“Moving the Rowers”: biomechanical background

Dr. Valery Kleshnev
Australian Institute of Sport

Introduction

Many rowers, rowing coaches and sport scientists believe that “moving the boat” forward is the main target of rowing. They express this idea directly or through derivatives of this concept such as:

- Rowers should pull the handle harder (earlier, longer) and push the foot-stretcher less. Pushing the foot-stretcher moves the boat backward.
- Pulling the foot-stretcher during the recovery phase is a way of increasing of boat speed. This expressed in more scientific way: The power reaches a second peak during the recovery phase as the rower exerts a propulsive force on the foot-stretcher (3).

From the first glance, the “moving the boat” concept looks like the only possible way of explaining of what is actually happening during the rowing. Really, rowers seat in the boat and travel in it, not vice versa. Boats are aligned at the race start not the rowers and bow-ball of the boat defines the place in the race. So, the idea of concentrating all efforts on moving the boat as fast as possible looks like the only way of achieving good results in rowing.

In fact, this theory is very similar to the ancient Ptolemaic theory of the universe, which explained sunrises and sunsets by the movement of the Sun around the Earth. However, it took a dozen of centuries to found out that the picture is reverse: the Earth goes around the Sun. A couple of centuries after that the exact theory was developed by Newton: the Earth and the Sun go around a common centre of mass, but position of the centre is much closer to the Sun because its mass is much greater than the mass of the Earth.

The similar theory applicable to the rowing: when rowers move on the slides in the boat, they mainly move the boat around themselves. The ratio of the rower’s to boat’s displacement is the inversely proportional to the ratio of their masses (5). For example, if a 90 kg rower moves in a 15 kg boat (masses ratio 6:1) a distance of 0.63 m, then the displacement of the rower’s centre of mass will be only 0.09 m and the boat moves 0.54 m (displacement ratio 1:6).

However, the purpose of this paper is not to discuss theoretical concepts, but rather their practical applications. We will try to answer the following question: How rowers should apply their force to maximise performance?

Firstly, let’s check out in more detail what is happening with rowers’ and boat’s velocities during the stroke cycle

Kinematic analysis

The top chart on the Figure 1 represents oar angles and the bottom chart shows velocities. Stroke cycle timing (X axis) for both charts are relatively aligned X-axis. The red line on the top chart shows horizontal oar angle (divided by 10 for compatibility with vertical angle). We assume that the stroke cycle starts during recovery at the perpendicular position of the oar (zero degrees) relative to the boat axis. Horizontal oar angle defines the following key points of the stroke cycle.

- **cycle start and finish –** zero angle or perpendicular position during recovery,
- **catch angle** - minimal negative angle,
- **release angle** - maximal positive angle,
- **total rowing angle –** difference between catch and release angles.

The blue line on the top chart represents vertical angle of the oar. We assume that its zero value corresponds to the position of the blade centre at the water level. The blade profiles are shown at different points of the stroke for easier understanding. Minus three degrees angle corresponds to the blade position fully covered under the water. This value was taken as the criterion of blade depth. Vertical oar angle defines the following key points of the stroke cycle:

- **vertical catch slip angle** - difference between catch angle and an horizontal angle at the point where vertical angle decreases below -3 deg.,
- **vertical release slip angle** - difference between an horizontal angle at the point where vertical angle increases above -3 deg and release angle,
- **effective angle** – ratio of the rowing angle below –3 deg. to the total rowing angle.

