News and Comments

The British Coaching Conference 2007 was held on the 27-28th January near Reading. Two presentations by rowing Guru Thor Nielsen were interesting as per usual. The next talk, "Physics of rowing", was one on which we cannot fail to comment. The presenter had developed quite an interesting computer model of rowing and some gadgets. However, instead of explaining the model, he presented a mixture of trivial things (bigger blade produces less slippage in water, a heavier gearing perceived as a heavier load) and undocumented conclusions on gearing, optimal stroke rate and boat speed variation. No description of methods or supporting evidence was presented. This and an absence of any references categorises the presentation as an example from upper-left quadrant in our scientists' classification (RBN 2006/1).

This case forced me to make a more general comment on mechanical modelling in rowing. This area originated from Alexander's 1925 paper followed by important works of McMahon, Pope, Zatsiorsky, Lazauskas, Atkinson, van Holst and others (see Attachment). It is getting more and more popular during the last years. The results of mechanical modelling can have valuable applications and improve equipment design (first of foremost) and rowing technique. However, pure mechanical models do not take into account the human factor, which has the biggest "share" in sporting performance. **Sport in general and rowing in particular is competition between human beings, not mechanical objects.** If we were to follow the conclusions of pure mechanical modelling we may improve performance by seconds, but we may lose minutes owing to a reduction of muscular power and efficiency. Examples of such controversy between Mechanics and Biomechanics are endless and here we give you just two of them:

- Variation of the boat speed was the corner stone of many simplistic mechanical models. It was claimed to be the main reason of energy losses in rowing. Even special boats for asynchronous rowing were designed and built in the 1970s for reduction of the boat speed variation. A World Championship was won in such a boat, but the crew rowed synchronously, which obviously disapproved the "theory". However, it appears to be very persistent and still heard quite often from coaches and "scientists". The main verbal expression of this erroneous theory is: "do not disturb (stop) the run of the boat at catch". The consequences of this are a soft ineffective catch, and early opening the trunk and slow force increase, which we found is very important for effective drive (RBN 2004/01-2). We calculated (RBN 2003/12) that rowers lose about 6% of power or 2% of boat speed due to its variation during the stroke cycle. This parameter can hardly be changed with rowing technique. We may save only a fraction of a second using optimal recovery speed, which was well described by Sanderson & Martindale (10). The main influence on the variation of boat speed is the movement of heavy rowers in a light boat. If we want to reduce this factor, we need to use boats like that shown below, but it is very unlikely that they'll be faster.

- Another example of controversy between Mechanics and Biomechanics is the shape of the force curve. Bill Atkinson (2) found using mechanical modelling that an application of the peak force at the end of the drive would improve performance by 4.5s compare to a front-loaded drive. However, the former style would require much higher peak power, which must be produced by weaker muscles of the arms and trunk (RBN 2006/6). Smaller muscles have lower efficiency and simply may not cope with the load. In addition, there are other variables, which are not included in the model: temporal structure of the drive (RBN 2004/01-2) and trampolining effect of flexing oars (RBN 2006/02). It is interesting that in Atkinson's model the blade propulsive efficiency is higher in a front-loaded drive, which confirms our theory.

Concluding, mechanical modelling can be used in rowing, but it has quite significant limitations: 1) models can be useless if they are too simplistic and do not take into account all significant variables; 2) a number of variables and coefficients are very difficult to quantify, which significantly reduces accuracy of the model; 3) the human factor must be involved in a model, which is not an easy thing to do and requires an individualised approach.

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Some References on Mechanical Modelling in Rowing

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Feedback & comments

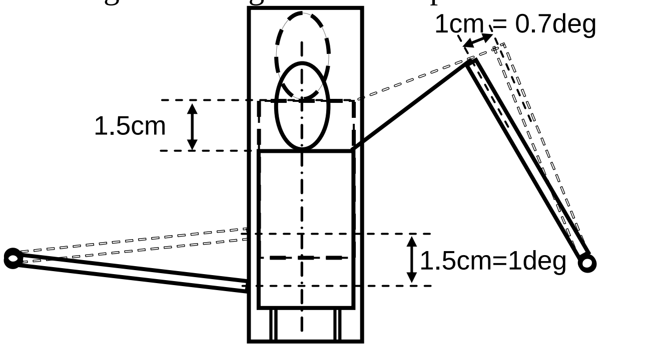
✓ In RBN 68(7, 2006/11) we discussed the influence of the span/spread on gearing. Since than we received a number of comments from coaches like this: "I agree with your points. I've never understand why span/spread influence gearing".

We tried to find origins of the span-gearing idea. Many thanks to Bruce Grainger, who pointed to Karl Adam and kindly supplied citations from his books (1, 2), which have been summarised for us by Volker Nolte with commentary as follows: "Adam's …theory is based on the idea … that the rower's force initiates on the foot-stretcher and he saw this force longitudinal to and in the middle of the boat. This would mean that the moment arm of this force always was the span (D for Dollenabstand). The blade force was perpendicular to the blade, so its moment arm was the outboard (A – Aussenhebel). Therefore, Adam defined his gearing as D/A. Since the outboard is normally about three times larger than the span, Adam concluded that 1 cm change in span is equal to 3 cm change of outboard." Volker continues, "This conclusion never sat well with me, since practical experience showed that changing the outboard had more of an effect than the span. So, I got in quite heated discussions with Adam about this. The problem is that his basic assumption of the position and direction of the handle force was incorrect."

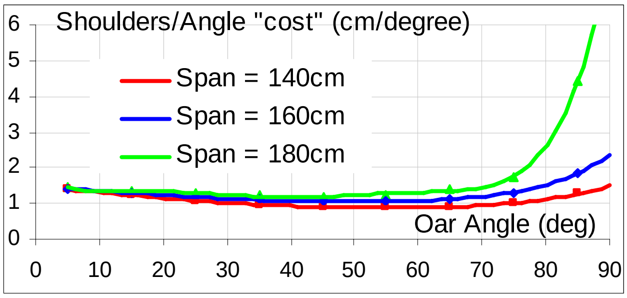
We completely agree with Volker's point. The stretcher force is transferred through the riggers to the pin and the only difference between them is the relatively small force of the hull inertia. In fact, the same forces are applied by the rower to the stretcher and pin, so there is no lever between them from the rower's point of view. Lateral movement of the pin does not change the gearing itself.

✓ We received another interesting comment from Einar Gjessing of Norway, creator of the famous "Ergorow" machine, which he patented in 1973. Einar has written: "The most important, but a missing parameter could be the influence of the ratio between handle and shoulder speed at the beginning of the stroke. If the rower's arms at the catch are held perpendicular to the shell, then 12mm of the shoulders move correspond to only 4mm the handle (Ratio 3/1). In the middle of the stroke the ratio has decreased to 1/1. High ratio just after the catch indicates fast movement of the shoulders and is probably the main reason of the feeling of easy gearing. I hope this fact can be helpful in understanding relations between gearing effect, span, catching angle, stretcher position and boat types."

We agree with Einar that the ratio of the shoulders/handle movement can be higher at longer catch angles. The figure below explains this:



The chart below shows how much the oar angle "costs" in the shoulders movement at various oar angles and span for a common inboard (88cm) and dimensions of the athlete (shoulder to handle distance 70cm, shoulders width 40cm):



The "cost" increases significantly at angles greater than 70 deg and with a very wide span (180cm), which in practice can not be found in sculling and rowing. If even a huge difference in span (±20cm, which never happens in reality) can not change the "cost" significantly in the range of real angles, then what we can say about ±2cm?

