Two vs. One – The Advantage of Fish Schooling in Out-of-Phase Motion

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Abstract

The purpose of this research is to emulate the motion of a school of fish in order to extract propulsive properties from the movement of their fins. The research is done on a system using two oscillating foils in out-of-phase configuration. The main goal of our project is to compare the propulsive efficiency of one oscillating foil to two.

Key Terms

Throughout our research we used the MMGS measurement system.

h_0, θ_0 - Amplitude of heaving and pitching, respectively.
a – The distance from edge to the axis.
s – Foil's span length.
c – Foil's chord length.
b – semi-chord.
U_∞ - Velocity of water.
ω – Angular velocity.
φ – Phase difference.
t – time.

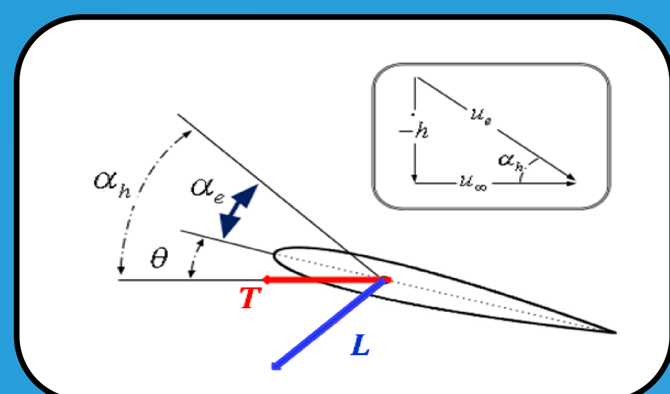

Fig. 1: Forces acting on an oscillating foil.

Lift – Force perpendicular to the vector of velocity (Fig. 1).
Thrust – The forward force that propels the object (Fig. 1).
Reynold number - The ratio of inertial forces to viscous forces within a fluid.

Formulas

Pitching (θ) – The rotation movement of the foil about vertical axis.

$$\theta(t) = \theta_0 \cos(\omega t)$$

Heaving (h) – The horizontal movement of the foil.

$$h(t) = h_0 \cos(\omega t + \varphi)$$

Angle of Attack (α_e) – The angle between the foil's chord line and the velocity vector.

$$\alpha_e(t) = \tan^{-1}\left(\frac{-\omega h_0 \sin(\omega t + \varphi)}{U_\infty}\right) - \theta_0 \cos(\omega t)$$

Strouhal Number (St) - A non-dimensional number that characterize the fluid flow.

$$St = \frac{2 f h_0}{U_\infty}$$

Reduced frequency (k) - Dimensionless number used for the case of aerodynamics.

$$k = \frac{\pi f c}{U_\infty}$$

C_L - Coefficient of Lift:

$$C_L = \pi b\left[\frac{\dot{\alpha}}{U_\infty} + \frac{\ddot{h}}{U_\infty^2} - \frac{ab\ddot{\alpha}}{U_\infty^2}\right] + 2\pi C(k)\left[\frac{\dot{h}}{U_\infty} + \alpha + b\left(\frac{1}{2} - a\right)\frac{\dot{\alpha}}{U_\infty}\right]$$

$$C(k) = 1 - \frac{0.165}{1 - \frac{0.0455j}{k}} - \frac{0.335}{1 - \frac{0.3j}{k}}$$

In order to calculate the propulsive efficiency of the foils we used:

$\eta = \frac{C_T U_\infty}{C_P}$ where,

C_T is the coefficient of thrust and C_P the coefficient of power:

$$C_T = \frac{\bar{T}}{0.5\rho U_\infty^2 sc} \quad \text{and} \quad C_P = \frac{\bar{P}}{0.5\rho U_\infty^3 sc}$$

Methods and Materials

We used two identical NACA 0012 foils with chord equal to 60 [mm] and Span 210 [mm] attached to a system (Fig. 2) that allows each one to oscillate horizontally in a water tank where the velocity of the water is 150 [mm/s]. We wrote a code in Arduino to operate the oscillating foil system and get data. First, we used the system with only one oscillating foil, then we tested it with two oscillating foils in a side-by-side array with a distance of 45 [mm] between them. Additionally, we used Matlab code in order to analyze and compare the data we got from the oscillating foil system [1].

