Original Research

Marinus van Holst (m.holst@hccnet.nl), mechanical engineer from Nederland sent us his really interesting study on ***Lift and Drag forces on the blade.*** *Marinus presents equations, which link the lift and drag forces with the angle of attack. The modelling can be done much easier now than before, using the experimental data.*

Since Volker Nolte's PhD thesis, *"Wie wird ein Ruderboot angetrieben?"* ("How is a rowing boat propelled?") hydrodynamic lift force has attracted the attention of many people in the rowing community. It seems to have received an almost mythical status for some. From the messages in rowing newsgroups, one gets the impression that lift is good and drag is bad. This is understandable because drag and lift are terms originally used in aero engineering and for an airplane lift means payload (good) and drag means fuel consumption (bad). A great amount of research was carried out to develop an airfoil (a wing cross section) that produces maximum lift and minimal drag. In rowing things are slightly different: It is very good to understand the meaning of lift and drag, but the possibilities for taking advantage of this knowledge (rowing faster) are very limited.

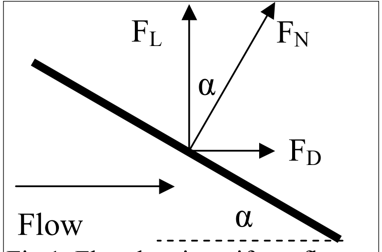


Fig 1. Flat plate in uniform flow

A body moving through a flow experiences a force. In general the direction of the force is not the same as the direction of the flow. Therefore the force can be resolved into a component perpendicular to the flow direction, the lift force, and a component along the flow direction: the drag force. (In the case of an airplane, lift also means "against gravity"; hence its name). The resolution is a geometrical exercise and not a physical one, and its consequence is that the drag component does work and the lift component does not. This has of course a physical meaning: work (actually power) can also be calculated as the scalar ("dot") product of the force vector and the velocity vector. When the body exposed to a flow is a flat plate and considering a two dimensional case as in Fig 1, the force F_N is perpendicular to the plate (because at every elementary area the force is the resultant of the normal pressure on both sides) and the angle α between the F_L and F_N is the same as the angle between the plate and flow direction, the angle of attack α. There is a strict relation between the drag and lift force:

$$F_D / F_L = \tan\alpha$$

Recently Caplan and Gardner (1) did experiments to find the lift and drag forces on a flat plate and on a hatchet blade. The results were expressed in lift and drag coefficients C_L and C_D. The definitions follow from

$$F_L = C_L\, 0.5\, \rho\, v^2 A$$
$$F_D = C_D\, 0.5\, \rho\, v^2 A$$

where ρ is the density of water, v is the flow velocity and A is the blade area. The graphs they found can be approximated very closely by

$$C_D = 2C (\sin\alpha)^2$$
$$C_L = C \sin(2\alpha)$$

where C is a dimensionless constant, which represents a function of the shape of a surface of the blade. This confirms the relation:

$$F_D / F_L = C_D / C_L = \tan\alpha$$

These expressions were not presented in (1). Some small differences between the flat plate and the hatchet blade were found but they are not relevant in this context. Important was: the blade force is perpendicular to the flat plate and perpendicular to the chord of the hatchet blade. No in-plane forces (friction) were measured.

This results lead to an alternative formulation for lift and drag forces and coefficients. The normal force on the blade:

$$F_N = \sqrt{F_D^2 + F_L^2} \text{ and } C_N = \sqrt{C_D^2 + C_L^2}$$

With the expressions above this becomes

$$C_N = 2C\sin\alpha + \sqrt{1+(\cos\alpha})^2$$

The waste power P_W delivered by the blade on the water is a part of the rower's power output that heats up the water instead of propelling the boat:

$$P_W = F_D\, v = F_N\, v \sin\alpha$$

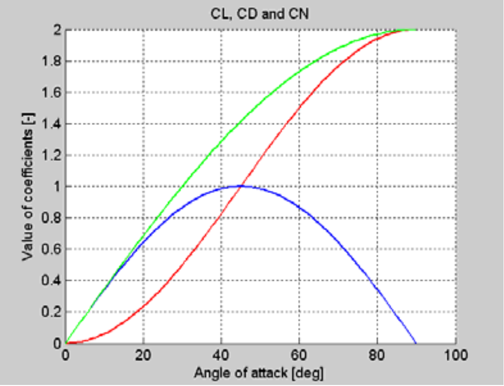


Fig 2 C_D - red; C_L – blue; C_N - green

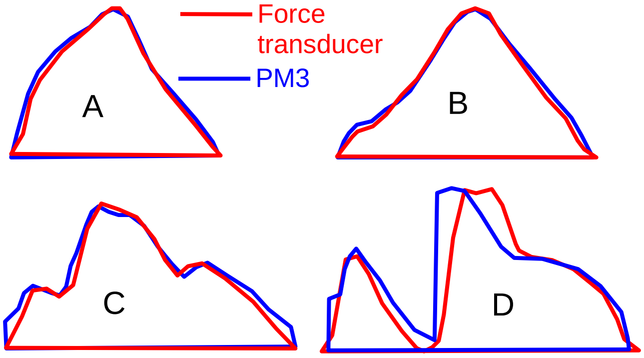
References

1. Nicholas Caplan N., Gardner T.N. 2007. A fluid dynamic investigation of the Big Blade and Macon oar blade designs in rowing propulsion. Journal of Sports Sciences, 25(6): 643-650.