Concluding, this effect is very small in practice and can not support the idea of span/spread influence on gearing.

By the way, this chart can be useful when you want to know how much you should move the stretcher to change the angle by one degree. At the perpendicular one degree "costs" about 1.45cm of the arc length in sculling and 1.75cm in rowing.

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2. Adam K, Lenk H., Schroder W. 1982. Kleine Schriften zum Rudertraining. Bartels&Wernitz Druckerei und Verlag KG, Germany, pp.268-272.

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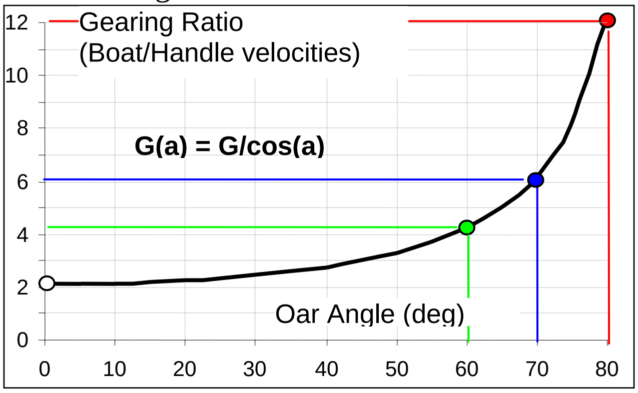
Facts. Did you know that…

…the effect of the oar angle on gearing is significant at angles greater than 45deg? The chart below shows the dependence of the actual gearing on the oar angle:



- An angle of 60deg makes it twice as heavier;
- An angle of 70deg makes it three times as heavier;
- An angle of 80deg makes it six times as heavier.

The chart is valid for both catch and finish angles, but the latter usually do not exceed 45deg, so the effect at the finish is not significant.

We know that catch angles mostly lie between 60 and 70deg (average is 64.0deg) in sculling and between 50 and 60deg (average is 54.2deg) in rowing. This means that**,** on average**,** gearing in rowing is 34% lighter at the catch than in sculling. This can be related to other facts, which probably compensated for this difference:

- In general, outboard/inboard ratio in rowing is 7.8% heavier than in sculling (the average in the four Olympic rowing classes being 2.26 compared to 2.10 in sculling, RBN 2006/11).
- Racing stroke rate on average is 2.4% higher in rowing than in sculling in similar boat types (37.3 and 35.7 in W2- and W2x, 38.7 and 38.1 in M2- and M2x, 40.9 and 40.2 in M4- and M4x, RBN 2003/01). This happens in spite of higher speeds in sculling boats.

Feedback & comments

✓ We received a number of interesting comments and questions about gearing and dimensions of oar/span/spread.

Jamie Croly, RSA Junior Women Coach has written: "I have felt that we have not explored the full range of possibilities offered by the newer oars and sculls that can be adjusted. Most of the mind sets of coaches are still stuck in the old school of thinking where a change in the inboard automatically affected the outboard and gearing. It seems a little strange that most rowing texts that offer a chapter on rigging have the same measurements. … This is obviously a left over from when club only had one set of blades that had to be used in many boats. In order to keep the "internal" position the same to get the same feel the coach only had the option of moving the pin. Why are oars only rowed 370-380 and sculls 282-292? Why not 350 or 400, 270 or 300?"

✓ Other interesting comments came from Stephen Aitken, an ARA Coach Educator and Coach at Tideway Scullers School. Stephen set angles 70deg at the catch and 40deg at the finish as a target. Then using the boat and rower geometry he derived the oar dimensions and span, which would be required to achieve these criteria in different categories of rowers. He found that the shortest dimensions for sculling inboard/oar-length/span in juniors (stroke length 144cm) should be 78/251/138cm and the longest dimensions in seniors (stroke length 167cm) should be 93/295/166cm.

We used similar method, based on the ratio of stroke length to rower's body height. From database of 4620 samples we found that the average ratio was 85%. Then we derived the normal stroke length and rigging dimensions, which required achieving a total angle 110deg in sculling and 92deg in rowing. Other variables for the calculation were the average gearing ratio from RBN 2006/11 and overlap values from RBN 2006/12. The Table shows the results of the calculations:

		Sculling			Sweep		
Body Height (cm)	Stroke Length (cm)	inboard (cm)	Oar Length (cm)	Span (cm)	inboard (cm)	Oar Length (cm)	Spread (cm)
165	140	77	254	134	100	329	68
170	145	79	261	139	103	338	71
175	149	81	268	143	106	347	74
180	153	84	275	147	108	355	76
185	157	86	282	152	111	364	79
190	162	88	289	156	114	373	82
195	166	90	296	161	116	382	84
200	170	93	302	165	119	390	87
205	174	95	309	170	122	399	90

You can see that Stephen's minimum and maximum dimensions are quite close to our data for rowers of height 165 and 200cm.

Concluding, normal rigging dimensions from text books would suit a sculler of 190cm height and rower of 193cm. It is make sense to vary the dimensions for rowers of significantly different height, or they should row at different angles.

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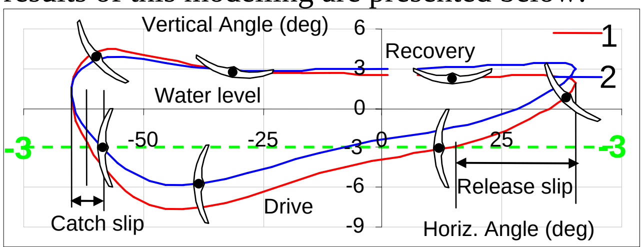
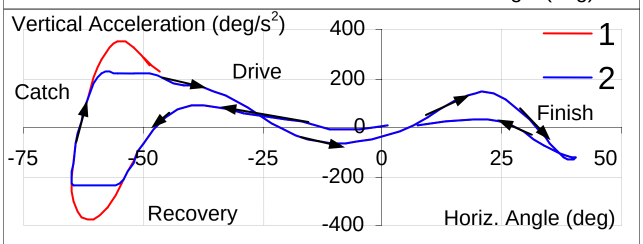
Facts. Did you know that…

…gravitational acceleration is not enough to insert the blade quickly into the water at the catch? Some coaches believe that the rowers should just take the weight of the arms off the handle and "let the blade go" into the water. To check it, we made calculations of the angular acceleration of the oar under gravity and verified them using an oar angle transducer.

The free-falling angular acceleration of a standard sculling oar (2.90/0.88m, centre of mass (CM) at 1.42m from the handle top) was found about 240 degree/s^2 and for a sweep oar (3.77/1.15m, CM at 1.80m) it was 200 deg/s^2. At the catch the oar has to change its vertical angle from +5 degrees (positive indicates centre of blade above water level) down to -5 degrees, i.e. it has to travel about 10 deg. At that angular acceleration it takes about 0.28-0.32s, which is nearly one third of the drive time. The best athletes achieve peak accelerations more than 400deg/s^2. This means they apply an upwards vertical force to the handle, increasing the acceleration to nearly double that of gravity.