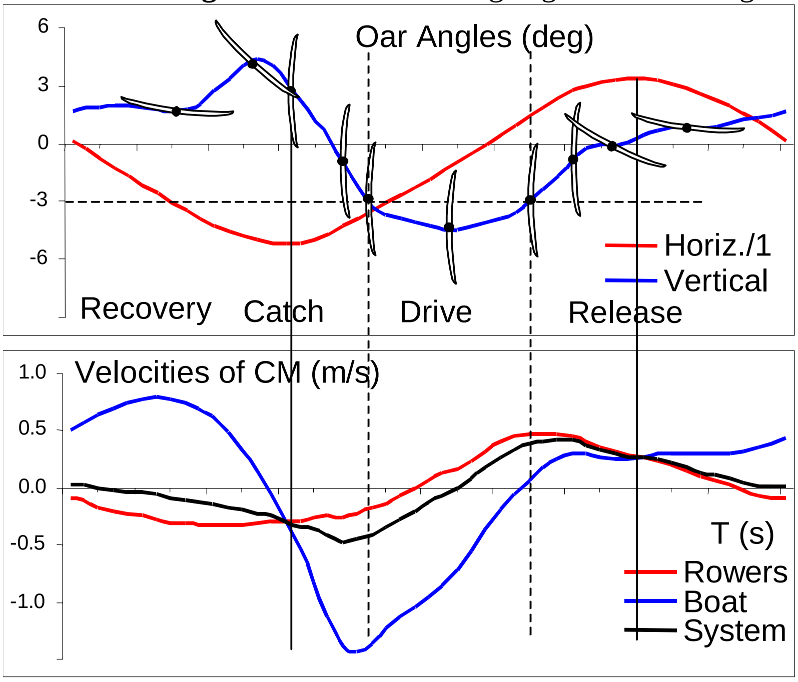

Figure 1. Oar angles and relative velocities (deviations of the instantaneous velocity from the average velocity during stroke cycle) of the boat, mass centres of stroke and bow rowers, and the whole rowers-boat system. Measured data of men's pair, rate 34.5.

All three lines on the bottom graph represent deviations of the instantaneous velocity from the average velocity during the stroke cycle. Zero value means travelling with the velocity equal to the average during stroke cycle, positive values correspond to faster speed and negative values means slower speed. Let us analyse each of the three lines:

- Boat shell velocity (blue line) has the maximal value at the end of recovery and then it drops down very quickly at catch having minimal value at early drive phase. The boat speed is quite far from their maximum at the end of the drive and it accelerates during recovery.
- The velocity of the centre of mass of the rowers-boat system (black line) decreases all the way through recovery and even during the significant sections of the drive at its beginning and end, when the blade is not fully covered. It accelerates only during drive phase when blade is covered enough (centre of the blade a bit below water level) to provide sufficient propulsive force.
- Velocity of the rowers centre of mass (red line) crosses the other two at catch and release, when rowers change the direction of the movement and their speed is equal to the boat speed and, therefore, to the total system speed. During recovery the rowers' speed is slower than the boat and whole system speeds and it is faster during the drive phase.

Fluctuations of the velocities confirm our above considerations about displacements. The ranges of velocity fluctuations were: 2.1 m/s for boat, 0.7-0.9 m/s for rowers, and 0.6 m/s for whole system.

Kinetic analysis

Now, lets try to find out how we can increase rowers' performance, i.e. average speed of the rowers-boat system. Rowers cannot do much with the system speed during recovery phase, because its deceleration is effected by such environmental factors as water and air resistance. We assume these factors as constants, because their mechanics lies outside the scope of this paper, in the area of rowing equipment development. We only can suggest here: do not rush at the recovery beginning; this increases boat speed fluctuations and drag (3).

The only time when rowers can increase the system speed is during the drive phase (more precisely, only that part of the drive when more than half of the blade is covered by water). The more acceleration of the system during this period, the higher average speed and performance. From another point of view, the system accumulates kinetic energy during the supported drive phase and loses it during the unsupported recovery phase.

Let's consider kinetic energy of the rowers-boat system (Figure 2), which is defined using simple equation:

$$\boldsymbol{E = m\, v^2 / 2} \qquad \textbf{(1)}$$

, where $\boldsymbol{m}$ is a active mass of the body and $\boldsymbol{v}$ is velocity of its centre of mass.

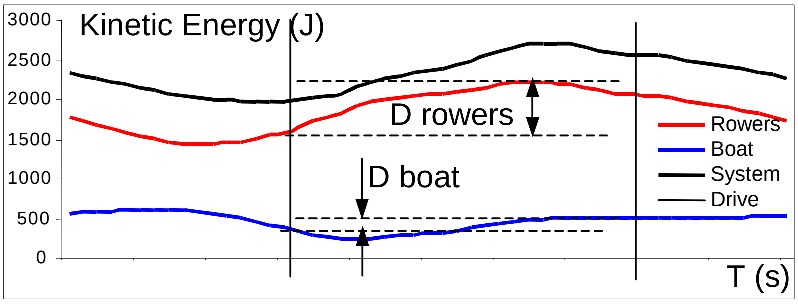

Figure 2. Kinetic energy of the boat, rowers' centre of masses, and the whole rowers-boat system. Measured data of men's pair, stroke rate 34.5.

The average kinetic energy of the rowers is much higher than the boat energy, which once again confirms our considerations about displacements and velocities. The kinetic energy of the rowers is the major component of the whole system energy (2).

The gain of the energy during the drive phase is much higher for rowers than for the boat. In practice, the rowers' mass accumulates 82-90% of the system kinetic energy during the drive phase and the boat acquires only 10-18%. During recovery the boat shell receives nearly the same amount of energy from the rowers as during the drive phase, but this exchange of energy between boat and rowers does not affect deceleration at the whole system.

