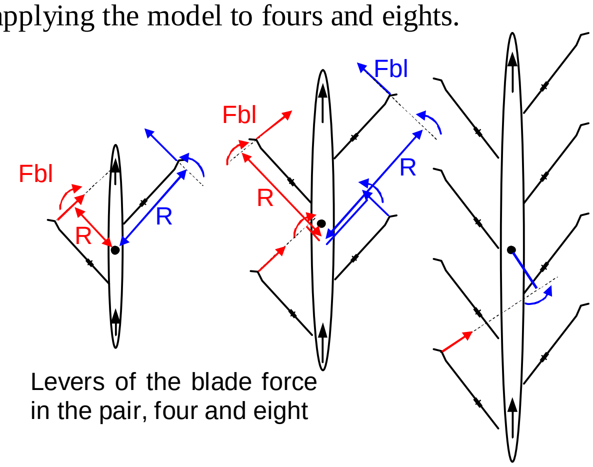
Recently, a paper on the **positioning of rowers** was published by John Barrow of Cambridge University (1) and received quite wide response in media. John wrote: *"We consider the optimal positioning of crew members in a (sweep) boat in order to avoid a sideways wiggle. We show that the traditional (alternate port and starboard) rig always possesses an oscillating non-zero transverse moment and associated wiggling motion. … We find the one zero-moment rig for a Four and show there are four possible such rigs for an Eight, of which only two (the so called 'Italian' and 'German' rigs) appear to be already known…."*

We already discussed the boat wiggle in a pair (RBN 2002/04, 2008/01-2) and found that the model proposed by Einar Gjessing (where the moment of the blade force is considered) is the most appropriate method to analyse this problem. Now we will look at applying the model to fours and eights.



Levers of the blade force in the pair, four and eight

Levers of the blade forces were calculated for the most common range of oar angles in sweep rowing from -55 deg at the catch to 35 deg at the finish. As it was expected, in the four with the normal rig the sum of the levers was found non-zero and equal to 0.47m (Fig. 1), which turns the bow to the port side. In the Italian rig the sum was zero, so the boat goes straight at the equal application of force. Similarly, in the eight with normal rig the sum of the levers was found 0.93m. In the eights with the Italian, German and other two rigs proposed by Barrow the sum was zero.

It is interesting that the stroke in the eight with any rig has a negative lever from the catch to the oar angle -40 deg. This means **<u>the stroke rower turns the eight during the catch to the same side.</u>** This happens because the line of the blade force passes the centre of the boat from the stern side and the blade reaction force pushes the stern in the opposite direction.

What sort of boat wiggle can be created by the above non-zero levers? The blade force ***Fbl*** was modelled as a typical front-loaded curve with maximum magnitude 350N (800N at the handle). Rotating torque ***T*** was calculated for each rower as:

$$T = Fbl * R \quad (1)$$

This torque creates angular acceleration ***a***

$$a = T / I \quad (2)$$

where ***I*** is the mass moment of inertia of the boat with rowers, which was defined as a sum of the mass-moments of the boat and rowers, which were modelled as a product of rower's mass 90kg by square of the distance between their CM from the centre of the boat (Table 1). The angular acceleration ***a*** was integrated twice and it was found that **<u>each stroke with synchronous force application creates the boat yaw angle of 0.37 deg in a pair, 0.076 deg in the normally rigged four and 0.015 deg in the eight</u>**. This yaw must be compensated by a side force applied by the fin and rudder, which creates the wiggle of the boat. In bigger boats the wiggle is smaller, which is explained by the square increase of the mass moment of inertia.

How can rowers compensate for the wiggle? In RBN 2008/01 we found that a pair goes straight if the stroke rower applies 5% higher average force. For simplicity, we modelled the same difference between stroke and bow sides in all seats and surprisingly found that this difference should be similar in big boats. Fig. 1c shows the model of force curves, which keeps straight the normally rigged four. Stroke-side rowers (closer to the stern, doesn't matter which side) in both the four and the eight should apply force earlier, so the average value should be 5% higher. **<u>It is preferable to put the stronger stroke-side rowers closer to the bow</u>**, because these seats have the longest levers: 5% higher force (at the same curve) of 2 seat of the eight makes the wiggle 10% smaller, 4 seat – 7.5%, 6 seat – 5% and the stroke seat can make it only 2.5% smaller.

