ON THE HYDRODYNAMIC SHAPE OF LITTLE SKATE (RAJA ERINACEA) EGG CAPSULES

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While the unusual shape of skate egg capsules has evoked considerable speculation with respect to possible function, there has been no theoretical or empirical investigation of their shape-related properties. Little skate (Raja erinacea) egg capsules appear rectangular when viewed from the dorsal or ventral aspect; they are flattened in the dorsal-ventral plane with convex dorsal and ventral body walls (see Fig. 1). Four horns emanate from the corners and are oriented parallel with the long axis of the capsule. The anterior horns, curved ventrally, are shorter than the posterior horns, which bend towards one another. Slits on the outer seam of each horn, located about two thirds the distance to the end, are initially plugged with albumen. These slits open to admit sea water after approximately one third of the one to two year-long embryonic development. The present report describes flow tank experiments examining the hydrodynamic properties of these egg capsules, especially with regard to the influence of currents on flow of water through the capsule by way of the slits.

Little skate capsules at two stages of incubation were used for these experiments. Freshly laid capsules, collected within a week of oviposition, were used for measurement of drag. Freshly hatched capsules, laid in September 1994 and incubated in the year-round sea water system at the Laboratory, were used for experiments examining the effect of current on flow through the capsule, as well as for visualizing streamlines around the capsule. All experiments were performed in a laminar flow tank with a 5 x 1 x 1 ft working section. Current speed was measured with a video camera and video cassette recorder by introducing a bolus of dye and timing its transit through 20 cm. Five such measurements were made for each of five motor speeds at three separate locations in the working section of the tank. Speeds varied between 6 and 20 cm/sec.

Relative drag was measured by suspending capsules from a cantilever beam mounted on an axle and measuring the flow generated force exerted on the capsule through the beam to a calibrated Grass strain transducer. The output of a bridge amp connected to the strain gauge was amplified with a Tektronix DC amplifier and measured with an oscilloscope. Capsules were mounted in four orientations relative to the flow: the long axis parallel to flow, anterior horns forward; long axis parallel to flow, posterior horns forward; long axis perpendicular to flow, lateral seam facing forward; dorsal aspect facing flow. At each orientation, five current speeds between 6 and 20 cm/sec were tested in sequence from lowest to highest speed. Relative drag measurements were obtained for five randomly selected capsules.

To assess the effects of flow on water movement through the capsule, naturally hatched capsules were filled with methylthymol blue dissolved in sea water, the hatching seams were sealed with high pressure vacuum grease, and the capsules were placed on the floor of the tank

and subjected to defined flow speeds for one hour. The contents of the capsules were then collected and their optical absorbance measured at 600 nm (λ_{max} for methylthymol blue at pH of MDIBL sea water). Methylthymol blue was chosen because preliminary experiments established that the body wall is impermeable to this dye, thus, loss of dye in these experiments could only occur through the slits. Capsules were subjected to five flow speeds ranging from 6 to 20 cm/sec. Loss of dye due to manipulation of the capsules as well as simple diffusion was measured by exposing dye-filled capsules to zero flow in the flow tank for one hour. Capsules were tested at three orientations relative to flow at 11 cm/sec for one hour: long axis parallel to flow, anterior horns forward; long axis parallel to flow, posterior horns forward; long axis perpendicular to flow. Six capsules were used for these experiments. The above experiments indicated that dye was leaving the capsules under flow. To determine through which horns water exited the capsule when exposed to flow at the various orientations, capsules were filled with milk and the flow of milk from the slits was recorded with a video camera.

Figure 1 illustrates the shape of little skate egg capsules. The midline sagittal section shows the streamline shape of the capsule. The fineness ratio (length/thickness) of 3.9 $\pm$ 0.4 (n = 21) and the position of the thickest dimension, one third of the distance behind the leading edge, are characteristic of streamlined bodies. The cross-section taken through the thickest portion of the capsule also shows considerable streamlining.

