The motion of fish eggs relative to the surrounding water and its implication to oxygen transfer

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Introduction

Most marine fish reproduce by broadcasting small pelagic eggs to the open ocean. These pelagic eggs develop without parental care and rely on mass transfer with the surrounding water for oxygen supply and excretion of metabolic waste products. The ability of fish eggs to exchange oxygen and waste products with the environment is important for the development of the embryo and larvae. Our ability to model these processes is central for understanding fluctuations in fish growth and survivorship, especially under changing environmental conditions due to anthropogenic pressure.

In general, there are two physical mechanisms that govern the mass transfer of oxygen and waste products with the environment: diffusion and convection. The respiring embryo in the egg, acting as an oxygen sink and waste product source, establishes a concentration gradient between the egg surface and the surrounding water over which diffusion occurs. The rate of mass transfer via diffusion thus depends on the magnitude of the concentration gradient outside the egg. However mass transfer rate through convection depends on the motion of the water relative to the egg. Such motion tends to intensify such gradients, increasing mass transfer into the egg.

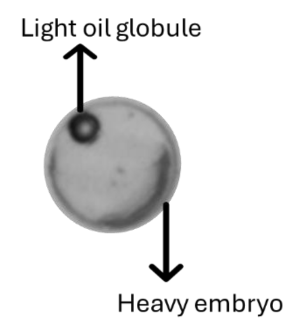

Figure 1 - an egg image rotated by the flow. The oil bubble and the embryo are marked in the figure. As the oil bubble density is lower than that of the water and the embryo density is denser than that of the water an internal restoring moment will be applied on the egg at the direction of the arrows

The prevailing view of mass transfer into pelagic eggs follows the paradigm that pelagic fish eggs are small enough to be considered passive particles having zero velocity with respect to the water around them. Accordingly, the process governing mass transfer into pelagic eggs is thought to be governed only by diffusion (Daykin, 1965; Kranenbarg et al., 2000; Rombough, 1988; Wickett, 1975), which is (1) limiting mass transfer rate and therefore respiration rate and (2) independent of environmental flow regime.

In my research, I challenged the idea that the egg does not move relative to the surrounding water by considering the non-uniform distribution of mass within the egg. Fish eggs comprise of an embryo with density higher than the surrounding water, and an oil globule with density lower than the surrounding water (fig. 1).

As the center of mass is not the same as the geometric center of the egg, a gravitational moment is expected to affect the motion of the egg by acting as a restoring moment. This effect results in a relative motion between the egg and the surrounding water, which may enhance the mass transfer into the fish eggs. My study implies that previous studies that assumed stagnant water conditions have probably underestimated the mass transfer rate into the eggs, and ignored the potential effects of small-scale water motion (i.e. turbulence and waves) on these rates.

<u>Research question and objective</u>

I hypothesized that fish eggs move relative to the surrounding water under turbulence and waves. To test that, I measured the motion of the eggs and that of the surrounding water and quantify the magnitude of the relative motion between them (if one exists) under different flow regimes. Additionally, I developed a mathematical model of the eggs' motion, and validated it against the measurement results, in order to use it to predict the relative motion beyond the measured conditions in the lab.

<u>Results</u>

To test my hypothesis, the orientation and location of fish eggs and the flow field were measured simultaneously. Then, the difference between the egg motion relative to the water flow field was analyzed. The measurements were conducted in an experimental setup consisting of a rotating cylinder, that generates flow fields in the frequencies and magnitudes in the range of time and length scale that fish eggs experience in the sea.

Observations show that the eggs keep their orientation with the oil bubble at the top of the egg and the embryo at the bottom of the egg under a range of rotational flow velocities[1] (fig 2). As the flow field created in the cylinder is of constant angular velocity, the water rotates as a rigid body and any particle of a uniform distributed density should have rotate with the water. The vertical orientation of the eggs shows that there is a relative motion between the eggs and the surrounding water.

