

Minireview

## Hitching a lift hydrodynamically - in swimming, flying and cycling

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### Abstract

Swimming animals set the water around them moving, and flying animals generate air movements. Other animals traveling with them can save energy by exploiting these movements of the fluid medium; similarly, a cyclist can save energy by riding close behind another. A new study of dolphin mothers and calves exemplifies the advantages of moving in concert.

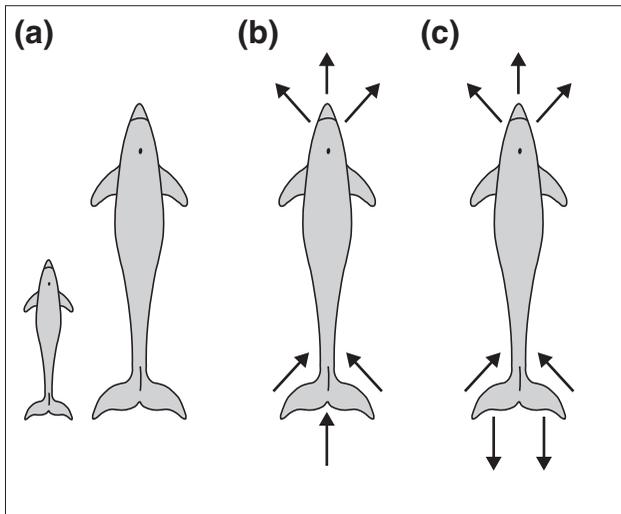
Animals set the fluid around them moving, when they swim through water or fly through air. In some circumstances, one animal can take advantage of the fluid movements generated by another, to reduce the energy cost of its locomotion. A possible example of an animal benefiting from this principle is a dolphin calf swimming with its mother. The animals swim side by side, laterally separated by 1-2 calf diameters, with the calf beside the rear half of the mother's body (Figure 1a). Weihs [1] has now analyzed the hydrodynamics of the interaction between them.

As a mother dolphin glides passively forward, water is pushed out in front of her and drawn in behind her (Figure 1b). These water movements could assist the swimming of an accompanying calf. When the mother swims by beating her tail fluke up and down, she drives a jet of water backwards (Figure 1c). This jet would impede the swimming of a calf immediately behind her, but a calf in the position shown in Figure 1a would be swimming in forward-moving water and so would, to some extent, get a free ride. The water around it would also be moving obliquely inwards, towards the mother, tending to keep the calf close to her. In contrast, a calf swimming beside the anterior part of the mother's body would be pushed

sideways away from the mother, making the association between the animals unstable.

A second effect will help further to keep the animals together. Water will accelerate (relative to the animals' bodies) as it enters the narrow gap between them. Consequently the pressure in the gap will be reduced, by Bernoulli's principle. (This is the principle that explains how aircraft can remain airborne: the pressure in the faster-moving air above the wings is less than the pressure in the slower-moving air below them.) If the animals leap out of the water as they swim (porpoising), as dolphins often do, the calf must leave the water at about the same angle as the mother to ensure that the two are still close together when they re-enter the water. Weihs [1] shows that this requirement is not too stringent; errors in the angle of the order of 10° can be tolerated.

Weihs measured photographs, taken from a helicopter, of mother-calf pairs of the dolphin genus *Stenella*. By applying his hydrodynamic analysis he estimated that the mothers' efforts were relieving the calves of up to 60% of the energy cost of their swimming. So far, no metabolic measurements are available to confirm this conclusion, but it seems clear that mother dolphins give their calves substantial help. Just

**Figure 1**

Diagrams showing (a) the preferred position of a dolphin calf beside its mother, and (b,c) water movements near a dolphin when it is (b) gliding passively forward and (c) swimming actively.

as baby monkeys could not keep up with their troop if their mothers did not carry them, dolphin calves might be unable to keep up with the adults if they did not keep close to their mothers.

A different hydrodynamic effect enables dolphins to save energy by exploiting the water movements generated by boats. A boat's movement disturbs the surface of the water, generating waves that spread out from the bow and stern. Dolphins commonly take up positions in these waves, so as to be swimming in the water that the boat is pushing forward. Williams *et al.* [2] found that trained dolphins swimming in the stern wave of a small boat took 5.5 breaths per minute; but when they swam well clear of the waves at the same speed they took 8.8 breaths per minute. Electrocardiographs showed that dolphins traveling at 3.8 m/sec in the stern wave had heart rates 20% lower than when they swam at 2.9 m/sec well clear of the waves. (No satisfactory record could be obtained of heart rates well clear of the waves at the higher speed.) These observations indicate that dolphins make large savings of metabolic energy by wave-riding.