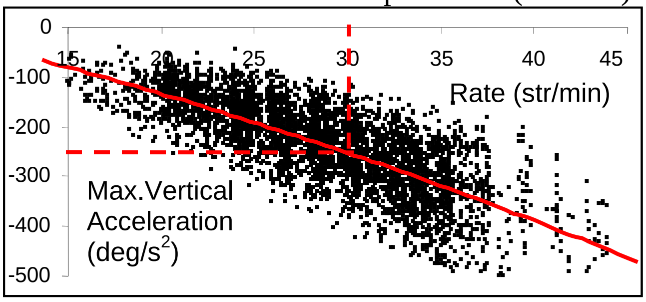
To illustrate, we took the measured vertical and horizontal angles of a good sculler (1) and differentiate the vertical angle twice to get its angular acceleration. Then we limited the value at the catch to 240 deg/s^2 (free-falling acceleration) and integrated the result twice to get the angle (2). The results of this modelling are presented below:





The vertical catch slip was measured from the catch to the point, where the angle of the blade reached -3deg, which corresponds to a fully immersed spoon. You can see that using only free-fall acceleration at the catch nearly doubles the vertical catch slip (from 6.0 deg up to 11.8deg). This increases the slippage of the blade in the water, decreases the blade propulsive efficiency and creates energy losses. Bearing in mind that the best athletes achieve the catch slip lower than 6deg, they have to apply quite a significant upward kick to the handle before catch.

The maximal vertical acceleration at the catch is highly dependant on the stroke rate (r = -0.76). Below is a statistics of this dependence (n=5222):



On average, the vertical acceleration exceeds the free fall value at stroke rates higher than 30str/min. This means rowers can "let the blade go" at a low rate, but have to apply upward force at a higher rate. Usually rowers can't compensate for a higher speed of horizontal movement of the oar at a high rate with a faster vertical movement. Evidence of this fact is the positive correlation of the stroke rate with the catch slip (r=0.24) and release slip (r=0.38).

Catch slip is shorter in scullers, but release slip is shorter in sweep rowers. The Table below shows normative data for slip and effective angle:

Catch Slip (deg)					
	Very Good	Good	Average	Bad	Very Bad
Sweep	6.9	10.1	13.4	16.6	19.8
Scull	4.3	7.1	9.9	12.7	15.5
Release Slip (deg)					
Sweep	3.6	9.0	14.3	19.7	25.1
Scull	7.7	13.2	18.7	24.2	29.7
Effective Angle (%) = (Total Angle) - Slips					
Sweep	82.5%	75.4%	68.3%	61.3%	54.2%
Scull	86.3%	79.7%	73.0%	66.4%	59.7%

Other points for an effective catch are:

- Do not raise the blade too high before catch: the catch slip has positive correlation (r=0.21) with the highest oar angle before catch.
- Using the thumb is the only method to accelerate the handle upwards before catch.
- The upward push before catch must be really quick. If it is applied for a long time, then the blade will be inserted too deep into the water, which is, in addition, not effective.

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Q&A

We have received very positive feedback on the previous Newsletter about vertical movement of the oar. Here we try to answer some questions, which were asked or can be asked.

Q: Can we accelerate the vertical speed of the oar at catch by means of changing its balance (shifting position of CM)?

A: The effect is very insignificant. Quite a big shift of CM (centre of mass = the point of balance) of the oar by 20cm towards the blade increases gravitational acceleration only by 10%. This shift requires an extra 200g weight on the tip of the blade, which makes the oar heavier and increases its moment of inertia by 10%. The latter reduces the oar acceleration when a constant force is applied, completely eliminating the effect of CM shifting. Alternatively, one can make the handle lighter, but this method has limitations because the handle can't be weightless.

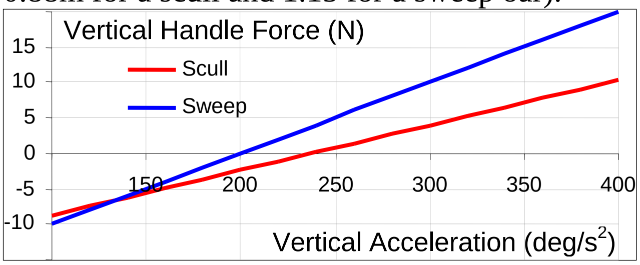
Another problem with shifting of the CM is that it makes it more difficult to remove the blade from the water at the finish. Therefore, we would not recommend it at all.

Q: What sort of force should be applied to the handle to achieve good vertical acceleration of the oar?

A: The handle force $\boldsymbol{F}$ is related to the moment $\boldsymbol{M}$ and lever $\boldsymbol{L}$, where $\boldsymbol{M}$ is related to the angular acceleration $\boldsymbol{\omega}$ and moment of inertia of the oar $\boldsymbol{I}$:

$$\boldsymbol{F} = \boldsymbol{M} / \boldsymbol{L} = \boldsymbol{I}\,\boldsymbol{\omega} / \boldsymbol{L}$$

We measured the moment of inertia $\boldsymbol{I}$, which was 3.2kgm for a standard scull and 6.6kgm for a sweep oar. These allow us to plot the relationship between vertical acceleration and extra force (in addition to gravity force) applied by a rower at the tip of the oar. (We took the standard inboard to be 0.88m for a scull and 1.15 for a sweep oar).

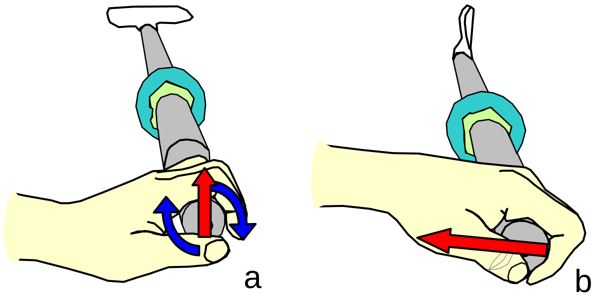


As you can see, a sculler needs to apply upwards only 10N (= a force of 1 kg-weight) extra vertical force at each handle to achieve a good level of the oar acceleration before catch. A rower needs to apply twice that force (about 2kgF) for the same acceleration. This force must be applied very quickly, like a kick, not a push.

Q: How can a faster vertical acceleration before the catch be achieved?

A: The main problem for a rower before the catch is combining the vertical push upwards with squaring the oar. It is much easier to separate these two movements and to do the squaring first and then to place the blade into the water. This method should be recommended for beginners and young rowers. However, as we showed before (RBN 2006/4), early squaring dramatically increases the aerodynamic resistance of the blade. Also, rough water conditions do not allow early squaring. Therefore, elite rowers very often practice a combination of squaring with simultaneous upwards acceleration of the handle.

Effective usage of the thumb is really important. It is easier to do in rowing, but in sculling the task is more difficult because the thumb also has to push the handle outwards to keep the oar button in contact with the swivel. The thumb must be placed at the outer-bottom edge of the grip and holds it with the base of the distal phalange (Fig. a).



During the recovery, the thumb must control the vertical position of the handle and push it forward. Suddenly, before catch the thumb switches from pushing forward to kicking upwards in combination with bending backwards (Fig. b), this allows a quick squaring of the oar followed immediately by placing it in the water.

Q: What sort of drills can be used for practicing quick catches?

A: The simplest drill is doing the catch only and targeting the shortest possible slip of the blade. As the ratio of handle to boat speed is lowest at long angles (RBN 2007/03), rowers can practise a good catch quite comfortably. It is more difficult to achieve a good catch at shorter angles, when the oar is close to perpendicular to the boat. So, the vertical kick at the catch must be emphasised during the "arms-only" and "quarter-slide" drills.