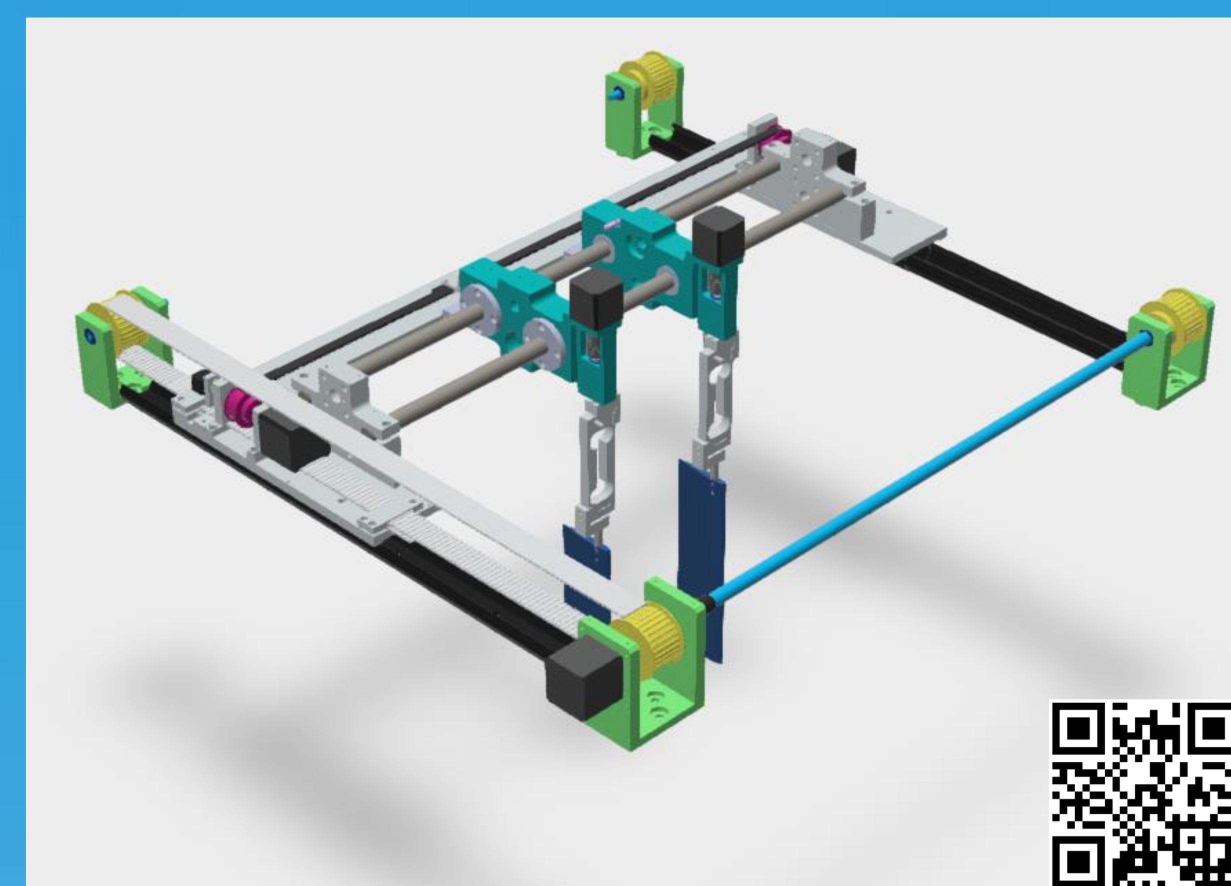

Fig. 2: The oscillating foil system.

Experiment

We gathered the data we got from the oscillating foil system ; the data was noisy so we filtered the data then we graphed the data (Fig. 3) in order to analyze the propulsion efficiency [2].