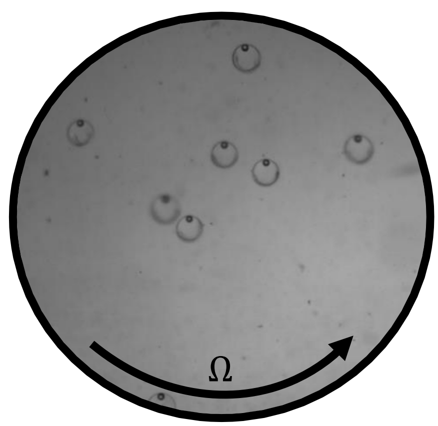

Figure 2 - the eggs orientation in a rotating cylinder

Furthermore, as the rotational velocity of the cylinder increases, the eggs angle increases as well (Fig. 3, 4). Since the internal torque of the egg depends on the angle of the egg and grows as the

[1] https://www.youtube.com/watch?v=IVwqzessI54

egg angle diverted from vertical orientation, it can be seen that the eggs respond to the growing torque by balancing it with their internal torque.

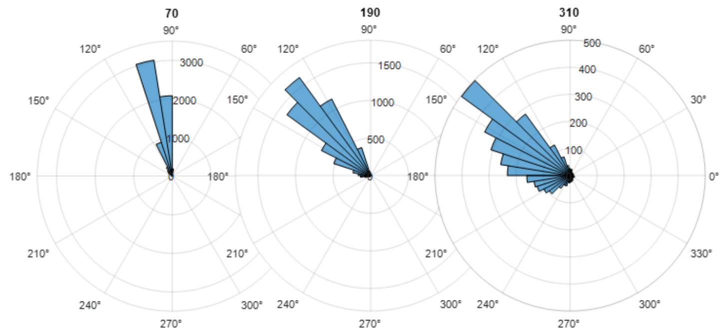

Figure 3 - histogram of all the eggs realizations in three different motor velocities

In addition to the measurements of the eggs orientation I am also developing, in collaboration with researchers from the Technion, an analytical model to predict the eggs motion under external torque applied from the water. It can be seen that the measurement of the eggs angle (orange) for different velocities agree with the external torque (blue) required to reach the same angle as predicted by the model. In addition, I am developing a mathematical solution for the flow field around the eggs to extract an analytical term for the external torque.

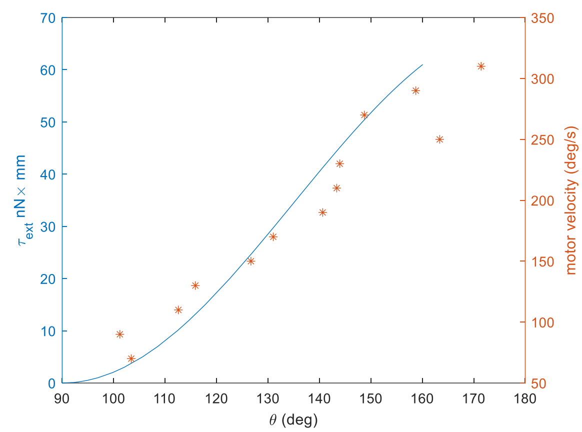

Figure 4 - the egg angle required to balance an external torque applied on the egg as predicted by the model, in comparison to the engine velocity required to bring the egg to the same angle from measurements

The idea of relative motion between pelagic fish eggs and the surrounding water was not suggested or examined before, thus not implanted in previous estimates of mass transfer rates.

My results suggest that previous models have likely severely underestimated the mass transfer rates into fish eggs and neglected the effect of environmental flow conditions on these rates.

Understanding the effect of flow regime on the mass transfer into fish eggs will enhance our ability to estimate larval development in different ocean conditions, the effect of climate change (Motani & Wainwright, 2015), and improve aquaculture by applying adequate flow for the eggs. Furthermore, my results may be relevant to other pelagic organisms, such as algae, that have non-uniform distribution of mass within them.

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