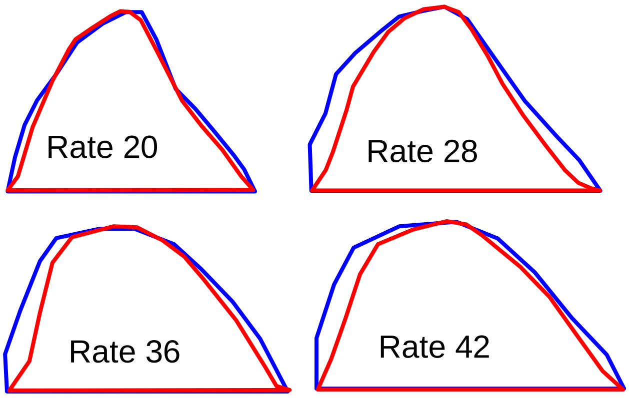
Q&A

We have received a very good feedback after previous publication on the comparison of force curves on PM3 monitor. Here we show the results of additional analysis, stimulated by two comments:

1. Scott Hamilton, an electronic product engineer with Concept2 Inc., advised us to upgrade the firmware of PM3 monitor. The latest version 101 was downloaded from www.Concept2.com site and uploaded into PM3. Scott has made it explicit that PM3 displays force/time curve, so we repeated the experiment with force/time curves on both PM3 and PC displays using the same video method as before (RBN 2008/04). The comparison has shown much better correspondence:



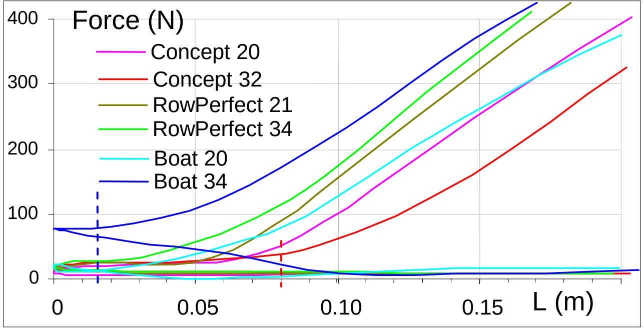
Only the curve D with very rough shape was a bit different, but this sort of curves can never be found in practice. Then we decided to check the correspondence at different stroke rates:



You can see that the correspondence is not so good at higher rates.

2. We had an interesting discussion with Cas Rekers, the inventor of RowPerfect machine about the reason of backlash of the force/length curve at catch. Cas informed us that the clutch itself is very precise and it takes less than ¼ mm of the chain translation to engage it. However, at the catch the driven shaft with flywheel rotates with significant speed, so the driving cogwheel and the chain must accelerate up to that speed before the clutch gets engaged. We both agreed to call the initial phase of the drive "handle acceleration" or "engagement length". During this phase the rotation of the cogwheel is slower than rotation of the driven shaft and the clutch is not engaged, similar to in a boat, the blade not yet being engaged. This means that no energy is added to the flywheel and the measured force is really small.

To compare the moment when the clutch engages with that of engaging the blade during on-water rowing, we used the data from our 2004 experiment (RBN 2005/03, 1), acquired on Concept2 and RowPerfect ergometers as well as on the water in a single scull, all at training (20-21str/min) and racing (32-34str/min) stroke rates:



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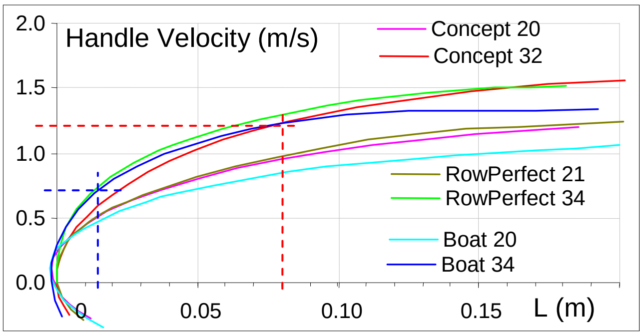

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The charts above show that the force starts increasing sharply, when the handle velocity ranges from 0.7m/s in a single at to 1.2m/s on Concept2 at 32str/min. On-water and on a RowPerfect less than 4cm distance is required to find the support, compared with 7-8cm for Concept2 at 32 str/min.

In general, the pattern of handle acceleration at catch is quite similar on both ergometers and on the water, because it depends more on the acceleration of the masses of the rower and boat/frame, than on the acceleration of the chain/oar only. Shorter engagement length indicates the difference between the systems with moving masses (boat and RowPerfect) and the stationary system (Concept2). On-water rowing at high rates has one distinctive feature, because significant oar inertia creates some force on the handle even before catch, when the handle moves towards the stern.

References

2. Kleshnev V. 2005. Comparison of on-water rowing with its simulation on Concept2 and Rowperfect machines. Scientific proceedings. XXII International Symposium on Biomechanics in Sports, Beijing. 130-133.

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