הטכניון מכון טכנולוגי לישראל TECHNION Israel Institute of Technology

SciTech summer science camp 2016

Fish-Like Propulsion of Marine Vessels

Propulsion System for Autonomous Vessels Using Oscillating Foils

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Ef**fish**ient* *adj.* */əˈfiSHənt/*

Propulsively efficient in the manner of natural fish bio-mechanisms.

$\stackrel{?}{=}$

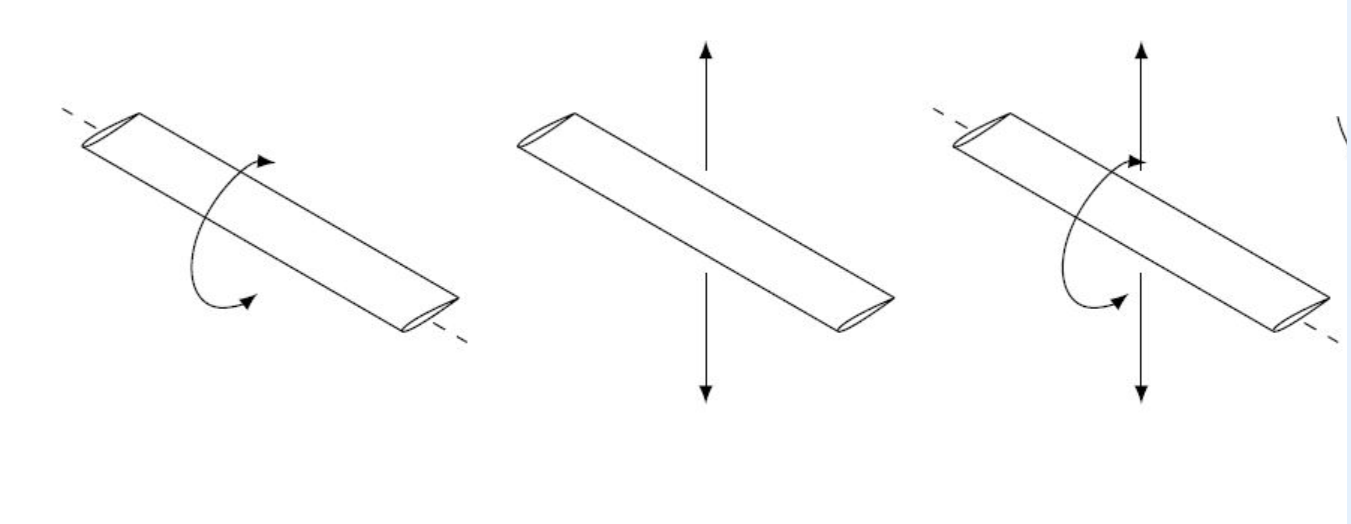
*not a real word

Background

- What is a hydrofoil?
- How is a vortex created?
- How do fish swim?
- What is Strouhal's number?
- How does an oscillating foil work differently from a propellor?

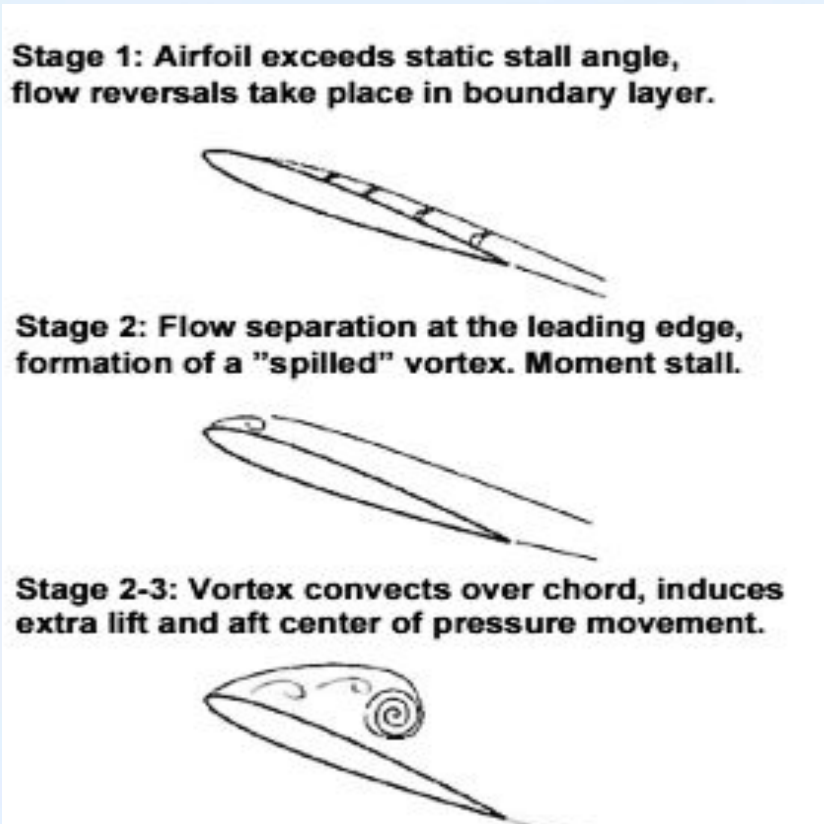
What is a Hydrofoil?