Alternation of the oar length, inboard and span could have very small effect on the wiggle. E.g. in the normally rigged four the stroke side must have 55 cm longer oars and proportionally 18cm longer inboard and span to compensate the wiggle at the same forces.

Concluding, **<u>Italian, German and two other zero-moment rigs are the optimal solution if you have rowers of similar strength. Boats with the normal rig can be kept straight if stronger rowers are placed on the stroke side closer to the bow.</u>**

References

1. Barrow J.D. 2009. Rowing and the Same-Sum Problem Have Their Moments. DAMTP, Centre for Mathematical Sciences, Cambridge University. http://arxiv.org/abs/0911.3551

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Appendices

Table 1. Mass moments of inertia in various boat types (kg m^2)

	Boat	Rowers	Total
Pair	15	88	103
Four	243	882	1125
Eight	3360	7400	10760

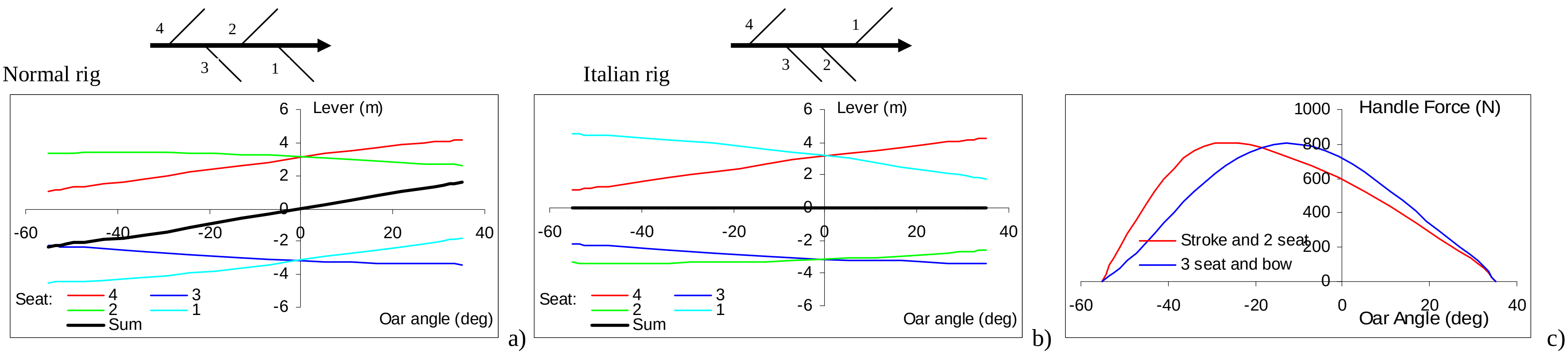

Fig. 1. Levers of the blade force in the normal (a) and Italian (b) fours (positive lever turns the boat towards the bow side, clock wise on the pictures and vise versa). Model of the forces, which creates even moments in the normal four (c).

Table 2. Average levers in fours (m)

Seat	Stroke	3	2	Bow	Sum
Normal rig	2.66	-2.90	3.13	-3.36	-0.47
Italian rig	2.66	-2.90	-3.13	3.36	0.00