All of the above considerations allow us to consider the acceleration of the rowers' mass as the most important factor of increasing of the average speed. The main slogan of rowing can be transformed in the following way:

"Moving the rowers"

Let's try to think about how can we move the rowers in the most efficient way. To do so, let's examine the mechanics of rower-boat-oar system using both concepts.

From the "Moving the boat" point of view, force *Fboat* must be applied to the shell to propel it (Figure 3). This force called "Net propulsive force" is equal to the difference between the gate propulsive force *Fgate* and foot-stretcher force *Ffoot*:

$$Fboat = Fgate - Ffoot. \qquad (2)$$

The main target of the "Moving the rowers" concept is developing the *Frower* force, which is applied to the rower's centre of mass. This force is equal to the difference between foot-stretcher reaction force *Fr.foot.*, which pushes the athlete forward, and handle reaction force *Fr.handle*, which pulls the athlete backward:

$$Frower = Fr.foot. - Fr.handle \qquad (3)$$

Both these reaction forces have the same magnitude and opposite direction relative to the action forces: *Ffoot.* and *Fhandle.*

Notice, that different concepts produce different recommendations on the emphasis of the force application. "Moving the boat" concept requires rowers to produce a higher gate force (and a correspondingly higher handle force) and to push the foot-stretcher less. “Moving the rower” concept needs to maximise foot-stretcher push and minimise handle pull.

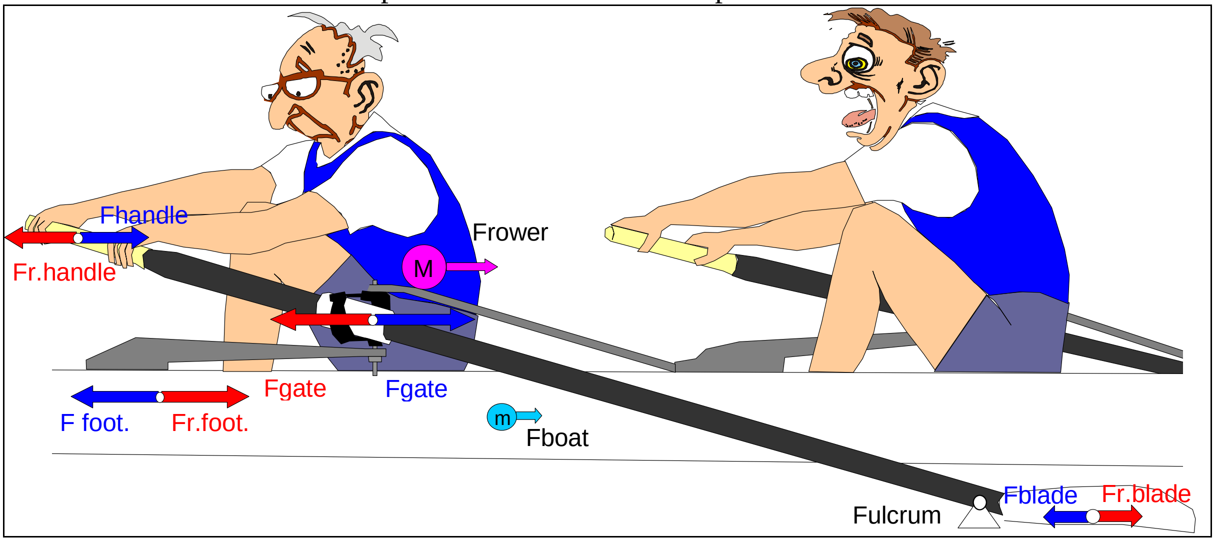

Figure 3. The main forces of the rower-boat-oar system.

In fact, there is nothing controversial in both concepts if rowers are considered at a constant velocity within the boat, i.e. with the same acceleration of all parts of the system. This acceleration can be defined as a function of applied force and the system mass *Msys*:

$$a = Fblade / Msys = Fhandle * (Lin. / Lout) / Msys \qquad (4)$$

, where *Lin.* is the oar inboard lever length measured between points of handle and gate forces application, and *Lout.* is the outboard oar lever length measured between points of gate and blade forces application. Rowers’ and boat forces are functions of applied handle force, leverage and share of active mass of the components in the total system mass:

$$Fboat = Fgate – Ffoot = Mboat * a = Fhandle * (Lin. / Lout)* (Mboat / Msys) \qquad (5)$$

$$Frower = Ffoot. – Fhandle = Mrower * a. = Fhandle * (Lin. / Lout)* (Mrower / Msys) \qquad (6)$$

In this case, it does not matter, which concept we are using. Everything is very simple: if rowers apply a bigger force and leverage is easier then the acceleration of the system and its components will be faster.

