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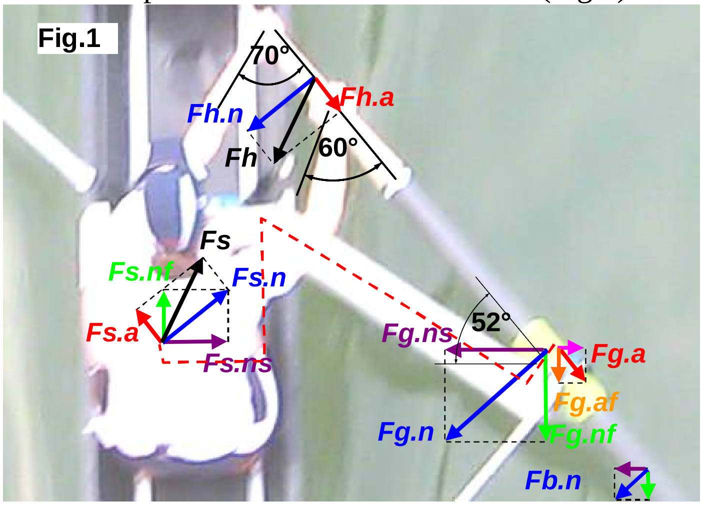
Dynamic analysis in transverse (horizontal) plane

When a rower pulls the handle in a boat, the force is usually applied not exactly at the perpendicular direction to the oar shaft. This is one of the differences between on-water rowing and an erg, where the force is always perpendicular to the axis of the handle. In rowing, at the catch, the angle between the oar and outside forearm is about 70^o, and for inside arm it is 60^o (Fig.1), so the line of the resultant force should be directed at the angle 66-68^o (outside arm pulls higher force). In sculling, the angle between the oar and forearm is sharper: at the catch it is about 60^o (Fig.2).



The resultant handle force ***Fh*** can be broken down into two components: a normal (perpendicular) force ***Fh.n*** and an axial force ***Fh.a***. At the pulling angle A=60^o the normal component ***Fh.n*** should be equal to sin(A)=86.7% of the total force ***Fh***, and the axial component ***Fh.a***=cos(A)=50% of ***Fh***.

When the axial component ***Fh.a*** is transferred through the oar shaft to the gate, it creates the same axial gate force ***Fg.a*** (ignoring a small axial force of hydrodynamic resistance from the blade). On the other side, to create the axial handle force, the rower has to apply a force at the stretcher of the same magnitude, but in opposite direction. As the stretcher is connected to the pin-gate through the rigger, these forces cancel themselves, i.e. they are internal forces and **the axial handle force does not contribute to the propulsion of the rower-boat system**. It does not create any power and energy losses, because there is no movement of the oar relative to the boat in this direction, but **works like a heavier gearing**: the total force is higher (by 13.3% at A=60^o), but slower by the same factor.

The normal handle force ***Fh.n*** is also transferred to the gate, where it is summed up with the normal blade force ***Fb.n***, which is created by reaction of the water. Therefore, the normal gate force ***Fg.n*** is higher than the handle force:

$$Fg.n = Fh.n + Fb.n = Fh.n\ Lout.a\ /\ (Lout.a + Lin.a) \qquad (1)$$

where ***Lin.a*** is actual inboard length, ***Lout.a*** - actual outboard. The normal gate force can be decomposed into forward ***Fg.nf*** and side ***Fg.ns*** components. On other side, the handle force creates an opposite reaction force ***Fs*** applied to the system through the rower's body. Its axial component ***Fs.a*** is balanced at the gate, but the normal component ***Fs.n*** can be broken down into forward ***Fs.nf*** and side ***Fs.ns*** forces. As the forward gate force ***Fg.nf*** is higher than the handle reaction force ***Fs.nf***, the difference between them makes a propulsive force, which is transferred from the blade in this way and accelerates the rower-boat system forward. Only the normal force ***Fh.n*** rotates the oar around the pin and creates velocity in this direction. A product of these force and velocity is the handle power, which is transferred through the leverage of the oar, applied by the blade to the water and spent on the propulsion of the rower-boat system and waste power of the blade "slippage" in the water (RBN 2007/12, 2012/06). Concluding: **Only normal handle force creates the propulsion of the system**.

When the force is measured at the pin in the forward direction only, the output is a combination of the normal-propulsive ***Fg.nf*** plus axial-parasite ***Fg.af*** components, so it is not possible to split them. Therefore, the pin force must be measured in two dimensions and the normal to the oar component must be derived using the oar-gate angle. Measurement at the gate is easier, as it detects the normal component directly (RBN 2010/03).

In sculling, the side components of two handle forces cancel themselves in the rower's body (Fig.2). Therefore, the resultant force has no side components and applied in the direction parallel to the boat. This could be a reason why the forces in sculling are higher than in rowing (RBN 2010/08) and similar boats are faster in sculling.

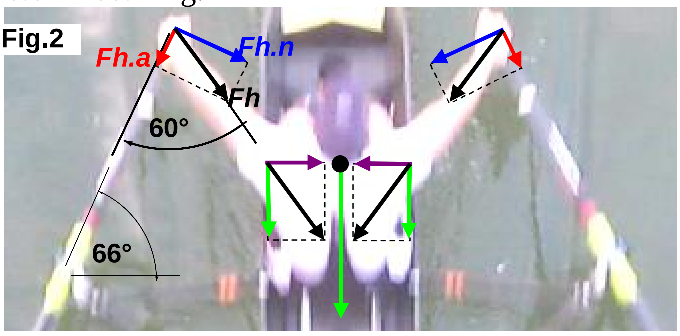
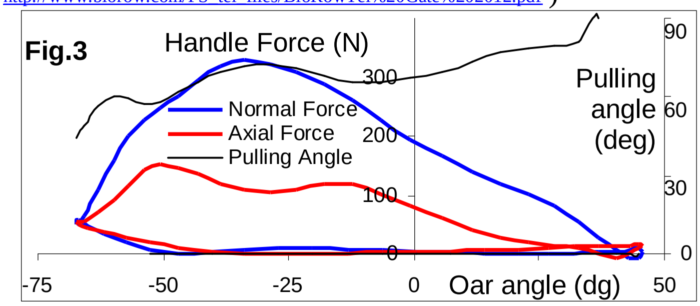


Fig. 3 shows the normal and axial forces in LM1x at 33 str/min measured with 2D instrumented gates (**BioRowTel**, http://www.biorow.com/PS_tel_files/BioRowTel%20Gate%202012.pdf)



The pulling angle (between the resultant force and the oar shaft) derived from the ratio of the forces achieves 90^o only at the very end of the drive.

Concluding: **A rower should maximise the normal handle force applying minimal axial force to keep the oar in the gate.**