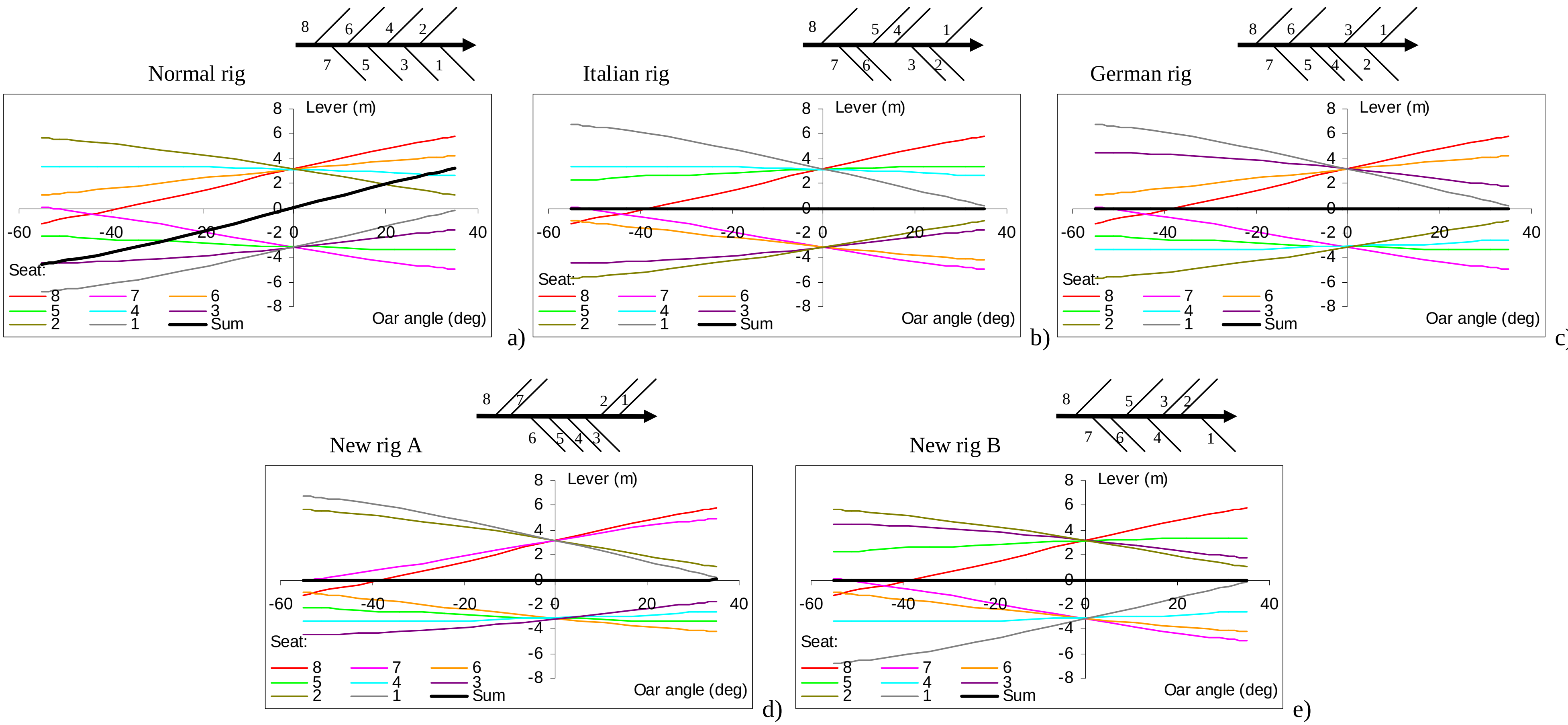

Fig. 2. Levers of the blade force in eights with the normal (a), Italian (b), German (c) and two new (d, e) riggs

Table 3. Average levers in eights (m)

Seat	8	7	6	5	4	3	2	1	Sum
Normal rig	2.20	-2.43	2.66	-2.90	3.13	-3.36	3.60	-3.83	-0.93
Italian rig	2.20	-2.43	-2.66	2.90	3.13	-3.36	-3.60	3.83	0.00
German rig	2.20	-2.43	2.66	-2.90	-3.13	3.36	-3.60	3.83	0.00
New rig A	2.20	2.43	-2.66	-2.90	-3.13	-3.36	3.60	3.83	0.00
New rig B	2.20	-2.43	-2.66	2.90	-3.13	3.36	3.60	-3.83	0.00