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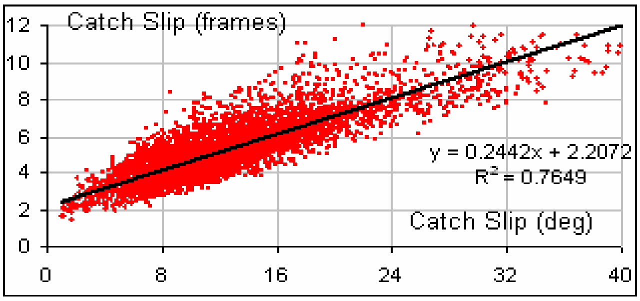
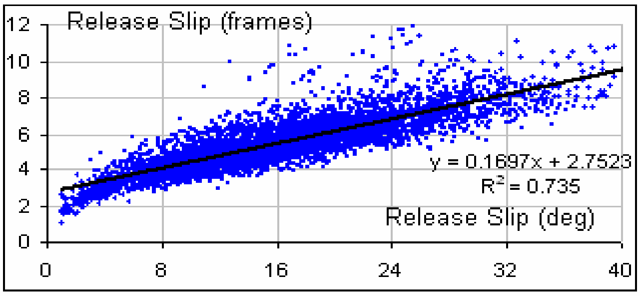
Q&A

Q: GB Senior Women coach Ron Needs asked: "How can you correlate angle data on catch and release slip (RBN 2007/4) to the number of video frames for respectively covering/uncovering the blade?"

A: We correlated catch and release slips measured in degrees (of horizontal oar movement) and in time (seconds converted to frames). The slips were derived from the catch (point where the oar changes direction) to the point, where the vertical angle reaches -3 deg (blade is fully covered).





The trend lines show that every video frame (0.04s) equates approximately to 4 deg of the catch slip and 6 deg of release slip. The difference can be explained by the fact that the blade moves faster at the finish of the drive.

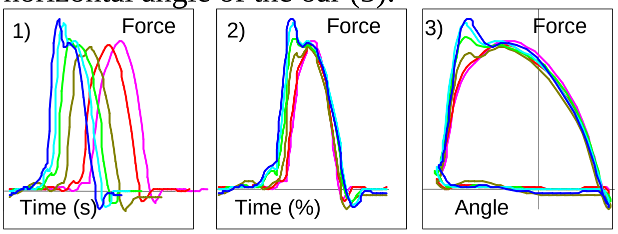
These are quite rough estimates: on the charts you can see that e.g. 8 deg slip can take time from 3 to 6 frames. The difference depends on the velocity of the oar movement, which is determined by stroke rate, boat speed and oar angle at catch. Higher rate, faster boat speed and shorter catch angles make the blade movement faster, so the same slip in degrees takes less time (fewer frames).

Also, from the charts you can see that both trend lines start from about 2 frames on the Y axis at nearly zero degrees on the X axis. This means nobody has a slip faster than two frames. The blade can move a very small distance horizontally, but the period can't be decreased because it takes time to accelerate the blade and move it to a specific vertical angle. Below is the table of normative values expressed in video frames:

	Very Good	Good	Average	Bad	Very Bad
Catch Slip (frames)					
Sweep	3	4	6	7	9
Scull	2	3	5	6	7
Release Slip (frames)					
Sweep	2	4	5	7	8
Scull	3	4	6	7	8

Ideas. What if…

…we look at the above example in a more general manner? As we saw, the results of analysis and normative values depend significantly on usage of time or oar angle as an independent variable. Three charts below present force curves of the same rower at stroke rates from 21 to 38 using various units of X axis: time in seconds (1), time as a percentage of the stroke cycle time (2) and horizontal angle of the oar (3):



As you may see, it is difficult to compare curves on Chart 1, because the durations of the stroke cycle are very different. Chart 2 is better for comparison, but width of the drive phase is quite different. Using Chart 3 we can perfectly compare force curves at different stroke rates.

Another aspect is the physical meaning of the area under the force curve: on Chart 1**,** it represents impulse; on Chart 2**,** it has no physical meaning; on Chart 3 it equal to the work per stroke. Impulse of the force and work (energy, power) correlate providing the velocity of movement is similar. Impulse can be high, but work is low in slow motions and vice versa in fast motions. At static efforts (velocity is zero) the impulse can be very high, but work equal to zero. Work and power are more informative variables in rowing than impulse. Concluding:

- Using time as the X axis is a simpler, more practical method of analysis. It can be easy linked with video**,** and define synchronisation in a crew.
- Using oar angle as the X axis works well in comparing data at different stroke rates. It represents visually the work done per stroke

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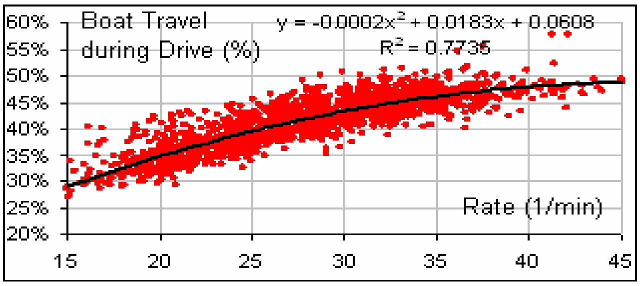
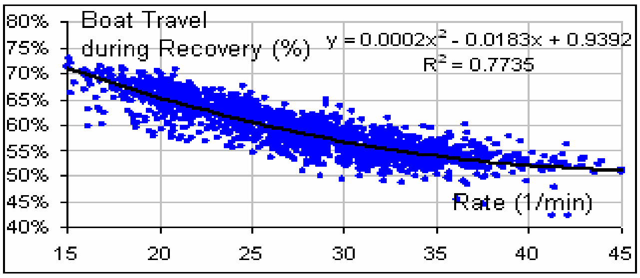
Q&A

Q: Australian coach Nick Garratt from Mosman rowing club, Sydney asked: "Can we use the ratio of distances, which the boat travelled during the drive and recovery phases as an indicator of power/efficiency of rowing technique?"

A: The distance of boat travel during the drive and recovery mainly depends on the duration of these phases. So, the ratio of the distances depends on ratio of times, i.e. rowing rhythm. We define rhythm as a ratio of the drive time to the total time of the stroke cycle (RBN 2003/03). Both rhythm and ratio of the distances are highly dependant on the stroke rate. Below are the trends of the distances, which the boat travels during the drive and recovery phases, taken as a percentage of the total distance per stroke cycle:





At the stroke rate below 20 str/min the boat travels only one third of the distance per stroke during the drive. At the stroke rates above 40 str/min this ratio is close to a half.

We tried to exclude influence of the stroke rate and analysed residuals from the trend, but didn't find any significant correlations of these two parameters with other biomechanical variables (forces, angles, power, etc.). The likely reason for it: a higher force/power increases the boat acceleration during the drive, but decreases the drive time, so the distance traveled remains the same.

Q: A number of coaches asked questions about relationship of performance on ergo and on water, which relates to rowing power and its utilisation. We already discussed rowing power (RBN 2002/01, 2004/06, 2004/09), but now try to review this issue again to make it clearer and more useful for coaches and rowers.

A: Using "ergo score" T r we can derive average "speed" v on ergo and then power P either directly from ergo monitor or using the equation

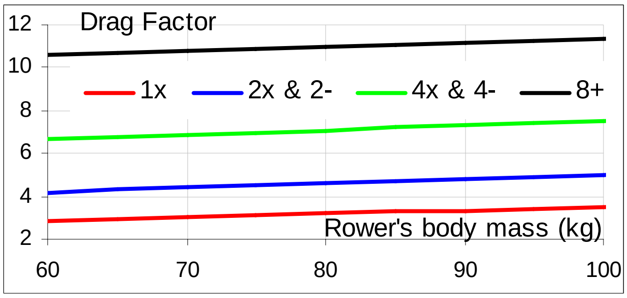
$$P = DFE * V^3 = DFE\ (2000 / T)^3$$

where ergo drag factor $DFE = 2.8$ was defined quite reliably from statistics of ergo testing.

