. Out of phase is when the foils oscillate with a phase shift of π. This poster studies the foils in In Phase.

What is the angle of attack?
α_e :angle formed between the vector of the velocity of water and the chord of the foil.

What are Lift, Drag, Thrust, and Efficiency?
Lift (L) = force by the water on the foil that acts perpendicular to its velocity vector (hence changes direction sinusoidally).
Drag (D) = backwards force due to friction between foil and water molecules.
Thrust (T) = forwards force due to foil oscillation.
Efficiency = the relationship between the input and output power [Figure 2].

How does Bernoulli's principle act on the foil?
Bernoulli's principle is that fluid pressure is lower at high speeds.
Water flows at different velocities on the sides of the foils, which generates a difference of pressure and, therefore, a force.

EQUATIONS

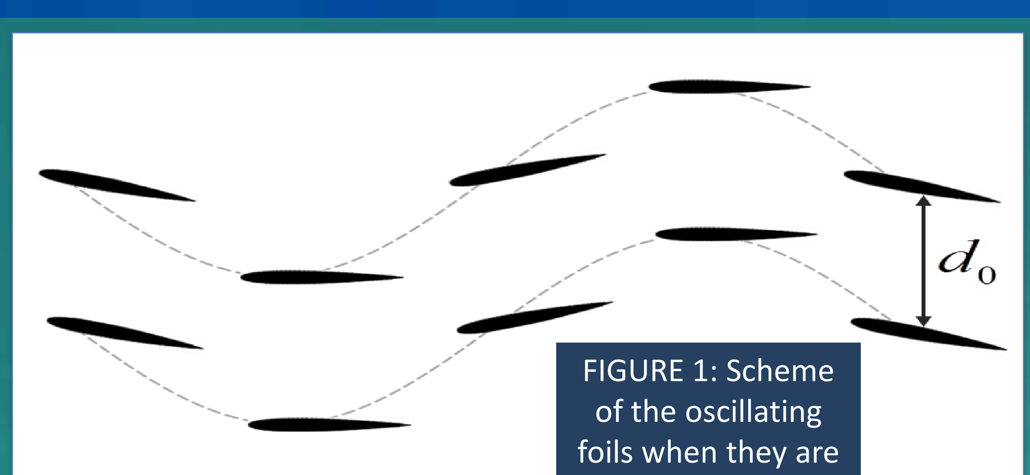

FIGURE 1: Scheme of the oscillating foils when they are 'in phase'.

$$\theta(t) = \theta_0 \cos(\omega t)$$
$$h(t) = h_0 \cos\left(\omega t + \frac{\pi}{2}\right)$$

$$St = \frac{fA}{\boldsymbol{U}_\infty}$$
$$Re = \frac{U_\infty c}{v} \text{ v is viscosity.}$$
$$k = \frac{\omega c}{2U_\infty}$$
$$L = \frac{1}{2}\rho U_\infty^2 c s C_L$$
$$D = \frac{1}{2}\rho U_\infty^2 c s C_D$$
$$T = \frac{1}{2}\rho U_\infty^2 c s C_T$$
$$P = \frac{1}{t}\int L \cos\theta \ \dot{h}\, dt$$

KEY

Units in $[mm.g.s]$
U_∞: Velocity of the horizontal uniform flow.
$h, \dot{h}$: Position and velocity of the heaving motion.
$\theta, \dot{\theta}$: Position and velocity of the pitching motion.
f: frequency, ω: angular velocity $\omega = 2\pi f$.
St: Strouhal Number, dimensionless number used to characterize the flow.
Re: Reynold's Number, dimensionless number that tells the turbulences of the flow.
k: Reduced frequency.
h_0: Amplitude of heaving.
θ_0: Amplitude of pitching.
c: chord length, s: span length .
C_T, C_D, C_L: Coefficients of Thrust, Drag and Lift.
$A = 2h_0$: Motion amplitude .
ρ : density of the fluid.

