Power/weight ratio and boat speed

In the previous Newsletter, we have found that at 2km and 5km distances the speed on erg is related to mass as $V \approx m^{2/9}$ and rowing power $P \approx m^{2/3}$. A heavier rower exerts more power, but also displaces more water in the boat, hence creating more drag, which doesn't happen on erg. Hydrodynamic drag contributes 87% of the total drag (2) and the remaining 13% is aerodynamic drag (at no wind). In the first one, 85% is the skin friction drag D_{fr}, which is directly proportional to the boat skin surface and related to water displacement and mass of the system as $D_{fr} \approx m^{2/3}$. If only the friction drag is considered (the shape and wave drag are omitted), then reversed proportions of the power and drag should cancel themselves out, $V \approx m^0$, and rowers of any mass should have no advantage. This was stated by Dudhia (1) for aerobic power. McMahon (3) speculated that if boat dimensions would be proportional to the rower's weight then it should be $V \approx m^{1/18}$, which gives 95kg rower 1.7% advantage over 70kg one. The most recent study of Pelz & Verge (5), used pure allometric scaling approach and non-understandable matrix transformations, derived a proportion $V \approx m^{1/36}$, which is 0.7% advantage for heavyweight.

The other factors affecting the drag are:

1. Boat deadweight. FISA rules prescribe the same minimal boat mass for all categories, so, the ratio of the equipment per rower mass is higher for lightweights. This causes three disproportions (RBN 2009/02), so lightweights have:

a) Relatively higher hydrodynamic drag resistance per kg of body mass caused by greater water displacement. This makes speed by -0.23% slower at 20kg rower's mass difference;

b) Lower energy losses caused by reduced fluctuations of boat velocity with lighter moving crew mass (advantage +0.42% for lightweights);

c) Relatively higher inertial losses because the rowers have to move relatively heavier boat mass back and forth (disadvantage -0.91% for lightweights).

The sum of above three deadweight factors gives disadvantage -0.73% for lightweights. (It is interesting that Dudhia (1) considered only two factors ***a*** and ***b*** above and surprisingly concluded that a lighter boat is not the best one: he found an "optimal" boat weight should be 28% of the rower's weigh, i.e. 21kg boat would be the best for 75kg rower).

2. Only 35% of the aerodynamic resistance depends on a crew size (2), which is also proportional to rowers' body surface $\approx m^{2/3}$ and is cancelled by reverse power proportion. Rowing equipment contributes the rest 65% of aero-drag (oars 50% and boat 15%), and this is very similar for all rower's categories. So, 8.5% (0.13*0.65) of the total resistance does not depend on the crew size and should be overcome by lower power in lightweight rowers, so they would have 2.68% (0.085^3) slower speed. This disadvantage increases at head wind, because the proportion of the aerodynamic resistance increases, but it decreases at tail wind. The sum of four factors above tells that lightweights should be 3.4% slower than similar heavyweight events.

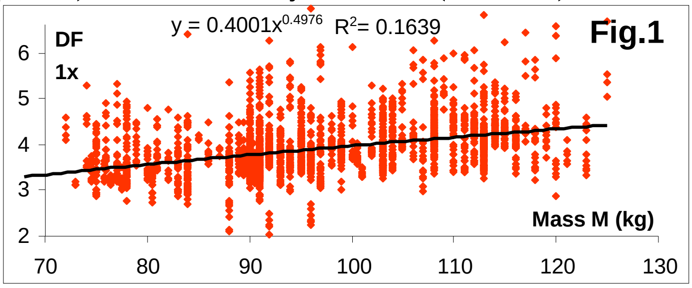
Let's try to compare these theories with the real data. The most of current World best times were set during the latest Worlds-2014 in Amsterdam: the open weight M2x was 1.56% faster than the lightweights, in M4- this difference was 1.54%; in W2x - 2.77%. Comparison of the average speed of the winners of World regattas over the last 21 years produces very similar numbers: 1.45% for M2x, 1.34% for M4- and 2.38% for W2x.