Then we need to determine what speed can be achieved in various boat types, providing that the rower applies the same power P to the handle of the oar. Only a part of total power P is delivered to the boat as a propulsive power $Pprop$, so we need to adjust P using the blade propulsive efficiency Eb. The equation for the boat speed is:

$$V = (Pprop / DFB)^{1/3} = (P * Eb / DFB)^{1/3}$$

where DFB is the drag factor of the boat type. Analysing our database we found that DFB depends on the rower's body mass (see also Table 1):



Blade propulsive efficiency varies in the various boat types and recursively depends on the boat speed and drag factor, which can make our model quite complicated. Therefore, we took only average value 81.6% for all boat types.

Calculated speed in the single corresponds quite well with the ergo score: say, **90kg sculler with ergo score 5:50 would show 6:38 on water (in neutral weather conditions and average rowing technique)**. However, in bigger boats we have got much faster speeds: e.g. an eight with average body mass 90kg and average ergo score 6:00 would be as fast as 5:06 on water. We already discussed this phenomenon in RBN 2005/11 in relation to the "Gold Times" and can speculate that in bigger boats a rower can not deliver the same power as he/she do on ergo, because of more difficult conditions (higher speed, synchronization, etc.). Therefore, for team boats we took their average relationship to the single, which was determined using the drag factors. Table 2 below presents this data for the rower's body masses 60, 70, 80, 90 and 100kg.

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Table1 .Functions of the drag factor on the rower's body mass in various boat types.

Boat	n	Equation DFB(Rower' Mass)	r
1x	366	y = 0.015750x + 1.930169	0.47
2x & 2-	566	y = 0.020972x + 2.931142	0.32
4x & 4-	388	y = 0.022704x + 5.270209	0.31
8+	115	y = 0.020116x + 9.363559	0.24

Table 2. Function of the boat speed on the ergo score for various rower's body mass.

Body mass (kg)= 60							
Ergo Score (min:sec)	Power (W)	Time 2000m on water (min:sec)					
		1x	**2x**	**4x**	**2-**	**4-**	**8+**
6:00	480	**6:29**	**5:59**	**5:35**	**6:11**	**5:37**	**5:22**
6:10	442	**6:40**	**6:09**	**5:44**	**6:21**	**5:47**	**5:31**
6:20	408	**6:50**	**6:19**	**5:53**	**6:32**	**5:56**	**5:40**
6:30	378	**7:01**	**6:29**	**6:03**	**6:42**	**6:06**	**5:49**
6:40	350	**7:12**	**6:39**	**6:12**	**6:52**	**6:15**	**5:58**
6:50	325	**7:23**	**6:49**	**6:21**	**7:03**	**6:24**	**6:07**
7:00	302	**7:34**	**6:59**	**6:31**	**7:13**	**6:34**	**6:16**
7:10	282	**7:44**	**7:09**	**6:40**	**7:23**	**6:43**	**6:25**
7:20	263	**7:55**	**7:19**	**6:49**	**7:34**	**6:52**	**6:34**
7:30	246	**8:06**	**7:29**	**6:59**	**7:44**	**7:02**	**6:43**
7:40	230	**8:17**	**7:39**	**7:08**	**7:54**	**7:11**	**6:52**
7:50	216	**8:27**	**7:49**	**7:17**	**8:04**	**7:21**	**7:01**
8:00	203	**8:38**	**7:59**	**7:26**	**8:15**	**7:30**	**7:10**
8:10	190	**8:49**	**8:09**	**7:36**	**8:25**	**7:39**	**7:19**
8:20	179	**9:00**	**8:19**	**7:45**	**8:35**	**7:49**	**7:28**

Body mass (kg)= 70							
Ergo Score (min:sec)	Power (W)	Time 2000m on water (min:sec)					
		1x	**2x**	**4x**	**2-**	**4-**	**8+**
5:50	522	**6:25**	**5:56**	**5:31**	**6:07**	**5:34**	**5:19**
6:00	480	**6:36**	**6:06**	**5:41**	**6:18**	**5:43**	**5:28**
6:10	442	**6:47**	**6:16**	**5:50**	**6:28**	**5:53**	**5:37**
6:20	408	**6:58**	**6:26**	**6:00**	**6:39**	**6:03**	**5:46**
6:30	378	**7:09**	**6:36**	**6:09**	**6:49**	**6:12**	**5:55**
6:40	350	**7:20**	**6:46**	**6:19**	**7:00**	**6:22**	**6:05**
6:50	325	**7:31**	**6:57**	**6:28**	**7:10**	**6:31**	**6:14**
7:00	302	**7:42**	**7:07**	**6:38**	**7:21**	**6:41**	**6:23**
7:10	282	**7:53**	**7:17**	**6:47**	**7:31**	**6:50**	**6:32**
7:20	263	**8:04**	**7:27**	**6:57**	**7:42**	**7:00**	**6:41**
7:30	246	**8:15**	**7:37**	**7:06**	**7:52**	**7:09**	**6:50**
7:40	230	**8:26**	**7:47**	**7:15**	**8:03**	**7:19**	**6:59**
7:50	216	**8:37**	**7:58**	**7:25**	**8:13**	**7:28**	**7:08**
8:00	203	**8:48**	**8:08**	**7:34**	**8:24**	**7:38**	**7:17**
8:10	190	**8:59**	**8:18**	**7:44**	**8:34**	**7:48**	**7:27**
8:20	179	**9:10**	**8:28**	**7:53**	**8:45**	**7:57**	**7:36**

Body mass (kg)= 80							
Ergo Score (min:sec)	Power (W)	Time 2000m on water (min:sec)					
		1x	**2x**	**4x**	**2-**	**4-**	**8+**
5:50	522	**6:31**	**6:02**	**5:37**	**6:13**	**5:40**	**5:24**
6:00	480	**6:42**	**6:12**	**5:47**	**6:24**	**5:49**	**5:34**
6:10	442	**6:54**	**6:22**	**5:56**	**6:35**	**5:59**	**5:43**
6:20	408	**7:05**	**6:33**	**6:06**	**6:45**	**6:09**	**5:52**
6:30	378	**7:16**	**6:43**	**6:16**	**6:56**	**6:18**	**6:01**
6:40	350	**7:27**	**6:53**	**6:25**	**7:07**	**6:28**	**6:11**
6:50	325	**7:38**	**7:04**	**6:35**	**7:17**	**6:38**	**6:20**
7:00	302	**7:49**	**7:14**	**6:44**	**7:28**	**6:48**	**6:29**
7:10	282	**8:01**	**7:24**	**6:54**	**7:39**	**6:57**	**6:39**
7:20	263	**8:12**	**7:35**	**7:04**	**7:50**	**7:07**	**6:48**
7:30	246	**8:23**	**7:45**	**7:13**	**8:00**	**7:17**	**6:57**
7:40	230	**8:34**	**7:55**	**7:23**	**8:11**	**7:26**	**7:06**
7:50	216	**8:45**	**8:06**	**7:33**	**8:22**	**7:36**	**7:16**
8:00	203	**8:57**	**8:16**	**7:42**	**8:32**	**7:46**	**7:25**
8:10	190	**9:08**	**8:26**	**7:52**	**8:43**	**7:55**	**7:34**

