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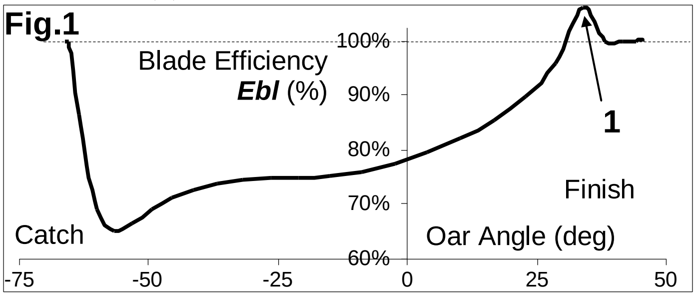
Oar blade as a jet engine

We already discussed the blade propulsive efficiency E_{bl} a number of times (RBN 2006/06, 2007/12, 2012/06), but still not completely satisfied with understanding of this important variable. Previously, E_{bl} was defined as a ratio of the propulsive power ***Pprop*** to the total power produced by a rower ***Prow***:

$$Ebl = Pprop / Prow = (Prow - Pw) / Prow \qquad (1)$$

where ***Pw*** is the waste power, which is lost on moving the water, when the blade "slips" through it. Fig.1 shows typical curve of ***Ebl*** in a single at 32 str/min. It looks like the blade efficiency increases towards the finish of the drive and becomes even higher than 100% (1), which confuses rowers and coaches.



A new idea came after a brief talk to aviation engineer during Ukrainian rowing seminar in Kiev, who asked: "Does the blade work as a jet engine or as a car wheel?" It looks like the first case is the right answer, because it is not possible to move on the water without moving it backwards.

In aviation and rocketry, a **specific impulse *Isp*** is the main way to describe the efficiency of jet engines. It represents the thrust force ***Ftrust*** with respect to the mass of propellant ***m*** used per time unit ***t***:

$$Isp = Ftrust / (g\, m / t) \qquad (1)$$

where ***g*** is gravity acceleration. ***Isp*** depends on velocities of exhaust gases ***Vg*** and the jet vehicle ***V***:

$$Isp = (Vg - V)\, m / t \qquad (2)$$

Efficiency of jet vehicle ***E*** is also related to ***Vg*** :

$$E = 2 / (1 + Vg / V) \qquad (3)$$

Efficiency and specific impulse are reversely related. At the start of runway, the efficiency of a jet plane is zero, because its velocity is zero, but the thrust and specific impulse are maximal. As the plane accelerates, its efficiency increases, and became 100%, if the plane speed is equal to the speed of exhaust gases, but the thrust and specific impulse became zero then. Therefore, design of a jet engine is a balance between its efficiency and thrust.

Similar things happen in rowing: at catch, the velocity of the rower-boat system is the lowest; then, it increases during the drive till the finish. Therefore, the propulsive power increases during the drive, as it is a product of propulsive force and velocity of system CM. Hence, the blade propulsive efficiency increases and became higher 100%, when the system velocity became higher than blade velocity. However, it doesn't mean the blade works better.

Of course, rowing is not exact jet propulsion and rower's energy substrates are not thrown directly backwards to create the thrust. However, jet fuel means energy, the energy per time is power, so, we decided to substitute the fuel flow used in jet engines with mechanical power produced by a rower ***Prow*** and define the specific impulse ***Isp*** of the blade as following:

$$Isp = Ftrust / Prow \qquad (4)$$

The previous definition of blade efficiency ***Ebl*** was dimensionless, but ***Isp*** has a dimension in ***s/m***, i.e reversed velocity, while dimension of ***Isp*** in jet engines is ***s***. To calculate ***Isp***, rowing power ***Prow*** was derived using traditional method (see RBN 2004/06):

$$Prow = Fh\, Vh \qquad (5)$$

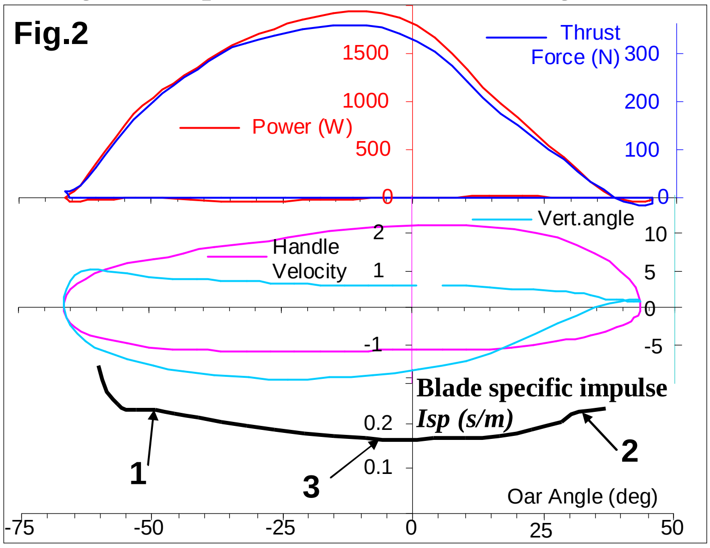
where ***Fh*** and ***Vh*** – handle force and velocity. The blade thrust ***Ftrust*** was derived as:

$$Ftrust = Fh\, (Lin / Lout) \cos(\alpha) \qquad (6)$$

where ***Lin*** and ***Lout*** - actual inboard and outboard (from pin to centre of the blade) and ***α*** - oar angle. Combining equations 2, 3 and 4 we can get:

$$Isp = (Lin / Lout) \cos(\alpha) / Vh \qquad (7)$$

Fig.2 shows power, thrust, handle velocity, vertical oar angle and ***Isp*** for the same data as on Fig.1:



The blade specific impulse ***Isp*** looks quite even during the drive. Its higher value ~0.23 s/m was found at the beginning and the end of the drive (1, 2); the lowest 0.16 s/m - at the perpendicular position of the oar (3). The average ***Isp*** of underwater blade work was 0.19 s/m at this sample. It decreases at higher stroke rates and boat speeds from 0.27 at rate 20 down to 0.17 s/m at 41 str/min.

Conclusions: **The specific impulse can be used together with blade efficiency for evaluation of the blade work. A higher specific impulse is generated at a lighter gearing ratio, but at a lower handle velocity at the same time.** Obviously, this is possible only when the blade has significant resistance in the water, which could be achieved either by **using bigger blade area, or by more effective thrust production using a better shape and/or utilisation of hydro lift effect**, which happens at the beginning and the end of the drive.

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