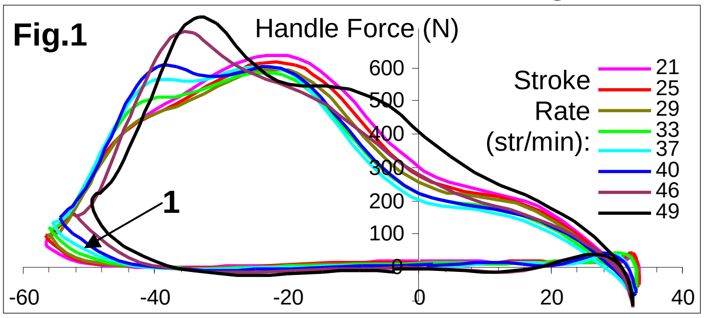
BIOROW BIOMECHANICS OF ROWING **Rowing Biomechanics Newsletter** No 170 2015 May

Oar inertia forces

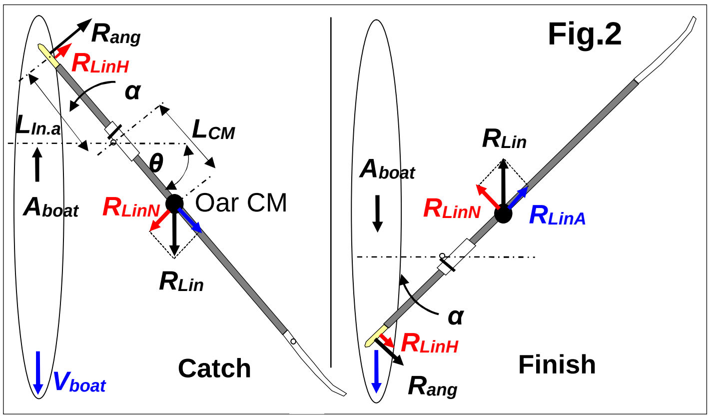
An oar changes direction quite rapidly at the catch and finish, which means it moves with angular acceleration and generates inertia forces. On Fig.1 (the data of LM4- rower), it could be clearly seen that the handle force increases at the end of recovery phase, before the catch (1). The higher the stroke rate, the higher acceleration and inertia forces: at 21 str/min the peak angular acceleration at catch was 8 rad/s^2 and the inertial handle force was 51N, while at rate 49 they were 28 rad/s^2 and 188N – more than three times higher.



Rotational inertia force R_{ang} at the handle could be calculated as a ratio of its torque M and actual inboard lever $L_{in.a}$:

$$R_{ang} = M / L = I\,\alpha / L_{in.a} \qquad (1)$$

Where I is the moment of the oar inertia (3.2kgm for a standard scull and 6.6kgm for a sweep oar) and α is the angular acceleration.



Also, the oar inertia has a linear component: at the catch, the boat moves with a negative acceleration, so the pin pushes the oar backwards, but the oar CM is offset from the pin outwards (Fig.2). This creates a linear inertia force R_{Lin} applied to the CM and directed forward, which could be decomposed into two components: the axial R_{LinA} pulls the oar outwards and is cancelled at the oarlock; the normal component R_{LinN} is pivoted to the handle as R_{LinH}, where it could be derived as:

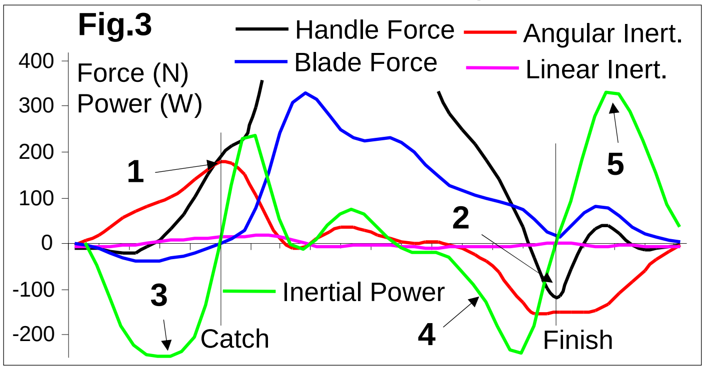
$$R_{LinH} = m\, a_{boat} \cos(\theta)\, (L_{CM}/L_{in.a}) \qquad (2)$$

where m is the oar mass (1.5kg for a common scull, 2.5kg – for a sweep oar), a_{boat} - boat acceleration, θ - oar angle, L_{CM} - distance from the pin to the oars CM (usually, 0.55m for a scull and 0.60m for a sweep oar).

Fig.3 shows measured handle force (in LM4- at 49 str/min) together with inertia forces calculated using equations 1 and 2. The blade force Fbl was derived as the difference between measured force Fh and calculated inertia forces, divided by a gearing ratio:

$$Fbl = (Fh - R_{ang} - R_{LinH}) / (L_{in.a} / L_{out.a}) \qquad (3)$$

where $L_{out.a}$ is actual outboard length.



The measured and calculated variables fit very well together: at catch (1), the measured handle force was 188N, angular inertia was 177N and linear - 13N; i.e., the measured force was only 2N (1%) lower than the sum of inertia forces, which could be explained by aerodynamic drag resistance at the blade helping the oar to change direction at the catch. **The angular inertia contributes 93% of the total force and the other 7% was related the linear inertia.**

In sculling, the sum of inertia forces at two sculls could be even higher: at maximal stroke rate 49 str/min it was found 250N for the angular component (because of higher angular acceleration 34 rad/s^2) and 25N for the linear component.

At finish, the situation is opposite: the inertia forces pull the handle forward, so the rower has to push it backwards to change direction. This creates negative peak of the force curve (2), but this is not the braking force, because the blade is already out of water at this time. The angular acceleration at the finish is slightly lower than at the catch (up to 24 rad/s^2 in both rowing in sculling), so and inertia forces are lower (155N in rowing and 180N in sculling). The boat acceleration is usually close to zero at the finish, so the linear component of oar inertia is very small.

The inertial power (Fig.3) has negative peaks up to -250W before catch and finish, when the inertial force and handle velocity are oppositely directed (power is their product), and positive peaks up to 330W - after catch and finish. The average inertial power over the stroke cycle is zero, but the rower has to spend metabolic energy on it anyway, because muscles do not work as a perfect springs. **The negative inertia power before the catch (3) could stretch muscles of shoulders and arms, which may help to obtain a stronger position and partly return a part of this energy during the drive using the elastic properties of muscles and ligaments**. Before the finish (4), a part of negative inertial power could be spent on propulsion, if the blade is still in the water. After the finish, **it make sense to minimise the energy spent on oar acceleration to the recovery (5): the handle should be pushed away smoothly, without sharp jerks**.