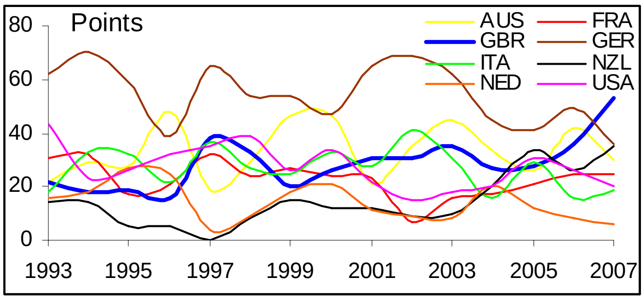
Body mass (kg)= 90							
Ergo Score (min:sec)	Power (W)	Time 2000m on water (min:sec)					
		1x	**2x**	**4x**	**2-**	**4-**	**8+**
5:40	570	**6:26**	**5:57**	**5:33**	**6:09**	**5:35**	**5:20**
5:50	522	**6:38**	**6:08**	**5:42**	**6:20**	**5:45**	**5:30**
6:00	480	**6:49**	**6:18**	**5:52**	**6:30**	**5:55**	**5:39**
6:10	442	**7:00**	**6:29**	**6:02**	**6:41**	**6:05**	**5:49**
6:20	408	**7:12**	**6:39**	**6:12**	**6:52**	**6:15**	**5:58**
6:30	378	**7:23**	**6:50**	**6:22**	**7:03**	**6:25**	**6:07**
6:40	350	**7:34**	**7:00**	**6:31**	**7:14**	**6:34**	**6:17**
6:50	325	**7:46**	**7:11**	**6:41**	**7:25**	**6:44**	**6:26**
7:00	302	**7:57**	**7:21**	**6:51**	**7:35**	**6:54**	**6:36**
7:10	282	**8:08**	**7:32**	**7:01**	**7:46**	**7:04**	**6:45**
7:20	263	**8:20**	**7:42**	**7:11**	**7:57**	**7:14**	**6:54**
7:30	246	**8:31**	**7:53**	**7:20**	**8:08**	**7:24**	**7:04**
7:40	230	**8:43**	**8:03**	**7:30**	**8:19**	**7:34**	**7:13**
7:50	216	**8:54**	**8:14**	**7:40**	**8:30**	**7:43**	**7:23**
8:00	203	**9:05**	**8:24**	**7:50**	**8:40**	**7:53**	**7:32**

Body mass (kg)= 100							
Ergo Score (min:sec)	Power (W)	Time 2000m on water (min:sec)					
		1x	**2x**	**4x**	**2-**	**4-**	**8+**
5:30	623	**6:21**	**5:52**	**5:28**	**6:03**	**5:30**	**5:16**
5:40	570	**6:32**	**6:03**	**5:38**	**6:14**	**5:40**	**5:25**
5:50	522	**6:44**	**6:13**	**5:48**	**6:25**	**5:50**	**5:35**
6:00	480	**6:55**	**6:24**	**5:58**	**6:36**	**6:00**	**5:44**
6:10	442	**7:07**	**6:35**	**6:08**	**6:47**	**6:10**	**5:54**
6:20	408	**7:18**	**6:45**	**6:18**	**6:58**	**6:20**	**6:03**
6:30	378	**7:30**	**6:56**	**6:27**	**7:09**	**6:31**	**6:13**
6:40	350	**7:41**	**7:06**	**6:37**	**7:20**	**6:41**	**6:23**
6:50	325	**7:53**	**7:17**	**6:47**	**7:31**	**6:51**	**6:32**
7:00	302	**8:04**	**7:28**	**6:57**	**7:42**	**7:01**	**6:42**
7:10	282	**8:16**	**7:38**	**7:07**	**7:53**	**7:11**	**6:51**
7:20	263	**8:28**	**7:49**	**7:17**	**8:04**	**7:21**	**7:01**
7:30	246	**8:39**	**8:00**	**7:27**	**8:15**	**7:31**	**7:10**
7:40	230	**8:51**	**8:10**	**7:37**	**8:27**	**7:41**	**7:20**
7:50	216	**9:02**	**8:21**	**7:47**	**8:38**	**7:51**	**7:30**
8:00	203	**9:14**	**8:32**	**7:57**	**8:49**	**8:01**	**7:39**

News

The Rowing World Championship 2008 just finished in Munich, Germany. British rowers have shown great performances and achieved the highest team score. Well done!

The chart below shows the variations in performance of the best rowing countries in 14 Olympic boat types over the last 15 years.



Q&A

Q: We have received very positive feedback on the latest Newsletter from a number of coaches and sport scientists. The correlation of the ergo score with the boat speed was found quite accurate. To make the tables more useful we regrouped them relative to the boat type instead of rower's weight (see Appendix 1 on http://www.biorow.com/RBN_en_2007_files/App2007RowBiomNews08.pdf). We received a number of questions essentially as follows: "What sort of force, oar angles and stroke rate should be applied to achieve a target boat speed?"

A: To answer this question, we need to determine work per stroke ***Wps*** using rowing power ***P*** and duration of the stroke cycle ***T*** or stroke rate ***R***:

$$Wps = P * T = P\ (60 / R)$$

If the force applied to the handle is constant, then work per stroke ***Wpsc*** could be derived as a product of the average force ***Fav*** and length of stroke ***L***:

$$Wpsc = Fav * L$$

However, the force is always variable, so the real work applied to the handle equal to an integral:

$$Wps = \int F \cdot dL$$

We compared values of ***Wps*** determined using these two equations and found that they have very high correlation (r = 0.985), which is evidence of quite a low influence of the shape of the force curve. This allows us to replace one variable with another using their ratio ***K***, which was found from our database:

$$K = Wpsc / Wps = 83.2\%.$$

The average force ***Fav*** can be expressed as:

$$Fav = K * P\ (60 / R) / L$$

The power P in this equation can be related to the boat speed using the method described in the previous Newsletter 2007/07. For illustration purposes we will show the estimated values of the force, stroke length and rate required to achieve the current World best times.

In our model, we estimated average body weight ***W*** and height ***H*** as the most common values among international level rowers. The stroke length ***L*** was estimated using its average ratio 85% to the rower's body height ***H***.

Oar angles ***A*** were derived from the stroke length ***L*** using actual inboard ***Inb*** from the data of the 2006 FISA rigging survey (RBN 2006/11).

$$A = L / (Inb\ (\pi / 180))$$

Racing stroke rates in various boat types were obtained from the average of our measurements during 2000-2004 (RBN 2005/02). Maximal force ***Fmax*** was derived using statistical average of the ratio of ***Fav*** to ***Fmax*** equal to 52%.

Boat	Time	W (kg)	H (m)	P (W)	Rate (1/min)	Angle (deg)	Fmax (kgF)	Fav (kgF)
W1x	7:07.7	85	1.85	410	34.1	107	74.8	38.9
W2x	6:38.8	80	1.85	390	35.9	107	67.6	35.1
W4x	6:10.8	80	1.85	392	37.4	110	65.4	34.0
W2-	6:53.8	85	1.85	394	37.4	87	65.6	34.1
W8+	5:55.5	80	1.85	397	39.1	89	63.3	32.9
M1x	6:35.4	95	1.95	544	36.3	112	88.4	46.0
M2x	6:03.3	90	1.95	541	38.2	113	83.7	43.5
M4x	5:37.3	90	1.95	547	39.3	113	82.2	42.8
M2-	6:14.3	95	1.95	558	38.8	92	84.9	44.1
M4-	5:41.3	95	1.95	553	40.5	93	80.6	41.9
M8+	5:19.9	95	1.95	586	40.0	94	86.6	45.0
LW2x	6:49.8	60	1.70	324	36.1	99	60.7	31.6
LM2x	6:10.0	70	1.80	464	38.8	104	76.5	39.8
LM4-	5:45.6	70	1.80	471	40.6	86	74.4	38.7

The common maximal and average forces in men are respectively 80-88 and 42-46kgF; in women, 63-74 and 32-38kgF; in lightweight men, 75 and 39kgF; in lightweight women, 60 and 31kgF. As we discussed in RBN 2006/05 these values of average force are equal to the weight in strength training and can be used for testing/training purposes. Don't forget that these variables are in balance: if one of them is lower (e.g. stroke rate), then others must be higher (stroke length or forces) if you want to achieve requited boat speed.