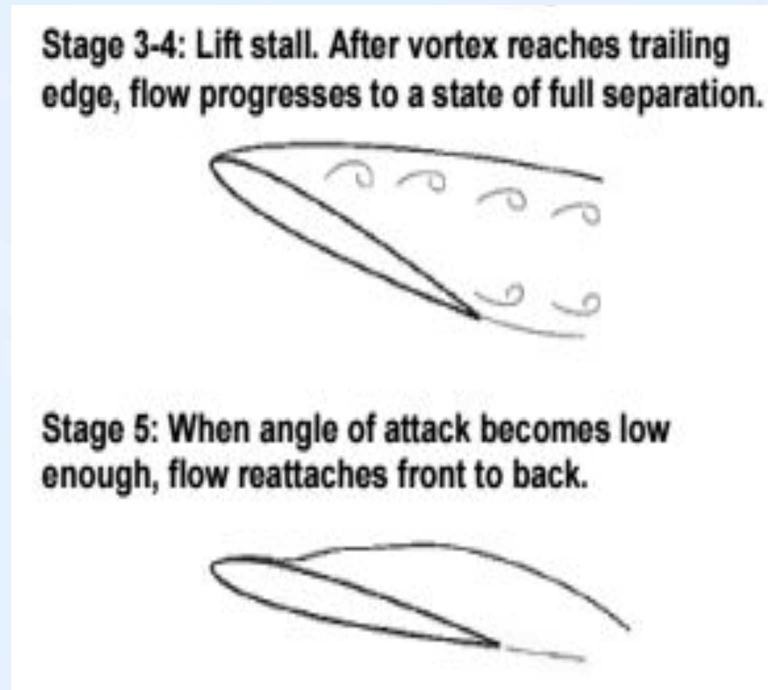
- An object that creates more thrust than drag while in a moving fluid
- Heaving vs. pitching
- Sinusoidal oscillation


(a) Pitching (b) Heaving (c) Flapping

* Diagram adapted from *Oscillating Hydrofoil Propulsion for Human-Powered Watercraft Applications* (2013) by R. Fernandez

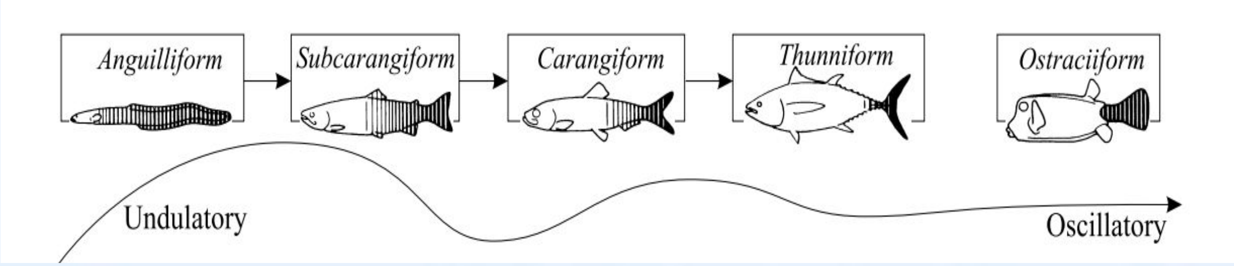
How is a vortex created?