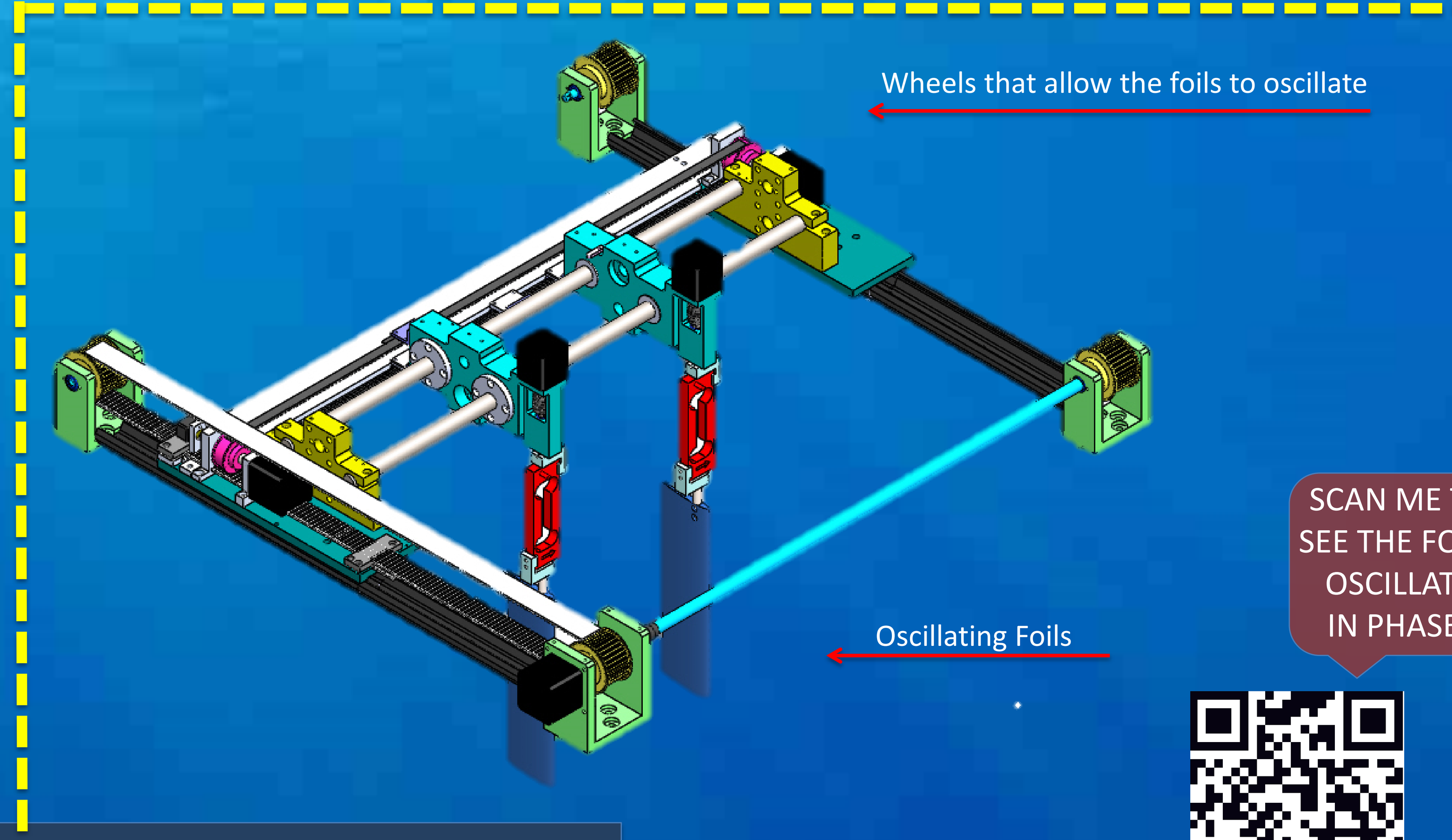

FIGURE 3: 3D diagram of the foil system.

SCAN ME TO SEE THE FOILS OSCILLATE IN PHASE!

PROCESS

1. Obtain the data from running the experiment for one foil [Figure 3].
2. Filter the data on MatLab.
3. Create the graphs for C_L, C_T, and Efficiency [Figure 4].
4. Repeat the process with two foils.
5. Compare the results of the graphs for one and two foils.
6. Discuss the results and come to a conclusion.