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Q&A

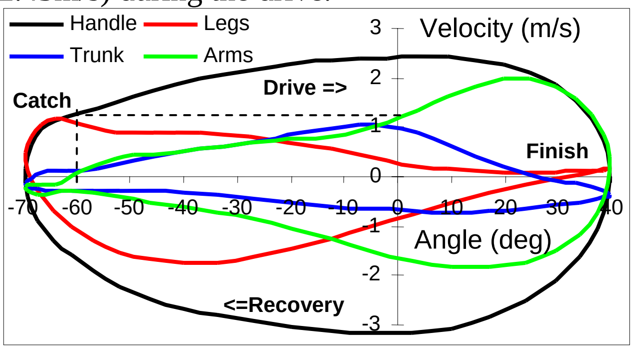
Q: A number of coaches sent us questions with the following general sense: "I agree that a large transverse force at acute catch angles may not cause energy losses in term of mechanics. However, it creates static work in the rower's muscles, which fatigues them and decreases muscular efficiency of their rowing technique".

A: There are three reasons why this concern does not make sense:

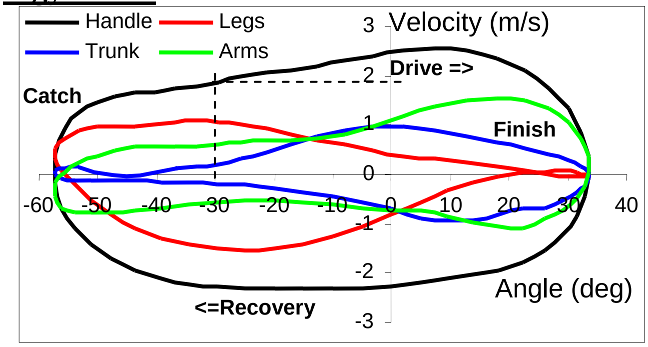
1. Absolute static action of the oar is not possible in rowing even when it is parallel to the boat. The blade slips through the water and any applied force creates some movement of the handle.

2. As you can see from RBN 2007/3 the real gearing ratio at a very long catch angle of 70 degrees is about 6. So, at a boat speed of 5m/s the handle should move at 0.8m/s even with the blade fully immersed in the water without slippage. However, as you saw from RBN 2007/4 it usually takes about 10 degrees of oar movement to immerse the blade fully. In this case, the blade is immersed at an angle of 60 degrees, when the gearing ratio is about 4 and the handle velocity must be at least 1.25m/s, which is quite a significant speed.

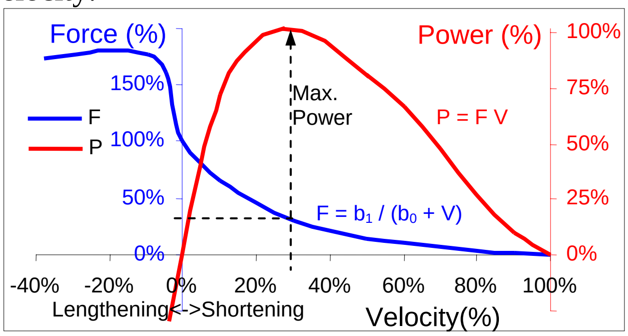
The chart below confirms our considerations. It shows the measured velocities of handle and body segments for a single sculler at a stroke rate 35str/min and average boat speed of 5m/s. The handle velocity at 60 deg is 1.23m/s, which is more than half of the maximal handle velocity (2.43m/s) during the drive.



3. Static and even eccentric work of some muscles and body segments happens very often in rowing even at significant handle velocities. The next chart shows that the trunk velocity in a sweep rower is close to zero during the first third of the drive, until the handle velocity reaches nearly 2m/s. All handle velocity is delivered by movement of the legs and arms only. This technical fault is usually called "grabbing with the arms". This example shows us that the static work of the trunk was caused not by heavy gearing or a long catch angle, but by an inefficient sequence of the body segments. Therefore, **<u>a reasonably long catch angle does NOT itself create static work and energy losses.</u>**.



Not only absolute static muscle contraction is a waste of energy. Movement with very slow or fast speed is also inefficient. The chart below illustrates the well-known Hill principle in muscle mechanics, discovered in the 1920s by the famous physiologist Archibald Vivian Hill. The hyperbolic relationship between velocity and force was obtained from a study of frog muscle tissue, but a number of recent researches confirmed that it can be valid for complex multi-joint movements, which we can measure as velocities of body segments. The Hill principle tells us that maximal power can be achieved in a movement at about 30% of both the maximal static force and the maximal unloaded velocity.



Negative power is the most inefficient unless it happens during very short time, when muscle works as a spring and returns energy to the system. In the second example above there is another technical fault of slide-shooting, when stretching of the back muscles consumes power produced by the legs. Obviously, too heavy or too light gearing can affect the force/velocity relationship and thus efficiency. However, **<u>an optimal body sequence, (i.e. rowing style) matched to the rower's characteristics and boat speed plays the most significant role in rowing efficiency</u>**.

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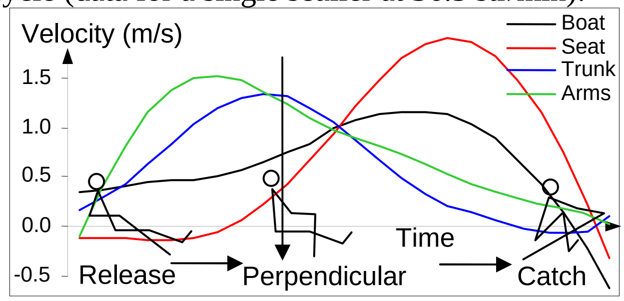
Q&A

Q: Nick Garratt, Head Coach of Mosman Rowing Club, Sydney, Australia is asking: "My athletes now row with very fast hands away and body over after the release… The changes are particularly noticeable at the current training rating of 18-20, and I suppose it could be argued that at race rate of 30-34 the recovery speed is pretty fast anyway. Does the boat speed increase when speeding the hands away and body swing, compared to the 'even speed in - even speed away' technique at the recovery? Or perhaps does the faster hands method allows more relaxation and recovery time and is therefore less fatiguing?"

A: In RBN 2004/07 we already discussed the boat velocity during recovery in conjunction with the stretcher force. We recommended minimising the stretcher pull, which makes the hull speed smoother during recovery. Now we will discuss the body segments' velocities. The chart below shows them (a positive velocity implying in the stern direction) in conjunction with deviation of the boat velocity from the average over the stroke cycle (data for a single sculler at 36.5 str/min):



At the beginning of the recovery, the velocities of the arms and trunk are quite high, but the boat speed increases only slightly. When the oar crosses the perpendicular position and the handles pass the knees, the seat velocity increases sharply, which causes displacement of the rower's whole mass. To do this the rower has to pull on the stretcher, which increases the boat speed dramatically. The peaks of the seat and the boat velocities coincide. Then the rower pushes the stretcher, which decreases both the seat and the boat velocities. These variations of the boat speed are a source of small energy loss, which increases with the stroke rate (1).

A fast movement of the arms itself at the beginning of recovery has practically no effect on the boat speed, because the arms have a very small mass. However, acceleration of the handle must overcome the moment of inertia of the oar that creates a negative force on the pin and decelerates the boat. If this is performed at low rates, very often the handle pauses at the middle of the recovery, which requires double activation of the muscles and is not good for balance and relaxation. At higher rates, this pause usually disappears, but the habit persists and can affect performance.