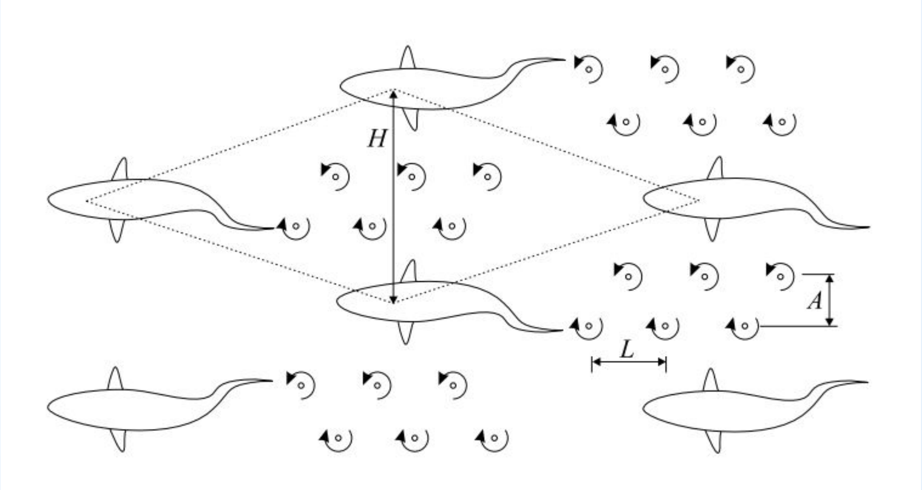


How do fish swim?

Body and/or Caudal Fin (BCF) Movement



Swimming in Schools

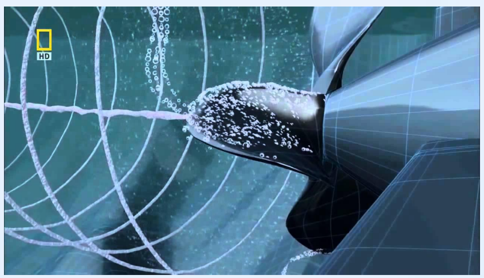


What is a Strouhal Number?

- Demonstrates the relationship between flow and oscillation - the