However, the situation when rowers move with a constant speed within the boat occurred quite rare: only occurring for a few moments in the middle of the drive. Rowers have to change the direction of their movement at the beginning and the end of the drive; they also change speed of the movement during the drive and recovery phases, plus crewmembers could have different speeds and accelerations of movements. For these circumstances the choice of the right rowing theory could be critical.

Let us compare accelerations of the boat, each rower in the pair and the whole system for two examples of rowing technique of different levels: Figure 4 represents data of the World Champions in this boat type and Figure 5 shows data of a finalist in the National Championship.

At catch, acceleration of the rowers is higher than boat acceleration and they use the kinetic energy of the boat shell to stop their recovery movement and accelerate their body mass before placement blade into the water. Notice, that the peak boat deceleration of the best rowers is much deeper at the same stroke rate (-10.1 and –6.9 m/s^2, correspondingly), but its time period is much shorter (0.48 and 0.59 s). This means better rowers accelerate their body mass more effectively at catch. Another difference is in the uniformity of the rowers’ CM motions: the champions do it together, but bow rowers in another crew push the foot-stretcher much earlier and harder preventing his partner from catching the water properly.

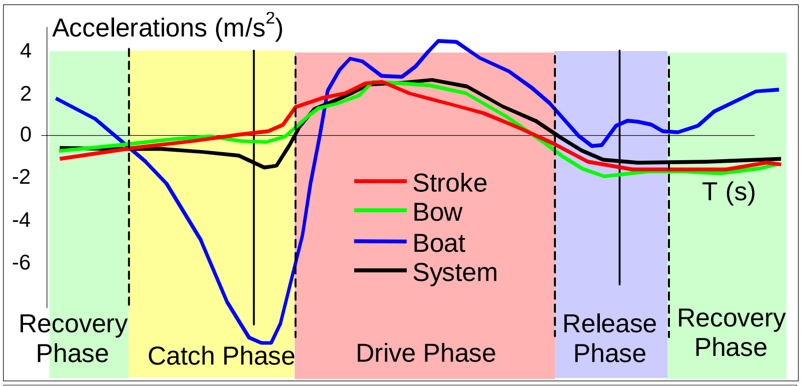

Figure 4. Boat, rowers CM and the system CM accelerations of World Champions (M2-, stroke rate 34.9).

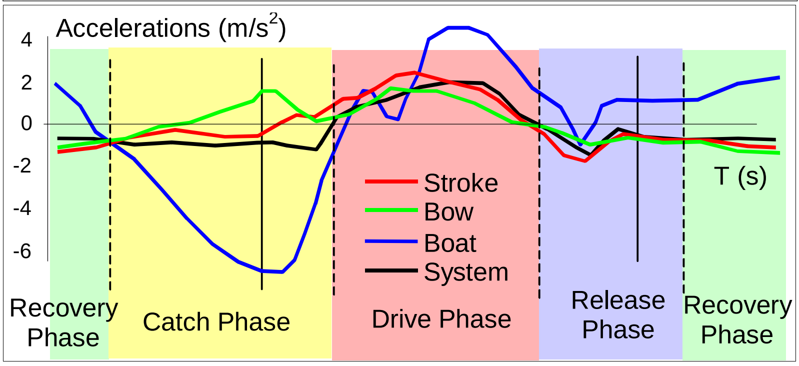

Figure 5. Boat, rowers CM and the system CM accelerations of national level rowers (M2-, stroke rate 35.0).

After placement of blade into the water the champions accelerate their body masses very quickly together with the boat that leads to a fast acceleration of the whole system, which became positive 0.11s after the catch moment. Another crew accelerates themselves and the boat much slower causing a slower acceleration of the system (0.18s after catch).

Symptomatically, the lower level rowers have a higher maximal positive acceleration of the boat shell (5.05 m/s^2) compared to the World Champions (4.60 m/s^2). This also means that they apply more “net propulsive force” to the boat shell. In the same time better rowers accelerate their body masses more, which significantly increases the speed of the whole rowers-boat system.

Conclusion

Advocating our “Moving the rowers” concept we do not pretend to invent anything new. We are just trying to apply scientific base to what the best rowers and coaches knew for ages. More than 70 years ago great rowing coach Steve Fairbairn said: “Find out how to use your weight and you will have solved the problem of how to move the boat” (1). We put the same idea in another wording:

“Move you body mass and accelerate it as much as possible during drive phase by means of a hard and long push against the foot-stretcher. Just do not forget to cover your blade during this push.”

References

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