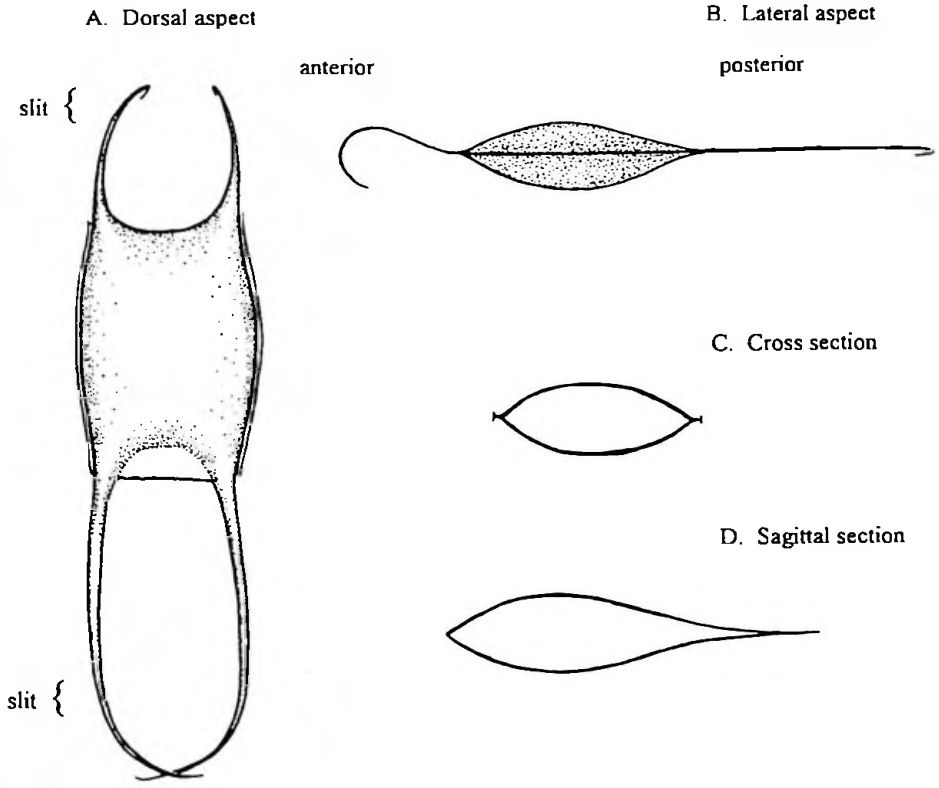

Figure 1. Illustration of the shape of little skate egg capsules. a) dorsal aspect; b) lateral aspect; c) cross section through thickest region.; d) midline sagittal section.

Relative drag measurements showed that the least drag occurred with the long axis of the capsule parallel to flow, regardless of which horns faced the current (Fig. 2). The capsule experienced somewhat higher drag when oriented perpendicular to flow with the lateral seam facing into the flow. Greatest drag occurred when the dorsal wall faced into the flow.

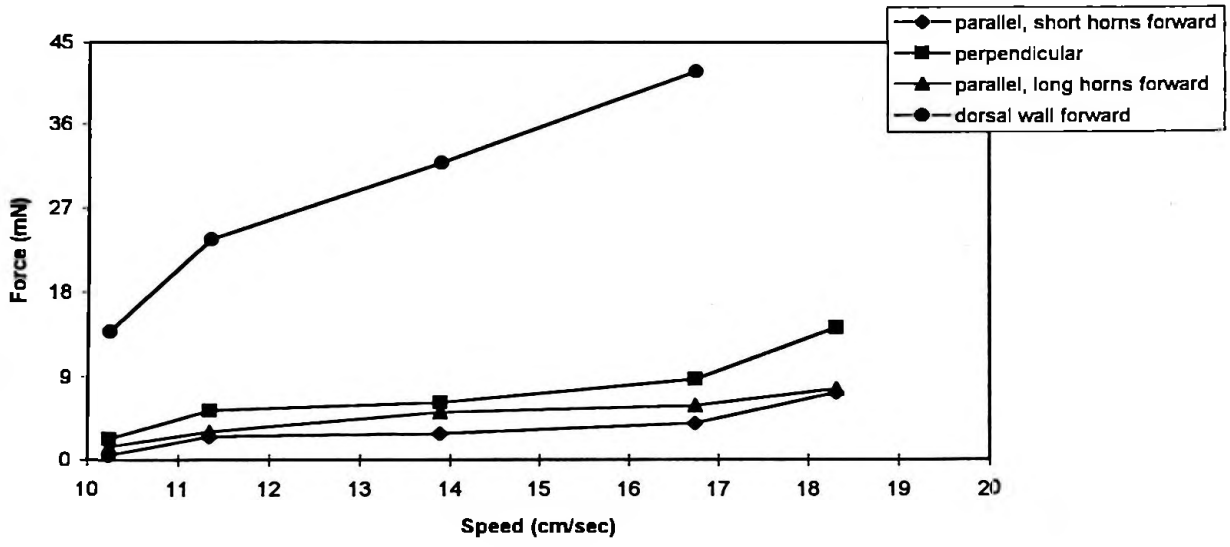

Figure 2. Relative drag measurements on capsules oriented as indicated at various flow speeds. Values presented are means for five capsules. Standard deviations are not shown because the values of the three curves at the bottom are not statistically different.