faster you swim, the more frequently you have to oscillate
- Determines an oscillating system's propulsion potential
- Dimensionless - ratio
- Range of 0.2-0.4

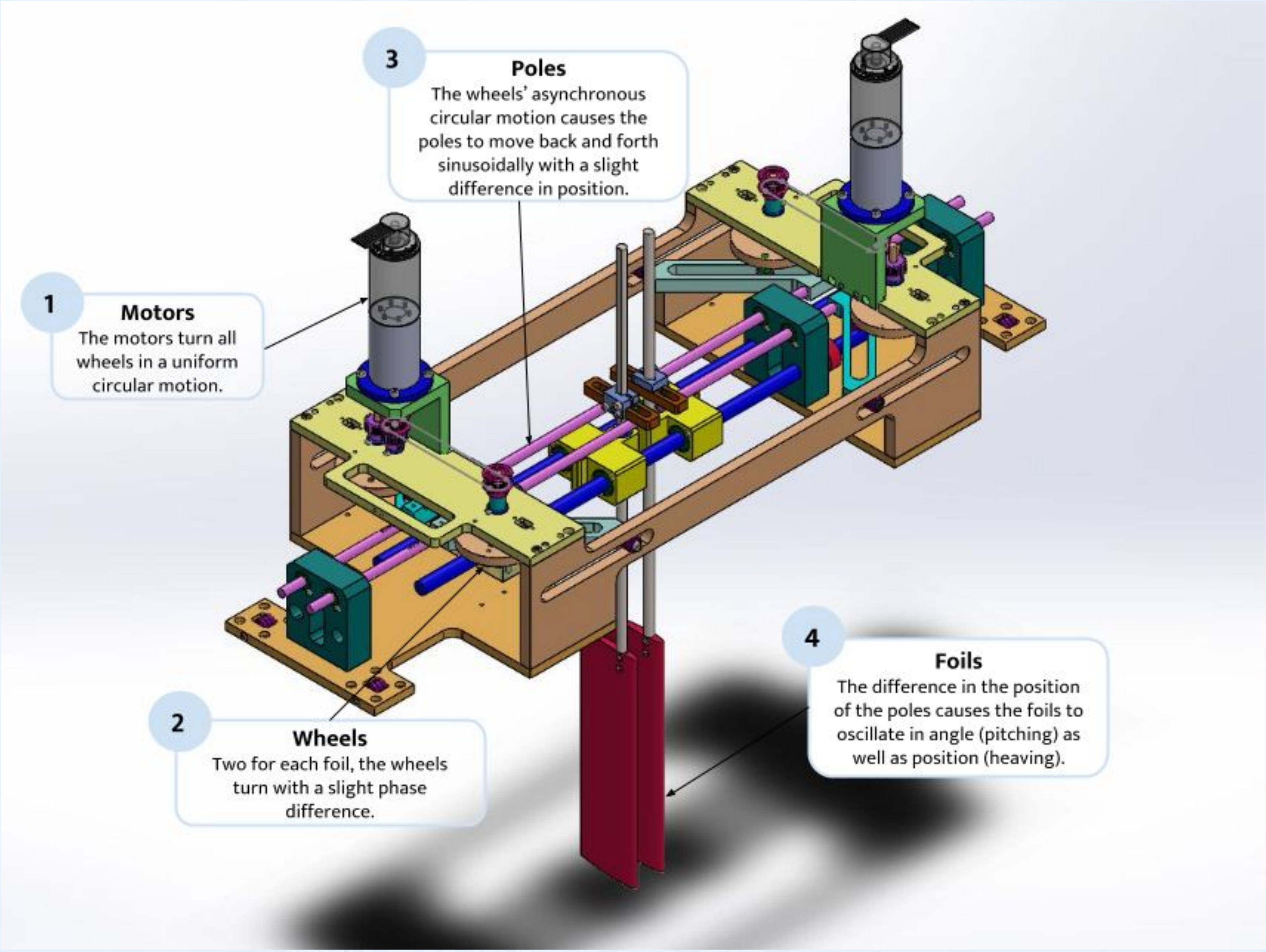
How does an oscillating foil work differently from a propellor?

