Does the pinching force dissipate the rower's energy?

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M. N. Macrossan

Centre for Hypersonics, School of Engineering, University of Queensland

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Abstract

Regardless of the angle the oar makes to the forward direction during a rowing stroke, there is negligible loss of energy between the oar and the gate. However, it does not follow from this that there is no decrease in oar efficiency at the extreme oar angles necessary for a very long catch. The loss of energy from the oar occurs, not at the gate, but at the blade. The water which is moved by the blade absorbs mechanical energy from the oar. Calculations, experimental data and on-water measurements of rowing show that the energy efficiency of the oar is generally lowest for oar angles less than 55 degrees to the boat-forward direction (*i.e.* in the early part of the stroke).

Introduction

The blade force is the (vector) sum of the forces exerted by the water on the submerged rowing blade as it moves through the water. This force can be resolved into a forward (propulsive) component, and a sideways component (pointing in towards the boat). Figure 1 shows schematic views of an oar at the beginning of the stroke and later in the stroke. In each case the blade force is shown acting in a direction approximately perpendicular to the oar-shaft axis. Thus the sideways force just after 'the catch' is much greater than the forward force, whereas the sideways force is near zero when the oar angle ψ approaches $90°$.

The term 'pinching force' is often used for the sideways component of the force exerted *by the oar on the boat* (at the gate/pivot). For an ideally rigid boat and rigging, the gate does not move sideways as this force is applied. Thus, the gate force transmits energy from the oar to the boat without loss and this is true regardless of the angle of the oar. Hence one might conclude that there is no extra waste of energy when the oar is near the catch [4]. Nevertheless, some rowers might ask themselves 'Isn't the blade moving water more sideways than backwards near the catch, and isn't this sideways movement a waste of energy?' This 'intuitive theory' is approximately correct[1]. Apart from energy converted to heat by friction, or by bending and twisting of the hull or oars, the only losses of mechanical energy from the system (*i.e.* everything which must be moved from the start to the finish in a race) are due to *external* forces acting on the system. If we

[1]It is not only when water is moved sideways that energy is dissipated. Energy is also dissipated when water is moved backwards.

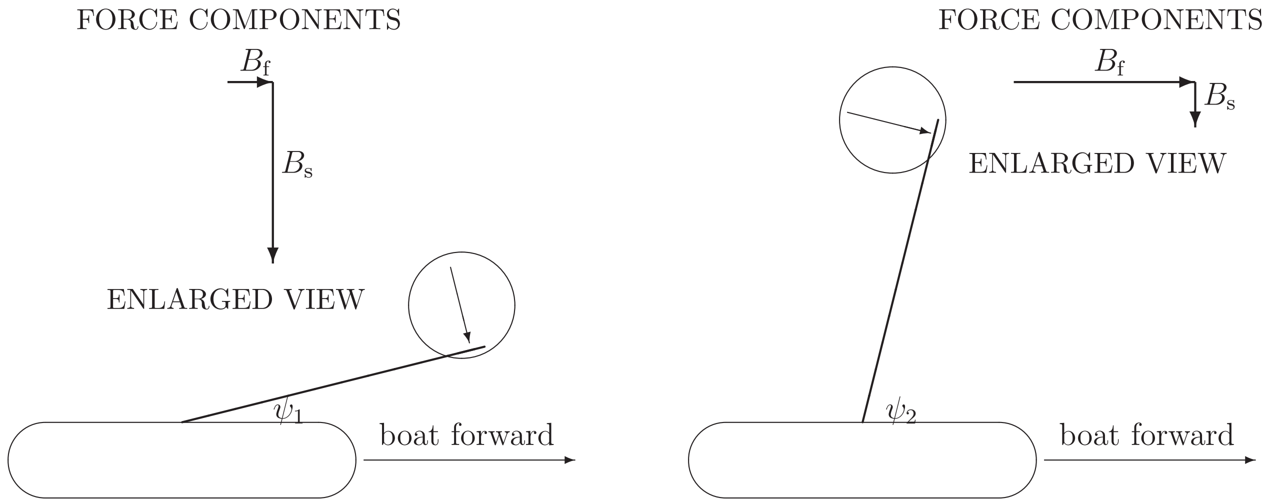

Figure 1: Schematic top views of boat and one oar for two oar angles, ψ_1 and ψ_2 (measured from the forward direction). The components of the water reaction force on the blade are shown (in enlarged views) as B_f (forward force) and B_s (sideways force). The resultant force is approximately perpendicular to the oar shaft.

ignore the slight up and down motion, the only relevant external forces are those acting in the horizontal plane; these are exerted by the water and air through which the system moves. Ignoring the air forces, the efficiency of the oar depends on how much energy is dissipated by the force *of the water* on the oar (an external force).

Affeld *et al.* [1] calculated that the efficiency of the oar was lowest almost immediately after the catch. The efficiency increased as the oar became more square to the boat. Similar results were given in [6], and these are shown in Figure 2. The figure shows the oar efficiency for two different assumptions for the direction of the blade force: (a) perpendicular to the oar shaft axis and (b) with a small deviation from that direction as suggested by experiment. In both cases the oar is relatively inefficient for oar angles less than 55° to the forward direction and least efficient at an angle of about 45°.