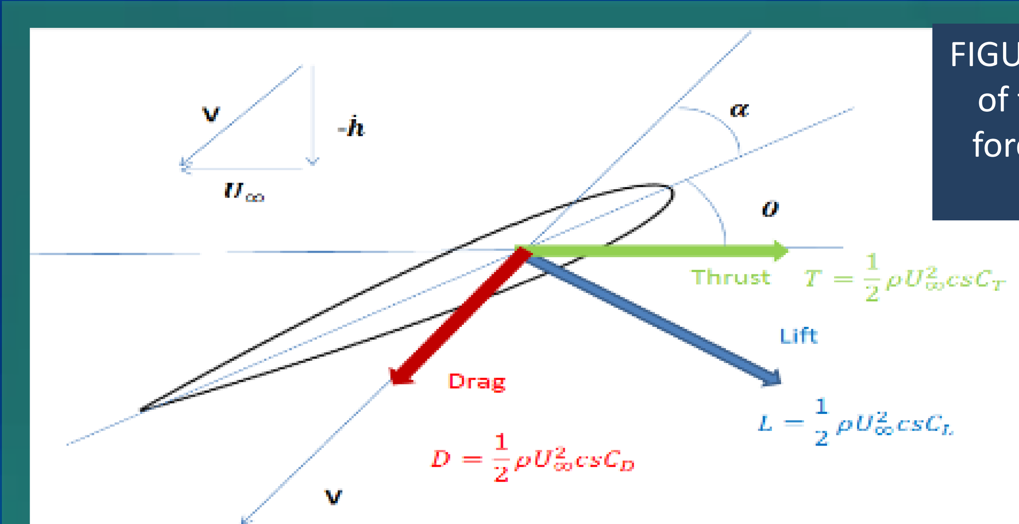

FIGURE 2: Diagram of the different forces acting on the foils.

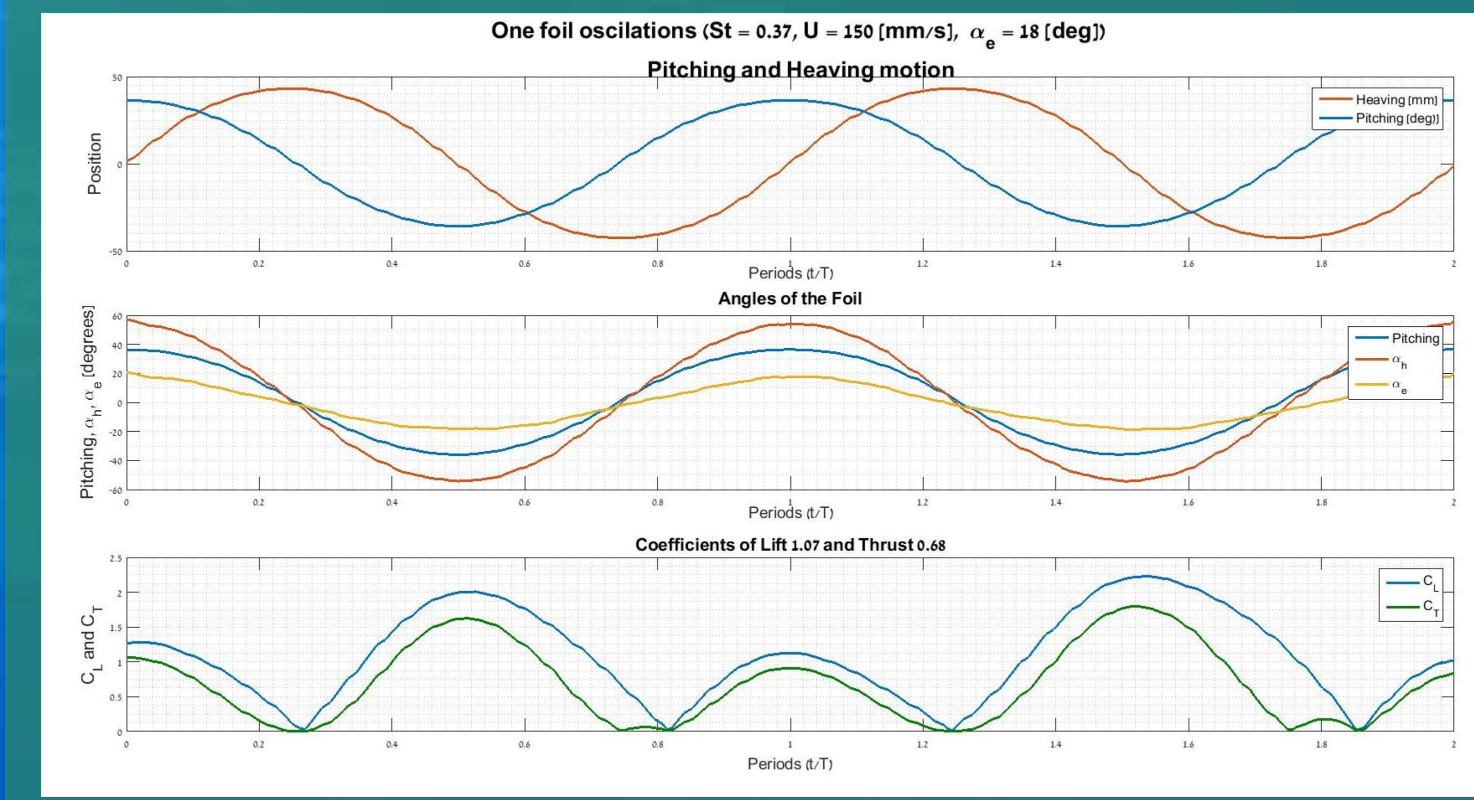

FIGURE 4: Graph showing the movements of the different functions and forces on the foils. Including Lift, Thrust, Heaving, Pitching, and the changing Angles of the foil.