- Cavitation

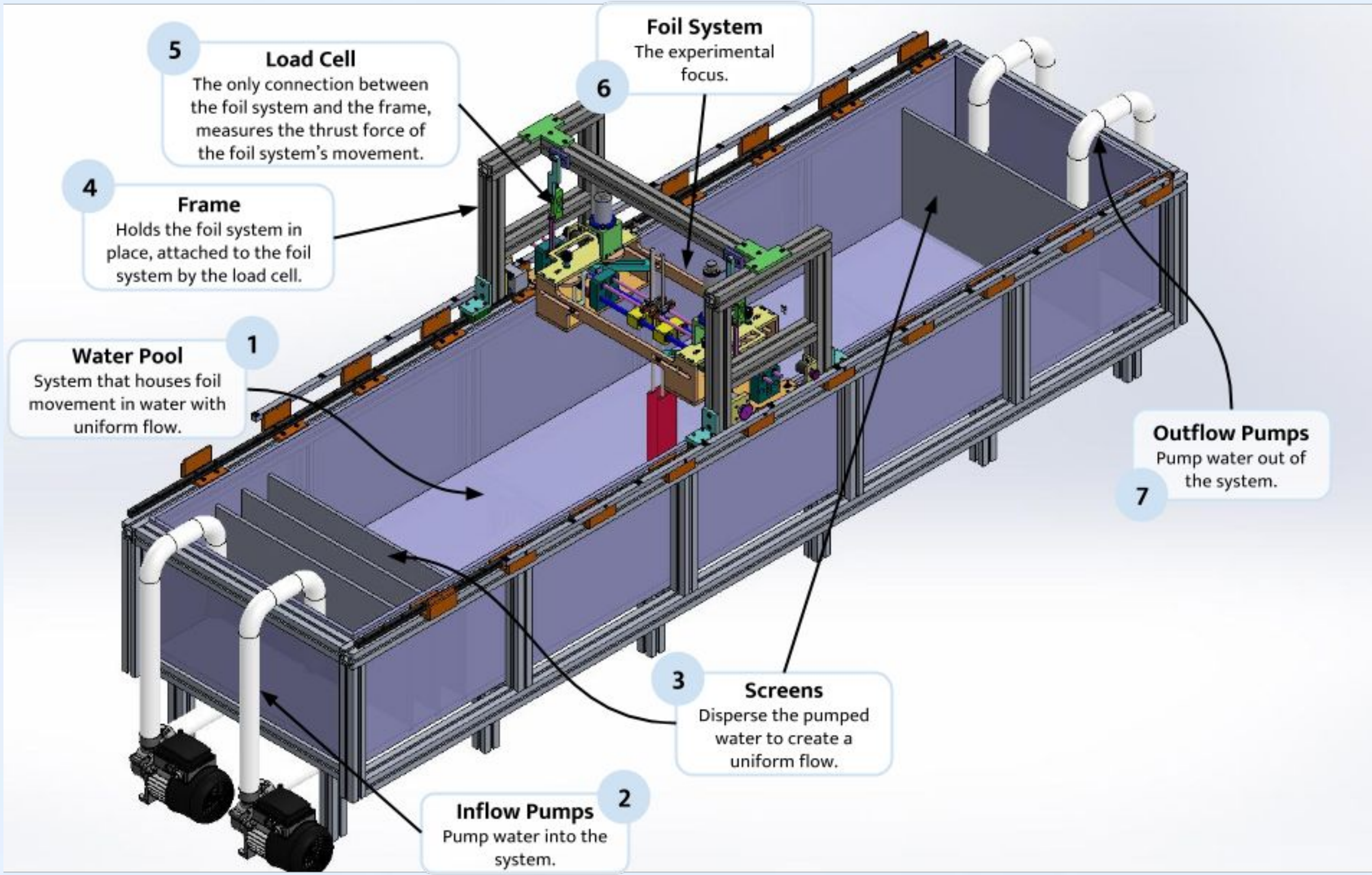


- Use of vortex streets

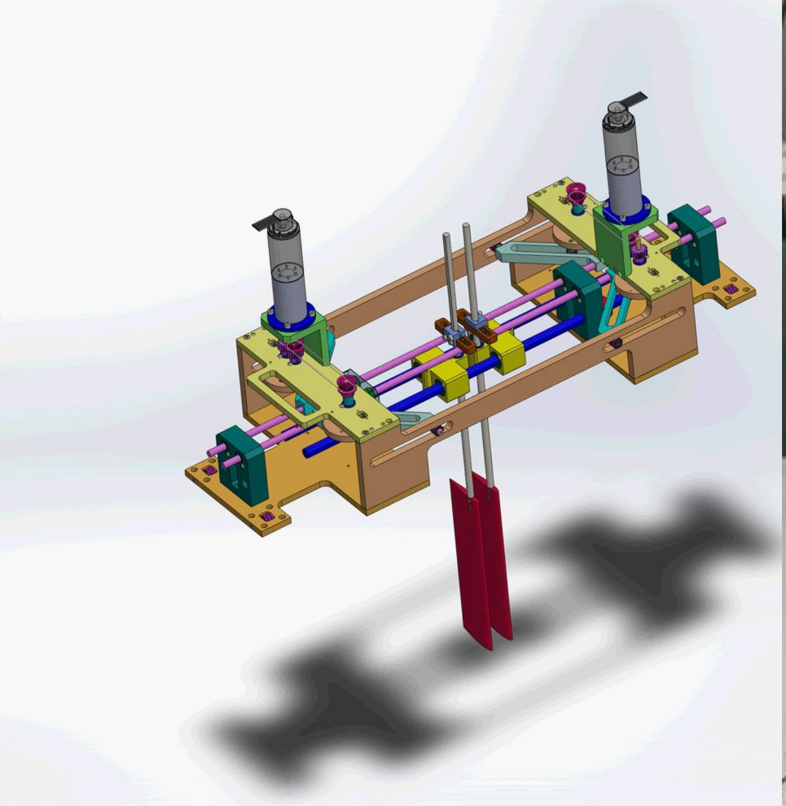
Experimental Setup

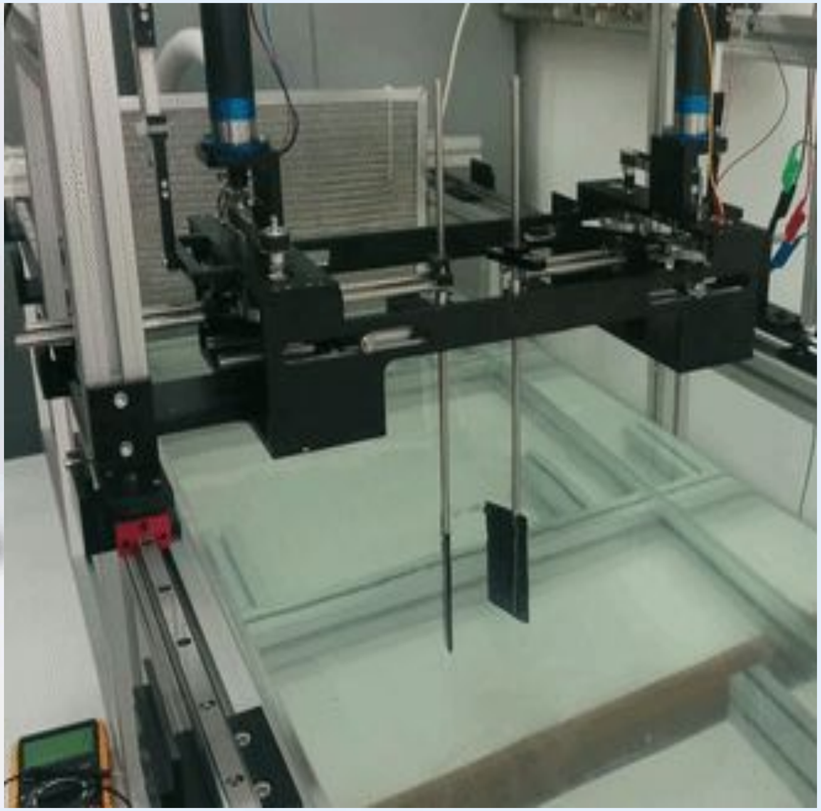


Experimental Setup

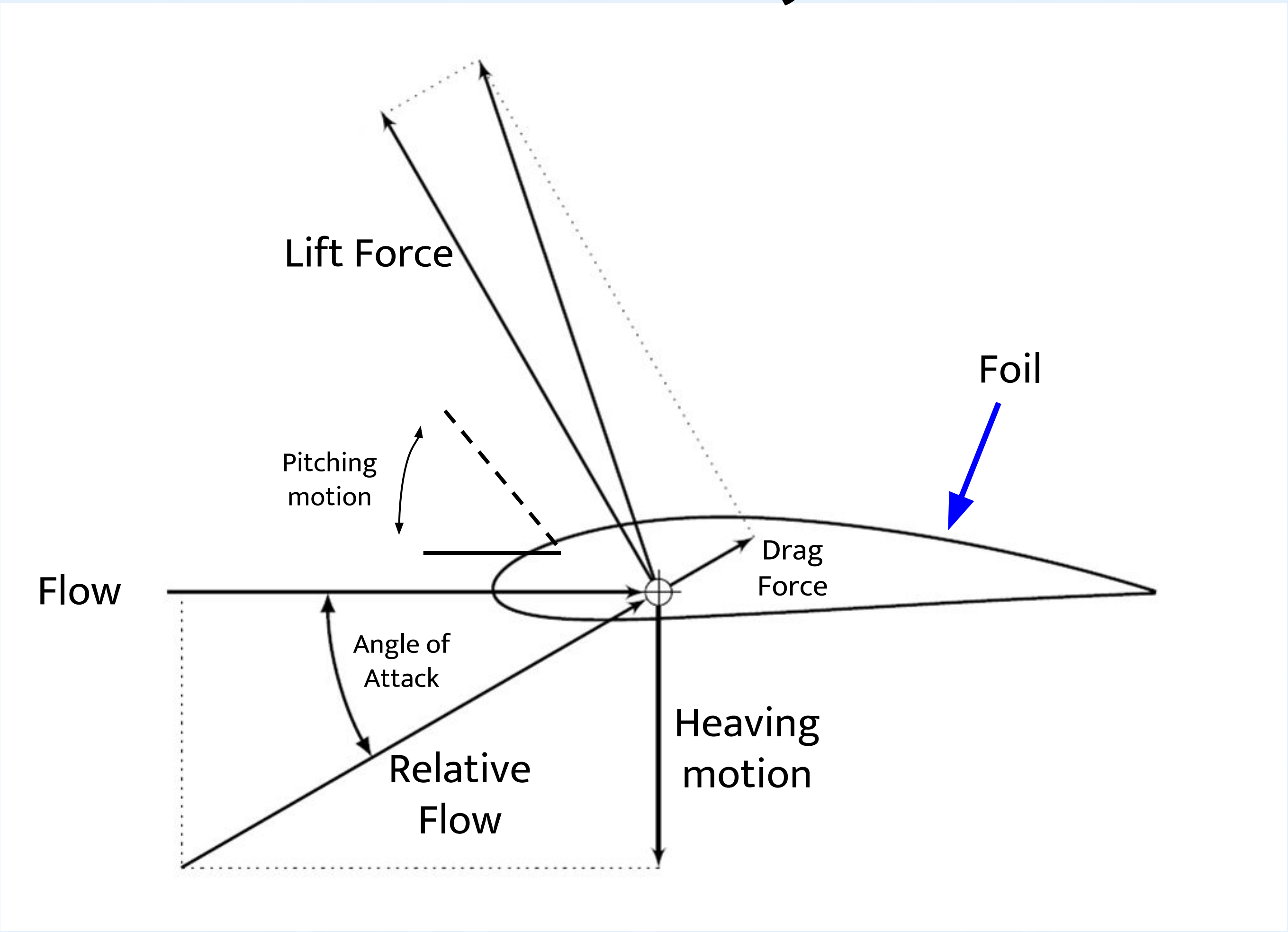


Operating System





Forces on a Hydrofoil



* Diagram adapted from *Oscillating Hydrofoil Propulsion for Human-Powered Watercraft Applications* (2013) by R. Fernandez

Computer Algorithm Settings

Input:

theta0 - Maximum pitch angle

h0 - Heave amplitude

l - Distance between center of system and parallel foil

alpha - Angle of attack

Output:

r - Radius of wheel

phi0 - Phase difference between wheels

