SWIMMING IN BIRDS. Propulsive mechanisms and functional morphology.

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Abstract:

Swimming and diving birds exist in several unrelated groups, but despite this phylogenetic diversity, several convergent characteristics of the propulsive appendages can be found. This convergence in morphology is most probably a consequence of the propulsive mechanisms used. This thesis deals with the hydrodynamic basis of these propulsive mechanisms and the functional morphology of the propulsive appendages of swimming and diving birds.
Foot-propelled birds are traditionally viewed as drag-based paddlers, but here, two different lift-based mechanisms are suggested to provide thrust for many diving birds. The first lift-based mechanism among foot-propelled birds is described for diving Great crested grebes (*Podiceps cristatus*). The foot stroke of the grebe is in a plane perpendicular to the swimming direction with the feet moving from a ventrolateral position to a dorsocuadal position. Following a study of the motion of the asymmetrically lobed toes of mechanically rotated feet, we conclude that the toes most probably function as self-stabilizing multiple slots that reduce the induced drag and thereby increase the lift to drag ratio and the propulsive efficiency. The second lift-based mechanism, which is predicted to be more generally applicable, is suggested by the result of the kinematics of a diving Great cormorant (*Phalacrocorax carbo*). The feet are moved from underneith the body in a plane parallel to the swimming direction towards but besides the tail with some motion perpendicular to the swimming direction, suggesting a lift-based mechanism.
Studies of the hind-limb morphology of birds, are used to relate size and leg length independent measures of the three skeletal bone elements of the leg to habitat use. The swimming birds form a well recognized group, with generally low measures of femur and leg length and higher measures of tibiotarsus and tarsometatarsus than predicted by the general norm for all birds. These results fits well with the predictions of drag reduction and propulsive efficiency of foot-propelled swimming birds.
The kinematics and momentary force production of wing-propelled, horizontally diving Atlantic puffins (*Fratercula arctica*) is described. The acceleration pattern of the body during a wing stroke cycle, show that the puffins can use an active, thrust producing upstroke. A force analysis suggest that the propulsive mechanism is most probably lift based. Two different lift-producing mechanisms are discussed and the propulsive mechanism of puffins is suggested to be based on non-steady-state hydrodynamics. The use of a leading edge vortex is proposed as a potential mechanism, where the half-folded (swept) wings of puffins might provide a way to stabilize the flow.
Taken together the results challenge the general assumption of higher propulsive efficiency of wing-propelled divers as compared to foot-propelled divers.

Keywords: Birds, *Podiceps cristatus*, *Fratercula arctica*, *Phalacrocorax carbo*, Swimming, Diving, Kinematics, Hydrodynamics, Functional Morphology.

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