Dissipation at the blade

The gate force transfers energy between the oar and the rigger/hull (and does so efficiently), but the energy transferred is not all the mechanical energy put into the oar by the rower; it is only the *remaining* part, after accounting for the energy dissipated at the blade. The power dissipation (rate of energy loss) by the blade can be calculated as the product of the blade force and the component of blade velocity in the direction opposite to the force [7]. It follows that, if the blade force vector happened to be exactly perpendicular to the blade velocity vector, so there were no component of velocity opposite to the force, the dissipation would be zero.[2]

[2]This can only happen if there were no water friction force. The water friction force though small [6], produces some dissipation. Moreover, the blade force is distributed over the blade surface, and the various points on the blade have different velocities relative to the still water. All these force-velocity vectors at every point on the blade surface would have to be mutually perpendicular, to get zero dissipation.

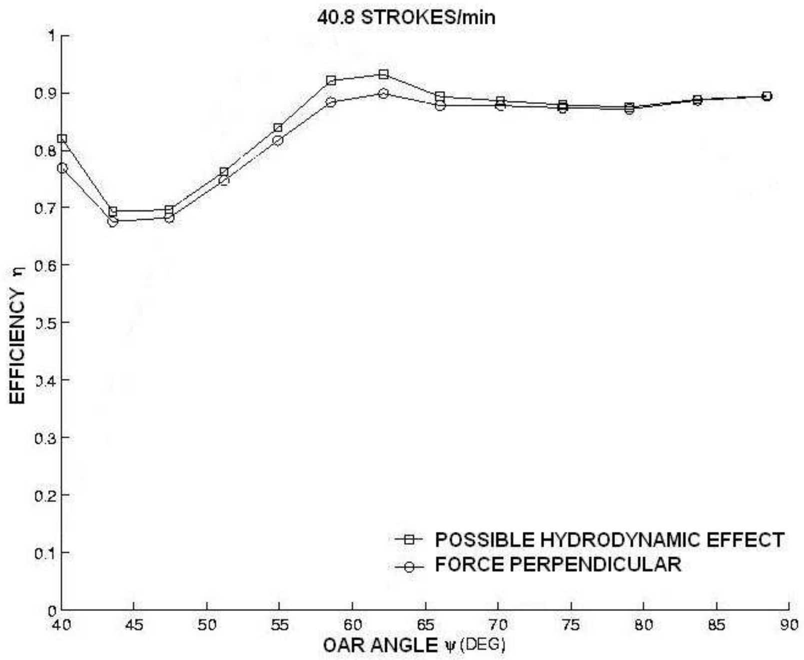

Figure 2: Oar efficiency η at various oar angles ψ, calculated from on-water measured data, with two different assumptions of blade force direction. Force assumed (a) perpendicular to blade-chord (lower curve) or (b) in direction shown by scale-model tests (higher curve: 'possible hydrodynamic effect'). Adapted from [6].

Whether the blade force is in the direction required to reduce the dissipation to zero (or close to it) is a question of fluid mechanical calculation or experiment. The theory (see [5], §10.2) for a thin hydrofoil moving through water predicts that the force is indeed perpendicular to the velocity vector so that the dissipation is zero.[3] Some have suggested[4] that the rowing blade might act 'like a hydrofoil' near the catch and, by implication, thus be highly efficient. However, the available experimental evidence for scale-model rowing blades [2, 3, 6] shows that the water force on the blade is not in the ideal 'hydrofoil-direction' but in a direction almost perpendicular to the oar shaft. Nevertheless, for some oar angles there is a slight shift of the direction of the force towards the hydrofoil-direction, such as to reduce the dissipation.[5] There are many reasons for caution when extrapolating this scale-model data to the full-size oar in real rowing (see [6], appendix A) but even if we did get the same shift in force direction for real rowing, the curve in Figure 2 labelled 'possible hydrodynamic effect' shows that the oar would still be least efficient near the

[3]The theory assumes that the water friction force is very small compared to the water pressure force, but this is not a severe limitation of its applicability. The most important assumption is that the hydrofoil is far removed from the air-water interface, so that the gravity force on the water may be ignored. This condition is violated for the case of the rowing blade. It seems to me that this is the most plausible reason why the resultant force is not in the ideal 'hydrofoil-direction'.

[4]Some examples are quoted in [7].

[5]For one particular motion of the blade relative to the water (known as 'zero angle of attack'), the scale-model measurements show a force very nearly perpendicular to the blade velocity (and of course, the oar shaft). The force however is negligible and this motion of the blade can only exist for a negligible instant at the start of the stroke, if at all [6, 7].

catch.

In conclusion we can say that the blade force dissipates a larger fraction of the rower's applied power in the early parts of the stroke than it does later in the stroke (*i.e.* the efficiency is lowest close to the catch). Part of the dissipation is due to the sideways component of the blade force. Whether there is much the rower can do to improve the efficiency while maintaining a race wining speed is, of course, another question, which is discussed to some extent in Ref. [7].

Acknowledgement

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