Q&A

Q: Csaba Győrösi, a rower from Külker Rowing Club in Budapest, Hungary asked: "I have hand-made slides for a Concept 2 ergometer weighing almost 20 kg. Do you think this extra weight will affect my rowing technique?"

A: This question relates to the topic of inertial losses in rowing, when two significant masses of the rower and boat or machine move in relation to one another (1). Ergo rowing is the simplest case; on-water model is similar, but affected by the acceleration of the whole rower-boat system, so it will be discussed later. From a stationary position at the catch or finish, some energy has to be spent to achieve a velocity **V** between the rower's centre of mass (CM) and ergo, which is a sum of rower's $\mathbf{V_{row}}$ and ergo $\mathbf{V_{erg}}$ velocities:

$$\mathbf{V = V_{row} + V_{erg}} \qquad (1)$$

Accelerations of the components and, therefore, velocities $\mathbf{V_{row}}$ and $\mathbf{V_{erg}}$ are reversely proportional to their masses:

$$\mathbf{V_{row} / V_{erg} = M_{erg} / M_{row}} \qquad (2)$$

where $\mathbf{M_{row}}$ is the rower's mass and $\mathbf{M_{erg}}$ is the mass of ergo+slides. This energy is transferred into kinetic energy $\mathbf{E_k}$, which can be expressed as:

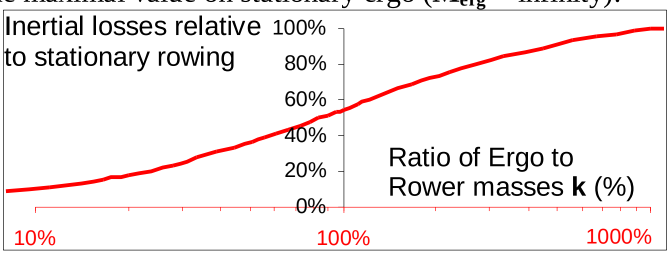
$$\mathbf{E_k = (M_{row} V_{row}^2 + M_{erg} V_{erg}^2) / 2} \qquad (3)$$

A rower could also spend metabolic energy on the deceleration of the masses at the end of the drive and recovery. However, these losses can be minimised using elastic properties of muscles and ligaments and kinetic energy can be transferred into propulsion (RBN 2006/10). Therefore, we do not take decelerations into account and multiply $\mathbf{E_k}$ by two, bearing in mind that the acceleration happens twice during the stroke cycle (during the drive and recovery).

Combining all three equations above, the total inertial losses $\mathbf{P_{in}}$ can be expressed as:

$$\mathbf{P_{in}=(M_{row}(V/(1+1/k)^2)+M_{erg}(V/(1+k))^2)=V^2(M_{erg}M_{row}/(M_{erg}+M_{row}))} \qquad (4)$$

Where **k** is a ratio of masses $\mathbf{M_{erg}/M_{row}}$. The higher mass of the ergo or boat, the higher inertial losses, which have the maximal value on stationary ergo ($\mathbf{M_{erg}}$ = infinity):

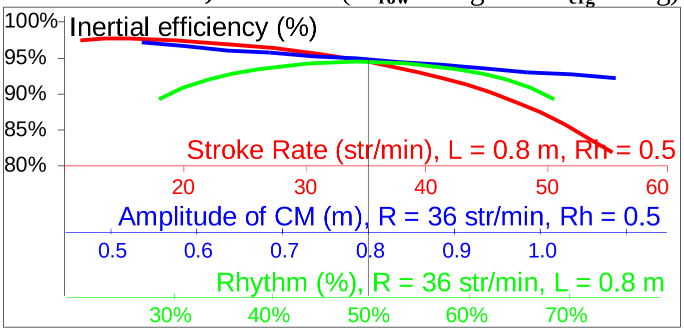


To answer Csaba's question, the extra 16 kg of his slides (compare to 4 kg standard C2 slides, assuming $\mathbf{M_{row}}$=90 kg and the stroke rate 36 str/min) would increase inertial losses by 35% (from 32W up to 43W) and by more than 100% compare to a boat or RowPerfect (21W), which requires earlier application of the stretcher force compared to the handle force (RBN 2005/03). Changing the drag factor wouldn't help in this situation. However, the inertial losses are still only 37% compared to a stationary ergo (116 W).

What can we do to decrease inertial losses? Velocity **V** is the maximal velocity between CM-s and defined by an average velocity $\mathbf{V_{av}}$ and a pattern of instantaneous velocity curve. The most efficient is a rectangular pattern with constant $\mathbf{V=V_{av}}$, but it is not achievable in practice. Triangular pattern with a constant acceleration and deceleration gives $\mathbf{V}=2\mathbf{V_{av}}$ and increases the inertial losses four times. Sinusoidal pattern, which is the most typical in rowing (RBN 2004/07) and was used in our model here, gives $\mathbf{V}=1.65\mathbf{V_{av}}$ and 2.7 times less efficient than the rectangular curve.

Average velocity $\mathbf{V_{av}}$ is defined by the drive and recovery times **(**$\mathbf{T_{dr}}$ and $\mathbf{T_{rec}}$) and amplitude of travel **L** of the rower's CM relative to machine: **V=L/T**. $\mathbf{T_{dr}}$ and $\mathbf{T_{rec}}$ depends on the stroke rate **R** and rhythm **Rh** (= $\mathbf{T_{dr}}$ / $\mathbf{T_{cycle}}$).

Absolute inertial losses $\mathbf{P_{in}}$ significantly increase at higher stroke rates and longer travel of rower's CM. However, the rower's power production $\mathbf{P_{row}}$ also grows (RBN 2004/09), so inertial efficiency $\mathbf{E_{in}}$ (=$\mathbf{P_{row}/(P_{row}+P_{in})}$) do not decrease dramatically. The chart below shows $\mathbf{E_{in}}$ at various combinations of **R, L** and **Rh** ($\mathbf{M_{row}}$=90kg and $\mathbf{M_{erg}}$=18kg):



Between stroke rates **R**=20 and 40 str/min efficiency $\mathbf{E_{in}}$ decreases only from 96.9% down to 93.8%, but then the curve becomes steeper and steeper, so **42-44 str/min could be an inertial limit of the stroke rate**.

The amplitude affects efficiency linearly: two times longer **L** (0.5-1m) decreases $\mathbf{E_{in}}$ from 96.5% down to 93.2%. It is difficult to measure the amplitude of CM travel, so we assumed it as a half of the handle travel. Volker Nolte (2) expressed an opinion that a rower should minimise CM travel to decrease inertial losses and maximise the handle travel to increase power production, which is correct mechanically. However, it is likely that it would lead to lower utilisation of big muscles of legs and trunk in favour of smaller muscles of arms and shoulders and could decrease overall rower's effectiveness.

Efficiency $\mathbf{E_{in}}$ is the highest at the rhythm **Rh** =50% (drive/recovery=1/1). Deviation of rhythm by 10% changes $\mathbf{E_{in}}$ only by 0.7%, but another 10% gives a loss of 3.7%.

Concluding, **the inertial losses can be decreased by means of quick acceleration between the rower's CM and ergo/boat at the beginning of the drive and recovery and maintaining a constant velocity between these masses as long as possible.** This is one more argument in favour of front-loaded drive and fast legs extension at the catch. **An optimal balance of stroke rate, length and rhythm needs to be found to maximise the power and minimise inertial losses.**

References

1. Marinus van Holst. 2009. http://home.hccnet.nl/m.holst/KinEn.html
2. Nolte, V. 1991. Introduction to the biomechanics of rowing. FISA Coach 2 (1): 1-5.

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