m - Pole divet

```
%% BACKWARDS ALGORITHM

%% input variables
function [r,phi0,m] = NitzansBackwardsKinematics(theta0,h0,L)
close all
r = h0/sqrt(2);
BarDistance = 30;

phistar = 2 * asin((sin(pi/4)*(BarDistance*tan(theta0)))/(2*r));

alphas = [5.3 10.6 15.9 21.2 26.5; pi 3*pi/2 0 pi/2 pi];
[~, closestIdx] = min(abs(alphas - r), [], 2);
dAlpha = alphas(2, closestIdx(1));
phi0 = mod(2 * dAlpha + phistar, 2*pi);

dDivets = 3.75; % Distance between divets
d = 500; % Distance between axis of symmetry and center of wheel
D = 100; % Distance between bar and center of wheel
dBar = 400; % Distance between foil and first divet

eqAlpha = deg2rad(180) - phistar / 2; % Alpha of equilibrium
q = D - r*sin(eqAlpha) + r*cos(eqAlpha); % Distance between pin and center of wheel at eq

l = d + q - L;

m = (dBar - l) / dDivets;
phistar = rad2deg(phistar)
phi0 = rad2deg(phi0)
end
```

Equations

Heaving $h = h_0 \sin(\omega t)$

Pitching $\theta = \theta_0 \sin(\omega t + \psi)$

Angle of Attack (AoA) $\alpha = \tan^{-1}\left(-\frac{\dot{h}}{V}\right) - \theta$

Coefficient of **Lift**:

$$C_l = \frac{\pi b}{V}\left(\dot{\theta} + \frac{\dot{h}}{V} - \frac{ba\ddot{\theta}}{V}\right) + 2\pi C(k)\left[\frac{\dot{h}}{V} + \theta + \frac{\dot{\theta}b}{V}\left(\frac{1}{2} - a\right)\right]$$