An interesting study was published by Nevill et al. (4), where 49 athletes were tested on erg and on water in single. It was found that the best fitted equation related boat speed ***Vb***, ergometer speed ***Ve*** and rowers mass ***m*** was:

$$Vb \approx Ve\ m^{-0.23} \qquad (1)$$

Assuming $Ve \approx m^{0.22}$ agreed in the previous Newsletter, this gives us $Vb \approx m^{0.01}$, which means only 0.25% disadvantage for lightweights.

In RBN 2007/07 we used linear trends to relate the drag factor ***DF*** with the rower's mass ***m***, then those equations were used in our Rigging Chart (8). Now we will use power trends to derive dependence of ***DF*** on the mass ***M*** of rower plus boat+oars (+18kg). For the singles (n=2296), it was $DF \approx M^{0.50}$ (Fig.1), for 2x/2- (n=1895) and 4-/4x (n=1119) it was very similar $DF \approx M^{0.63}$ (R^2=0.35 and 0.26) and for 8+ (n=728) it was statistically unreliable (R^2=0.006).



As the speed ***V***, power ***P*** and ***DF*** related as $V=(P/DF)^{1/3}$, then for the singles

$$V \approx (M^{0.66} / M^{0.50})^{0.33} \approx M^{0.054} \approx M^{1/18} \qquad (2)$$

This means 1.76% difference in speed between 70kg lightweights and 95kg heavyweights in singles. For two and four rowers' boats $V \approx M^{0.011} \approx M^{1/90}$, which means only 0.28% speed difference. As the first proportion is the closest to observed data of World best rowers and correspond to McMahon's theory, we would accept it as the weight correction factor.

Concluding: **To define on-water performance, the erg speed should be multiplied by the following weight adjustment factor k_w:**

$$k_w = ((M_{st} + m_b) / (m + m_b))^{0.054} \qquad (3)$$

where ***m*** is the athlete mass, M_{st} - some "standard" mass, say, 95kg, m_b boat+oars mass 18kg (Tabl.1).

References

1. *Dudhia A. 2001. Effect of Weight in Rowing.* http://www.atm.ox.ac.uk/rowing/physics/weight.html
2. *Filter K. 2004. The system crew – boat. Lecture.*
3. *McMahon, T.A., 1971. Rowing: a similarity analysis. Science 173, 349.*
4. *Nevill A. et al. 2010. Scaling concept II rowing ergometer performance for differences in body mass to better reflect rowing in water. Scand J Med Sci Sports 2010: 20: 122–127.*
5. *Pelz P., Vergé A. 2014. Validated biomechanical model for efficiency and speed of rowing. J. of Biomechanics 47(2014) 3415–3422.*
6. http://www.concept2.com/indoor-rowers/training/calculators/weight-adjustment-calculator
7. https://www.rowperfect.co.uk/erg-scores-how-to-adjust-for-athlete-weight/
8. *Rowing Speed and Rigging Chart* http://www.biorow.com/RigChart.aspx

Table 1. Weight adjustment factors at various "standard" masses $\mathbf{M_{st}}$ *and rower's weights* $\mathbf{m}$

	m						
M_{st}	60	70	80	90	100	110	120
60	100.0%	99.3%	98.7%	98.2%	97.7%	97.3%	96.9%
70	100.7%	100.0%	99.4%	98.9%	98.4%	97.9%	97.5%
80	101.3%	100.6%	100.0%	99.5%	99.0%	98.5%	98.1%
90	102.1%	101.4%	100.8%	100.3%	99.8%	99.3%	98.9%
100	102.3%	101.6%	101.0%	100.5%	100.0%	99.5%	99.1%
110	102.8%	102.1%	101.5%	100.9%	100.5%	100.0%	99.6%
120	103.2%	102.5%	101.9%	101.4%	100.9%	100.4%	100.0%

Values above 100% mean faster speed / shorter race time, below 100% – slower speed / longer time.
This table can also be used for direct comparison of rowers of different weights. E.g., if 90kg rower is 2.1% faster than a 60kg rower, then their performance is the same.