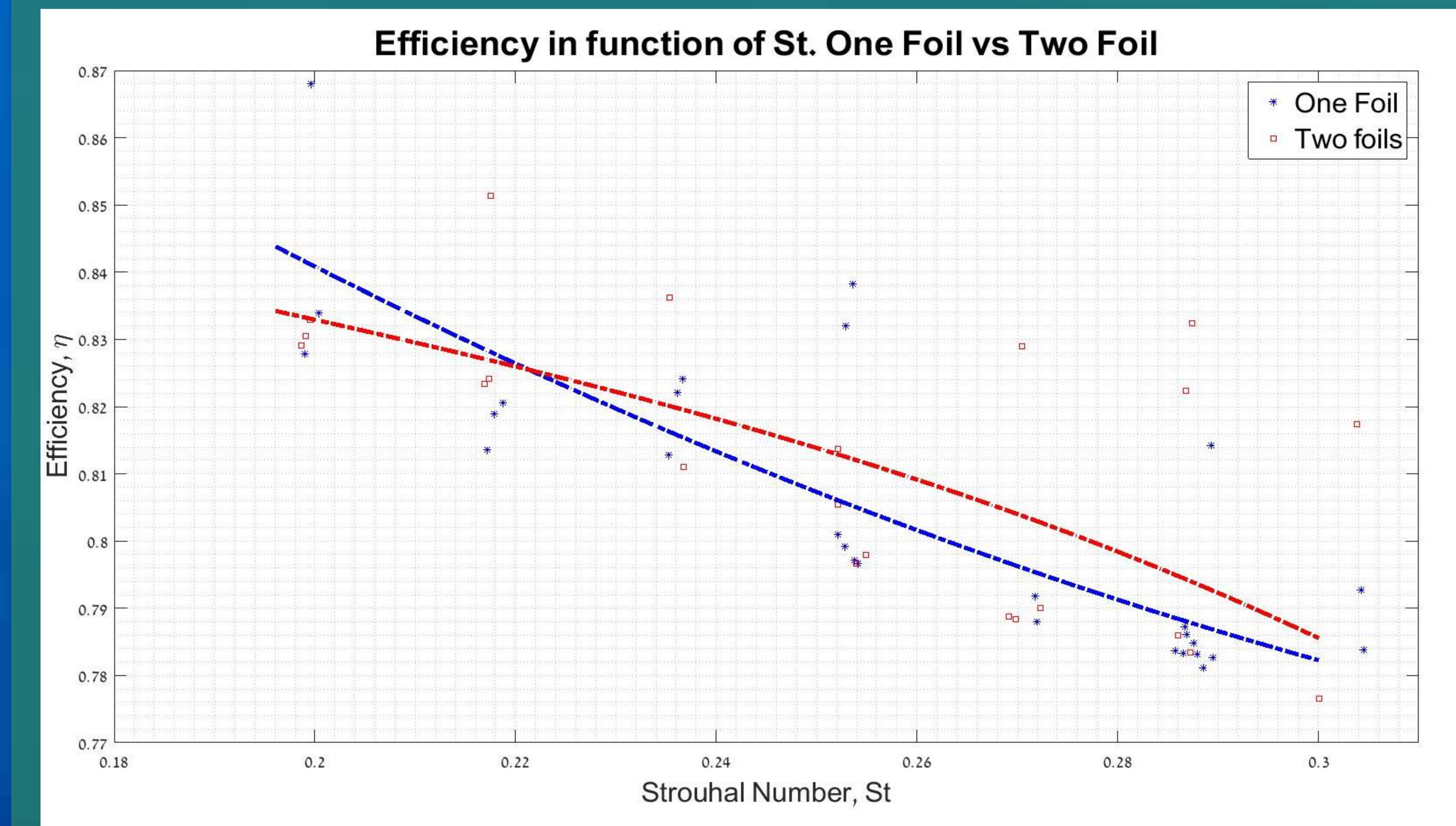

FIGURE 5: Graph of the efficiency in the function of St, showing the difference between using one foil and two foils.

CONCLUSIONS

If thrust is to be maximized, it is more efficient to have two foils oscillating in phase than it is to have one foil oscillating on its own. This is because the movement of water caused by each foil is used by the other one to generate extra thrust.
Two foils oscillating side-by-side are more efficient without losing any thrust, as shown in [Figure 5].

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