Coefficient of **Thrust**: $C_t = C_l \sin\beta$

Strouhal Number: $St = \frac{fA}{V}$

ω = *angular velocity of the center of the foil*

h_0 = *amplitude of heaving*

ψ = *phase difference*

a = *number of semichords from the mid-chord*

β = *angle between the lift force and the thrust force*

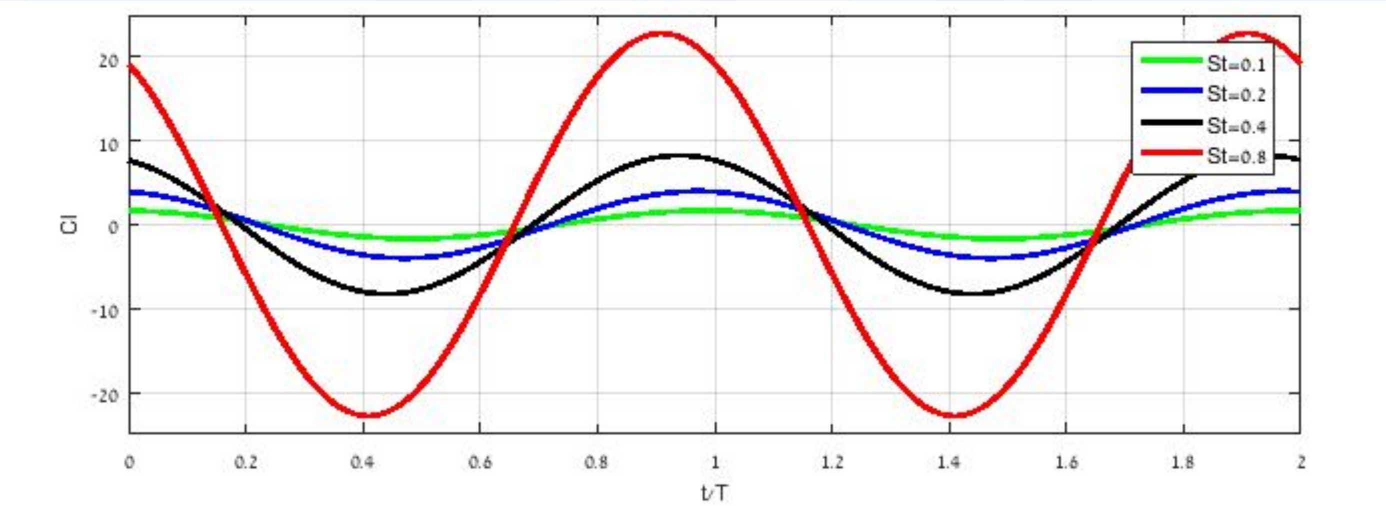
t = *time*

θ = *amplitude of pitching*

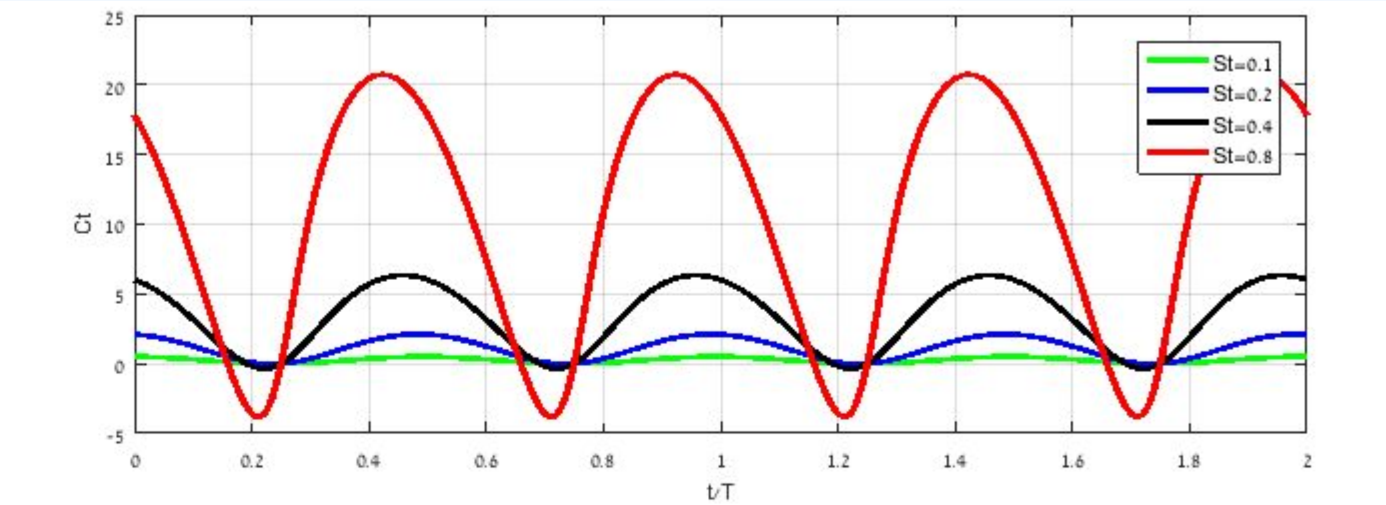
V = *flow velocity*

b = *semichord length*

Theoretical Results



*Coefficient of **lift** as a function of time (in periods of the system)*



*Coefficient of **thrust** as a function of time (in periods of the system)*

Conclusion

While we may not have gathered experimental data, we still learned a lot from our research, specifically:

- Two foils are more efficient than one due to the effects of schooling.
- Calculating lift on an oscillating foil requires the incorporation of wake effect, added mass, and quasi-steady lift.
- The coefficients of lift and thrust are affected by the value of the Strouhal number.

Next Steps

- Generate experimental results
- Compare theory to reality
- Calculate and graph propulsive efficiency

Acknowledgments

We would like to thank the principal investigator in this research, our mentor Guy Kagan, for his guidance and patience with our efforts. It was a pleasure working with him and his dog Angie.