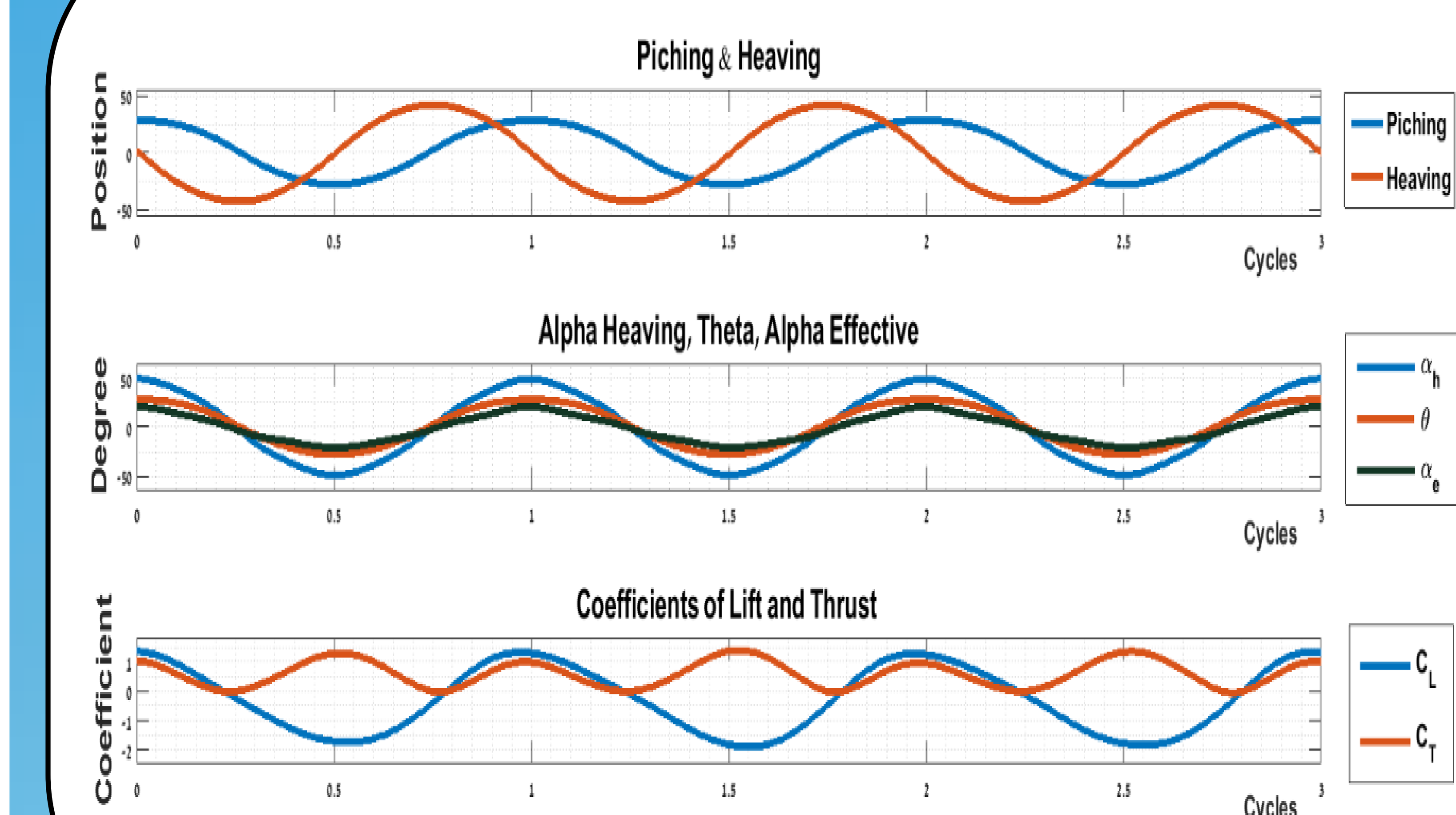

Fig. 3: Filtered data from the experiment.

