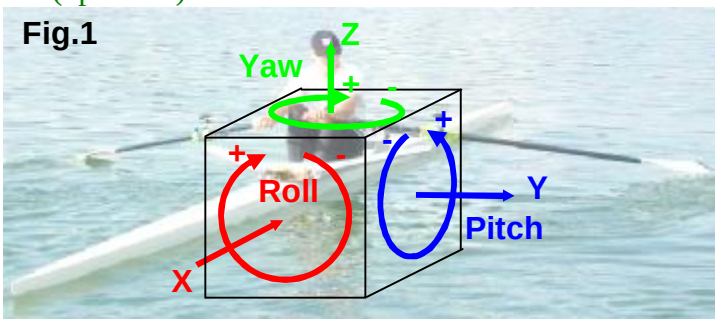
Rotational motions of the boat

There are three main axes in any vessel, called longitudinal X, lateral or transverse Y and vertical Z axes (Fig.1). The rotational movements around them are known as roll, pitch and yaw:

- Roll is when the boat rotates about the longitudinal X (front/back) axis.
- Pitch is when the boat rotates about the lateral or transverse Y (side-to-side) axis.
- Yaw is when the boat rotates about the vertical Z (up-down) axis.

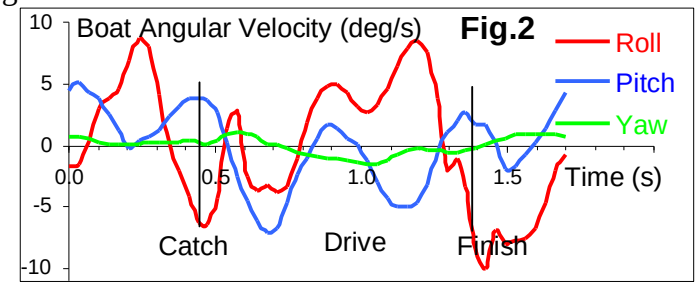
Fig.1



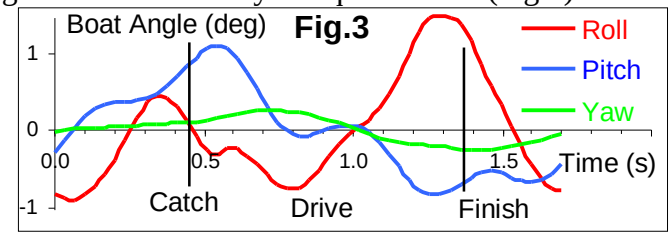
BioRowTel measurement system (1) is equipped with 3D gyroscope, which allows measurement of angular velocities of the boat rotation around all three axes. The agreement on the directions was made:

- Positive Roll is the port board up.
- Positive Pitch is the bow up, stern down.
- Positive yaw is the bow turning to starboard.

Fig. 2 shows angular velocities of the hull in a single sculler at a stroke rate of 35 str/min:



Angular velocities are difficult to interpret and make meaningful for a coach and rower. They were integrated into angles of roll, pitch and yaw, and then offsets were added to each of them to make the average over the stroke cycle equal to zero (Fig.3).



Though these angles are not strictly connected to the reference frame of the Earth/water, they are useful for evaluation of relative rotational motions of the boat and could be interpreted in the following way:

Roll is quite close to zero at the catch, when the boat is balanced. Then it became negative near to -1° (the right gate - port side goes down), which is the consequence of separation of the oar handles during the drive (RBN 2011/07). At the finish, the boat rolls on other side by more than +1° (left gate down), because the sculler pulls the handles at even height, but the gates height is different. During the recovery the boat roll repeats this cycle.

The boat pitch has its highest positive value +1 ° (stern goes down) soon after the catch, which is related to transfer of the rower's weight from seat to the stretcher (RBN 2011/03). At the middle of the drive the pitch remains close to zero (the boat is balanced). At the finish the pitch became negative close to -1 ° (bow goes down), which is explained by increased seat force and upwards force at the stretcher due to return of the trunk (RBN 2006/10).

The boat yaw is close to zero at the end of recovery and became positive at about +0.3° after catch, which is explained by asymmetry of the force application in this sculler: his right arm is pulling stronger to separate handles at the middle of the drive (RBN 2011/07). Then, the boat yaws on other side because left arm is catching up, and the minimal yaw value about -0.3 ° was achieved at the finish. During recovery, the yaw decreases to zero, which could be explained by the stabilising action of the fin.

The following table shows statistics of our measurements of amplitude (differences between maximal and minimal angles) of the roll, pitch and yaw:

Boat Type	n	Roll (deg)	±SD	Pitch (deg)	±SD	Yaw (deg)	±SD
1x	492	2.70	1.45	1.39	0.27	0.65	0.26
2-	185	1.42	0.81	1.29	0.16	0.58	0.16
2x	317	1.42	1.03	1.24	0.16	0.42	0.21
4-	137	0.53	0.64	1.01	0.15	0.45	0.15
4x	60	0.54	0.60	0.88	0.08	0.11	0.03
8+	35	0.14	0.08	0.81	0.43	0.05	0.01

The roll amplitude is the highest in singles and significantly decreases in bigger boats, nearly down to zero in eights, which is the most stable boat. Interestingly, there is no significant difference in roll between sweep and sculling boats.

Surprisingly, the difference in the pitch amplitude in various boats was relatively small: in the eights the pitch is only 40% less than in singles. The pitch amplitude significantly increases with the stroke rate (r = 0.86), which is explained by higher inertia forces.

The yaw amplitude is also reversely proportional to the boat size, decreasing nearly down to zero in eights. It pairs it slightly higher than in doubles and in fours - significantly higher that in quads, which is explained by the rigging asymmetry (RBN 2008/01, 2009/11).

All rotational motions of the boat should be minimised: pitch and yaw could increase drag resistance; roll may decrease power production and lead to injuries.

References

1. BioRowTel Rowing telemetry system, http://www.biorow.com/PS_tel.htm