Ducklings swim behind their mothers, benefiting from the water movements she generates in much the same way as dolphin calves benefit from swimming beside their mothers. The position immediately behind the mother is not disadvantageous in this case, because the water driven backwards to propel the ducks is well below their bodies, at the level of their feet. Fish [3] measured the metabolic rates

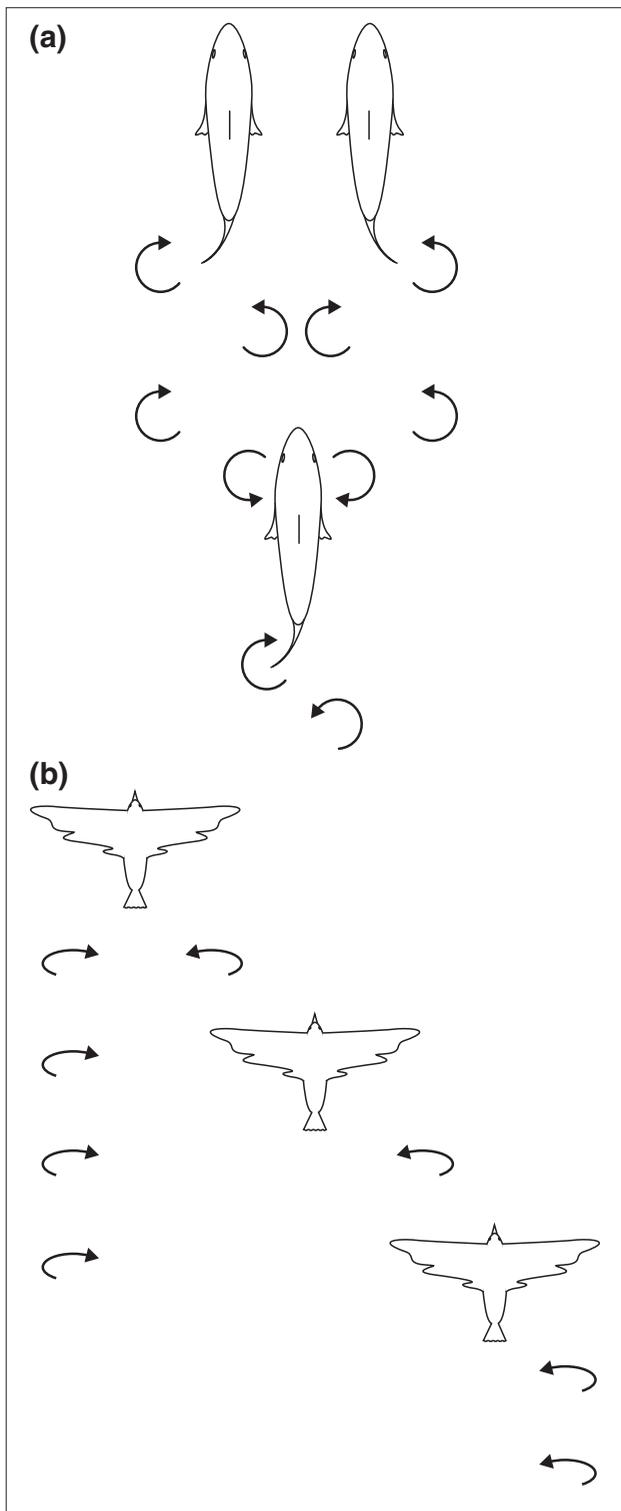
of groups of ducklings swimming in a flume behind a decoy. Solitary 3-day-old ducklings used 38% less metabolic energy swimming in the decoy's wake than when swimming without the wake (with the decoy suspended above the water surface). Further experiments with the decoy suspended showed that the mean metabolic rate of ducklings in a line of four was about 60% less than for a single duckling. The metabolic rates of ducklings in a group could not be measured individually, but observations of the feet showed that the rear duckling was paddling less vigorously than the leading one [4].

It has been argued that fish in a school may be able to benefit from each other's wakes [5]. The propulsive jet of water generated by the beating of a fish's tail weaves between a series of vortices. A fish swimming behind two others, between their wakes, can benefit from the forward-moving water on the outer sides of the vortices (Figure 2a). Observations of roach showed that fish swimming at the rear of a school beat their tails at frequencies around 10% lower than the leading fish in the school [6]. This suggests that they were using less energy than the leading fish.

Birds such as geese, flying in V-formation or in an oblique line, also benefit from their leaders' vortices. The wings drive air downwards to provide the upward lift that balances the bird's weight. Behind the wings, on either side of the downward-moving air, are trailing vortices (Figure 2b). When birds fly in formation, with each bird's wing tip behind its neighbor's wing tip, the leader's trailing vortex may be cancelled out, reducing the energy shed to the wake. In experiments with pelicans trained to follow a boat or an ultra-light plane, it was shown that birds flying in third position or further back in a formation had heart rates around 13% lower than birds flying alone; the leader of the formation had about the same wing beat frequency as a solitary bird, but birds further back in the formation beat their wings at lower frequencies [7].

Aerodynamic drag is responsible for only a small part of the energy cost of running for animals, but it is the largest cost in fast cycling. Consequently, racing cyclists can make large savings of energy by riding at the back of the pack [8]. Measurements of the oxygen consumption of cyclists on a straight road showed that, at 40 km/h, the last rider in a line used 27% less energy than a solitary rider, and a rider behind a pack of eight cyclists used 39% less energy than when cycling alone. Thus, it is unwise to take the lead in a race too early [9].

These examples have shown that many animals can save energy by traveling close to each other, but that the leader of the group generally derives no benefit. In the case of



**Figure 2**  
Diagrams showing how animals in a group can benefit from the vortices generated by their leaders. **(a)** Fish optimally positioned in a school. **(b)** Birds flying in formation.

dolphin mother-calf pairs, the calf derives clear energetic benefit by taking up a hydrodynamically advantageous position in close proximity to its mother.

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