The effect of flow on the loss of dye from the capsules when oriented parallel to flow with the anterior horns facing forward is shown in Fig. 3. The amount of dye remaining in the capsule after one hour exposure to flow was directly related to flow speed above 6 cm/sec. A linear regression analysis using all values plus the starting optical absorbance of the dye gave a correlation coefficient R^2 of 0.78.

When tested at the three low drag orientations shown above, there was little difference in the amount of dye lost at 11 cm/sec flow. However, fluid exited the capsule through a particular set of horns depending on orientation. When placed with the long axis parallel to flow, regardless of which horns faced into the flow, milk exited the capsule only from the two downstream horns. When placed perpendicular to the flow, milk left through one downstream horn and the upstream horn diagonal to it. Further analyses will be necessary in order to determine the exact relationship between capsule orienfation and flow induced water movement through particular sets of slits under various flow regimes. Coupled with pressure measurements, these experiments will provide an understanding of the precise factors that influence these hydrodynamic properties.

Little skate egg capsules exhibited specific hydrodynamic properties under the relatively ideal flow conditions examined here, including streamlining, low drag, and current induced flow

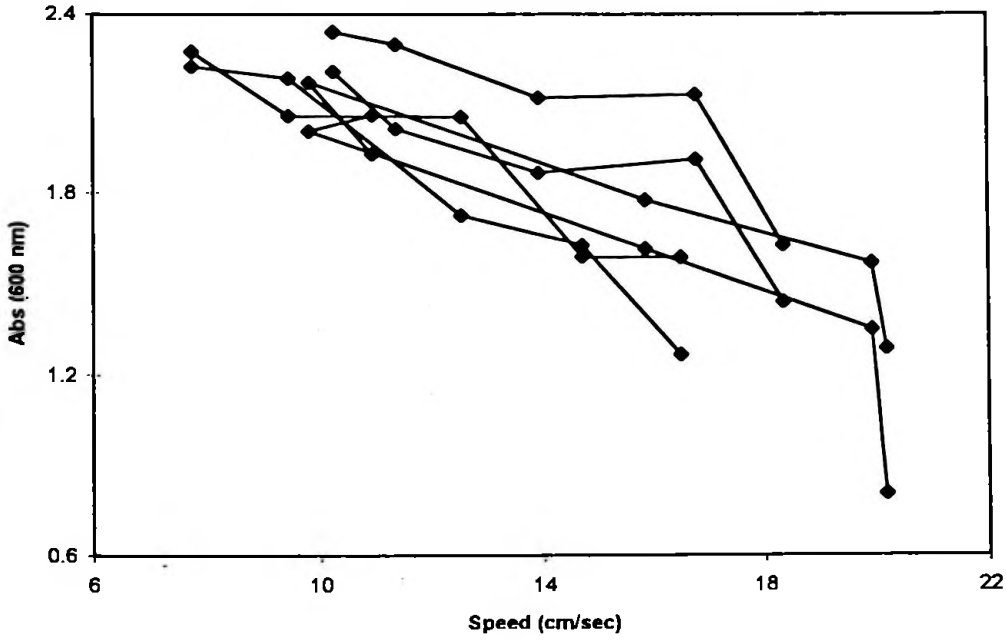

Figure 3. Scatter diagram of the optical absorbance of the methylthymol blue solutions remaining in six capsules after one hour at the indicated speeds. The lines connect the five values for individual capsules.

through the capsule via the slits. These hydrodynamic properties may enhance survivorship to hatching by providing a continual supply of fresh oxygen to satisfy the increasing respiratory demands as development progresses. However, while these capsules are clearly hydrodynamic, we can only speculate about the importance of their shape since natural spawning grounds have never been located. Therefore, the conditions, including flow patterns, under which these eggs successfully hatch are not known. As efforts to locate naturally deposited skate eggs continue, long-term experiments are underway to determine whether currents and current generated flow through the capsule are necessary for successful development to hatching.

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