Results and Discussion

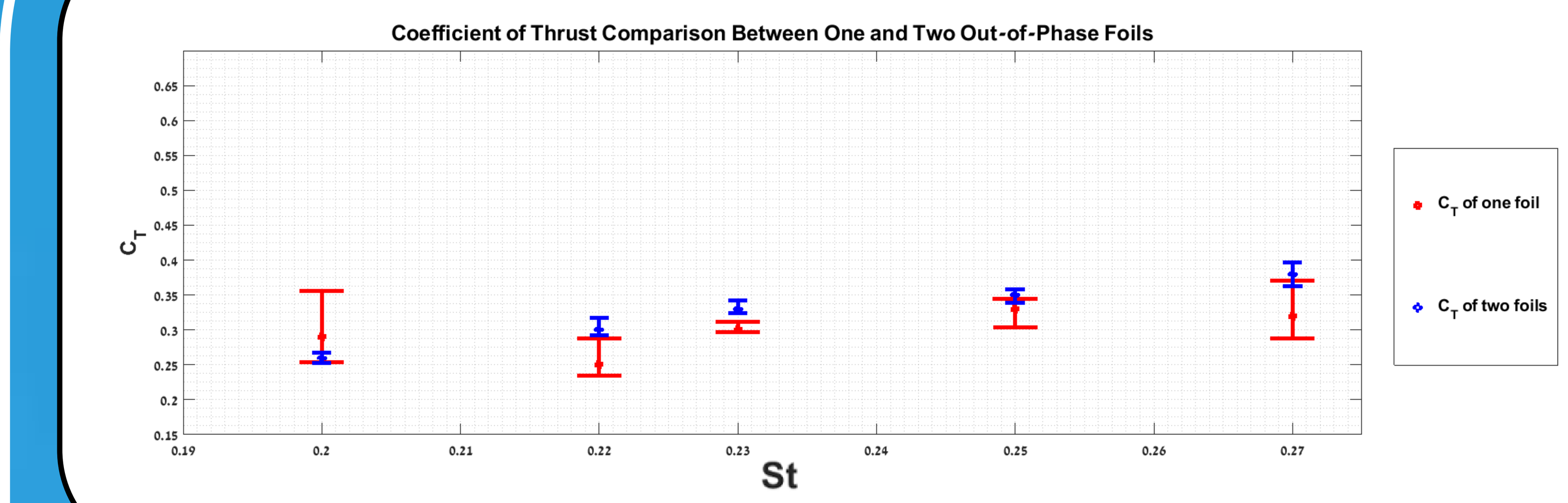

Fig. 4: Coefficient of thrust as a function of Strouhal number.

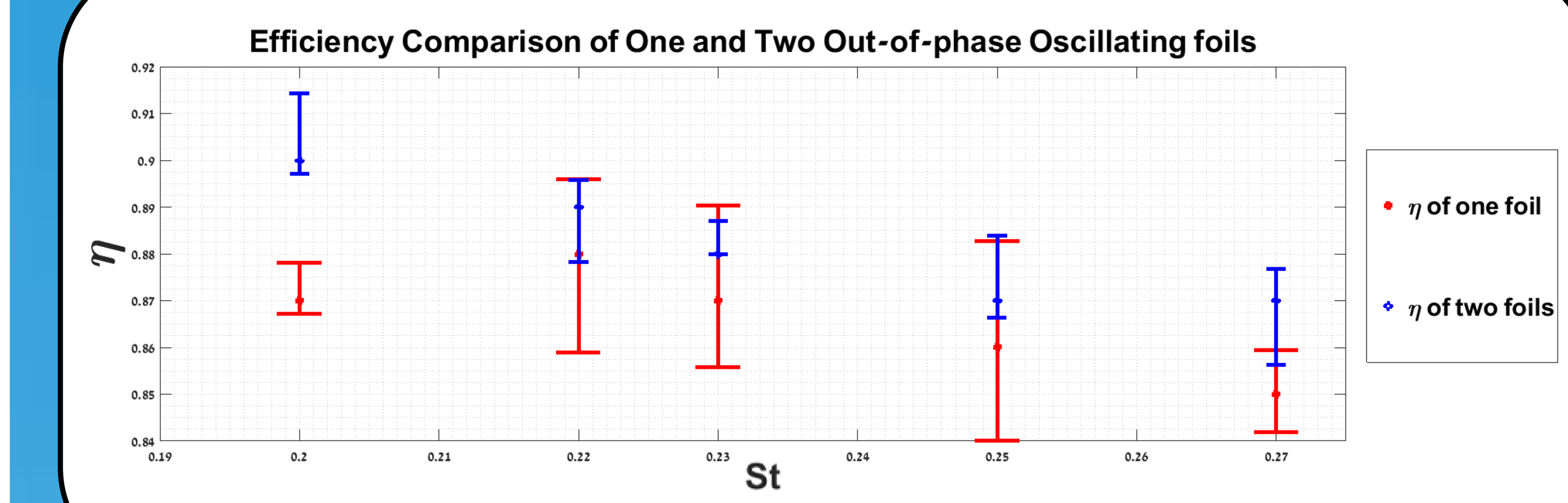

Fig. 5: Propulsive efficiency as a function of Strouhal number.

As shown in Fig. 4, the coefficient of thrust for two foils is bigger than for one foil. As shown in Fig. 5, the efficiency for two foils is bigger than one foil, and we get the biggest efficiency at St = 0.2.

Conclusions and Future Research

- Better propulsion performance is achieved with two oscillating foils.
- More effective coefficient of thrust is achieved with two oscillating foils.

This work is very useful for future development of Autonomous Underwater Vehicles' (AUV's) models. AUVs may one day propel themselves like fast fish of the deep ocean. Potential advantages over conventional propulsion include increased maneuverability and efficiency [3].

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