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Blade propulsive efficiency and effectiveness

We've already touched on the subject of blade propulsive efficiency before (1, 3, RBN 2007/12) and will discuss further now: what it means, how it can be evaluated and improved.

Fig.1, a

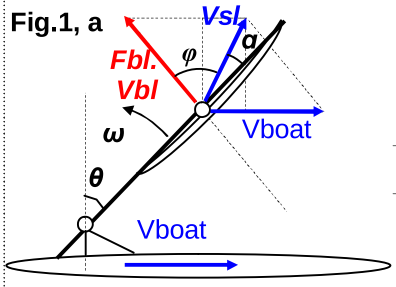
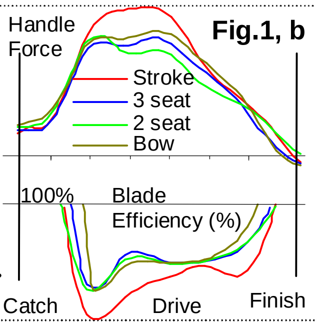


Fig.1, b



Let's remember that the blade efficiency Ebl was derived as a ratio of powers (Fig.1, a):

$$Ebl = (Ptot - Pw) / Ptot \tag{1}$$

Where $Ptot$ is the total power production of the rower, Pw is waste power spent on moving the water at the blade. These instantaneous powers were derived as:

$$Ptot = Fbl\ Vbl \tag{2}$$

Where Fbl is blade force, Vbl is blade velocity relative the boat reference frame, and

$$Pw = Fbl\ Vsl\ \cos\varphi \tag{3}$$

Where Vsl velocity of the blade slippage relative to the water, φ is the angle between vectors of this velocity and blade force Fbl. Angle φ is the reversed angle of attack a (assuming the blade force is perpendicular to its surface), so:

$$\cos\varphi = \cos(90 - a) = \sin a \tag{4}$$

Combining equations 1 - 4 and moving Fbl out of brackets, we get:

$$Ebl = (Vbl - Vsl \sin a)/Vbl = 1 - (Vsl \sin a)/Vbl \tag{5}$$

Then, we use a general equation of the drag force:

$$Fbl = k\, \rho\, A\, Vsl^2 \tag{6}$$

Where ρ is water density, A is the area of the blade, k is the combined drag factor of the blade, which depends on blade shape and angle of attack (the last defines a ratio of the lift and drag factors, see 2). So, the blade slippage Vsl can be defined as:

$$Vsl = (Fbl /(k\, \rho\, A))^{0.5} \tag{7}$$

Substituting Vsl in the equation 5, we get:

$$Ebl = 1 - ((Fbl /(k\, \rho\, A))^{0.5} \sin a) / Vbl = 1 - \sin a /(k\, \rho\, A)^{0.5} * Fbl^{0.5} / Vbl \tag{8}$$

This equation can be useful to answer the question: **What factors affect the blade propulsive efficiency?**

1. The blade efficiency is higher, when the angle of attack is sharper ($\sin a$ is lower). At $a=0$ (the blade velocity is parallel to its axis) the blade is absolutely efficient (***Ebl=100%)***. This effect can be called "an ideal hydro lift", when the vectors of force and velocity at the blade are perpendicular and drag and energy losses are zero.
2. The blade efficiency is higher, when any of the multipliers $k\ \rho\ A$ increase: the blade shape is more efficient (k↑), and/or the water is more dense (ρ↑), and/or the blade area is bigger (A↑).
3. The blade efficiency is higher, when ratio $Fbl^{0.5}/Vbl$ became lower, i.e. the blade force decreases, but blade velocity increases. This usually happens at the end of the drive (Fig.1, b), which explains the rise of the efficiency curve. The efficiency is 100%, when blade force is zero, i.e. the rower does not pull at all, but the blade still moves in the water. When the blade force is negative ($Fbl<0$), the blade efficiency can not be defined with the equation 8. However, from the equation 1, Ebl can be higher than 100%, if Pw is negative. This means that the energy is not spent on the moving the water at the blade, but it is taken from it and added to the total power of a rower, i.e. when the rower takes the run off.

The first two points above could be used to decrease the amount of energy wasted to slippage of the blade, though the water density is given by conditions and chances to improve the angle of attack, blade shape and area are quite limited. The 3rd point is quite controversial:

- The ratio of the blade force and velocity can be changed with gearing: say, at two times longer outboard and the same inboard, the blade force is decreased twice, but its velocity is increased by the same factor. However, the force in equation 8 is in square root, so the ratio $Fbl^{0.5}/Vbl$ decreases, which explains why **the blade efficiency is higher with heavier gearing** (RBN 2011/09).
- At the same blade slip Vsl, its velocity Vbl (relative to the boat) is directly proportional to the boat velocity $Vboat$. This explains why **the blade efficiency appeared to be higher in faster / bigger boats** (3), though the real slippage of the blade could be the same.
- Increasing the blade efficiency by means of decreasing the blade force does not make sense, because it decreases the total and propulsive power – the main objective in rowing. **In a crew, the strongest rower usually has the lowest blade efficiency and vice versa** (Fig.1, b). Therefore, a correlation between average force and blade efficiency within a crew is negative (r = -0.48).

Concluding: In its current definition, **the blade propulsive efficiency can be used for limited evaluation of the equipment qualities and rower's oar handling skills, but only at a constant blade force and velocity.** Another measure should be found for evaluation of combined effectiveness of the blade work.

References

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3. Kleshnev V. (1999) Propulsive efficiency of rowing. In: Proceedings of XVII International Symposium on Biomechanics in Sports, Perth, Australia, p. 224-228.