If a fast arms movement is connected with a fast trunk movement, then the rower has to use the stomach muscles very intensively. At higher rates this can be fatiguing. Also, it creates significant force on the seat, which pushes the boat downwards and increases drag (RBN 2006/10).

To conclude, at the moment we can guess that exaggerated speed of the arms and trunk is NOT a good way to start the recovery. More objective experiments are required to confirm the point.

Ideas. What if…

…you use our method of modelling the speed/rate relationship for developing normative splits for ergo training? In RBN 2005/10 and (2) we described the method and illustrated its application in race analysis. The method is based on the principle of constant effective work per stroke. Now we use its main equation on ergo:

$$V_1 = V_0 (R_1 / R_0)^{1/3}$$

Where V_1 is the target speed at the rate R_1, and V_0 and R_0 are race speed and rate. The Appendix 1 gives you normative splits at various training rates, which target various results at racing rates 32, 36 and 40. You can download the spreadsheet from http://www.biorow.com/Downloads.htm and use it in case you want another race rate or different training rates.

Examples of using the Tables:

1. Your target for a 2k ergo race is 6:00 at the rate 36. If you can train at the rate 18 at a split of 1:53, this means your muscles are ready to produce the same amount of work per stroke, as required for your target result and rate.
2. You can train at a split of 1:48 at the rate 20. This means your muscles are ready to produce 2k race time 5:44 at the rate 40. If you can't produce this result, then you lack endurance.

Enjoy your smarter training!

References

1. Kleshnev V. (1999) Propulsive efficiency of rowing. In: Scientific proceedings : ISBS '99 : XVII International Symposium on Biomechanics in Sports, p. 224-228.
2. Kleshnev V. (2006) Method of analysis of speed, stroke rate and stroke distance in aquatic locomotions. In: Scientific proceedings. XXII International Symposium on Biomechanics in Sports, Salzburg. pp 104-107.

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Appendix 1 to Rowing Biomechanics Newsletter 79(7) October 2007

*Table 1. Normative splits for Target Race Rate **32** str/min.*

Target 2k time at Rate:	**Split**	**Training 500m splits at different rates**																			
32	**500**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**	**42**	**44**	**46**	**48**	**50**
4:40	**1:10**	1:43	1:37	1:32	1:28	1:25	1:22	1:19	1:17	1:15	1:13	1:12	**1:10**	1:09	1:07	1:06	1:05	1:04	1:03	1:02	1:01	1:00
4:48	**1:12**	1:46	1:40	1:35	1:31	1:27	1:24	1:22	1:19	1:17	1:15	1:14	**1:12**	1:11	1:09	1:08	1:07	1:06	1:05	1:04	1:03	1:02
4:56	**1:14**	1:49	1:43	1:37	1:33	1:30	1:27	1:24	1:21	1:19	1:17	1:16	**1:14**	1:13	1:11	1:10	1:09	1:08	1:07	1:06	1:05	1:04
5:04	**1:16**	1:52	1:45	1:40	1:36	1:32	1:29	1:26	1:24	1:21	1:19	1:18	**1:16**	1:14	1:13	1:12	1:11	1:09	1:08	1:07	1:06	1:05
5:12	**1:18**	1:55	1:48	1:43	1:38	1:34	1:31	1:28	1:26	1:24	1:22	1:20	**1:18**	1:16	1:15	1:14	1:12	1:11	1:10	1:09	1:08	1:07
5:20	**1:20**	1:58	1:51	1:45	1:41	1:37	1:34	1:31	1:28	1:26	1:24	1:22	**1:20**	1:18	1:17	1:16	1:14	1:13	1:12	1:11	1:10	1:09
5:28	**1:22**	2:01	1:54	1:48	1:43	1:39	1:36	1:33	1:30	1:28	1:26	1:24	**1:22**	1:20	1:19	1:17	1:16	1:15	1:14	1:13	1:12	1:11
5:36	**1:24**	2:04	1:56	1:51	1:46	1:42	1:38	1:35	1:32	1:30	1:28	1:26	**1:24**	1:22	1:21	1:19	1:18	1:17	1:16	1:14	1:13	1:12
5:44	**1:26**	2:07	1:59	1:53	1:48	1:44	1:41	1:37	1:35	1:32	1:30	1:28	**1:26**	1:24	1:23	1:21	1:20	1:19	1:17	1:16	1:15	1:14
5:52	**1:28**	2:10	2:02	1:56	1:51	1:47	1:43	1:40	1:37	1:34	1:32	1:30	**1:28**	1:26	1:25	1:23	1:22	1:20	1:19	1:18	1:17	1:16
6:00	**1:30**	2:13	2:05	1:59	1:53	1:49	1:45	1:42	1:39	1:36	1:34	1:32	**1:30**	1:28	1:27	1:25	1:24	1:22	1:21	1:20	1:19	1:18
6:08	**1:32**	2:16	2:08	2:01	1:56	1:51	1:48	1:44	1:41	1:39	1:36	1:34	**1:32**	1:30	1:28	1:27	1:25	1:24	1:23	1:22	1:20	1:19
6:16	**1:34**	2:19	2:10	2:04	1:58	1:54	1:50	1:47	1:43	1:41	1:38	1:36	**1:34**	1:32	1:30	1:29	1:27	1:26	1:25	1:23	1:22	1:21
6:24	**1:36**	2:21	2:13	2:06	2:01	1:56	1:52	1:49	1:46	1:43	1:40	1:38	**1:36**	1:34	1:32	1:31	1:29	1:28	1:26	1:25	1:24	1:23
6:32	**1:38**	2:24	2:16	2:09	2:03	1:59	1:55	1:51	1:48	1:45	1:42	1:40	**1:38**	1:36	1:34	1:33	1:31	1:30	1:28	1:27	1:26	1:24
6:40	**1:40**	2:27	2:19	2:12	2:06	2:01	1:57	1:53	1:50	1:47	1:45	1:42	**1:40**	1:38	1:36	1:34	1:33	1:31	1:30	1:29	1:27	1:26
6:48	**1:42**	2:30	2:21	2:14	2:09	2:04	1:59	1:56	1:52	1:49	1:47	1:44	**1:42**	1:40	1:38	1:36	1:35	1:33	1:32	1:30	1:29	1:28
6:56	**1:44**	2:33	2:24	2:17	2:11	2:06	2:02	1:58	1:54	1:51	1:49	1:46	**1:44**	1:42	1:40	1:38	1:37	1:35	1:34	1:32	1:31	1:30
7:04	**1:46**	2:36	2:27	2:20	2:14	2:08	2:04	2:00	1:57	1:54	1:51	1:48	**1:46**	1:44	1:42	1:40	1:38	1:37	1:35	1:34	1:33	1:31
7:12	**1:48**	2:39	2:30	2:22	2:16	2:11	2:06	2:02	1:59	1:56	1:53	1:50	**1:48**	1:46	1:44	1:42	1:40	1:39	1:37	1:36	1:34	1:33
7:20	**1:50**	2:42	2:33	2:25	2:19	2:13	2:09	2:05	2:01	1:58	1:55	1:52	**1:50**	1:48	1:46	1:44	1:42	1:40	1:39	1:37	1:36	1:35
7:28	**1:52**	2:45	2:35	2:28	2:21	2:16	2:11	2:07	2:03	2:00	1:57	1:54	**1:52**	1:50	1:48	1:46	1:44	1:42	1:41	1:39	1:38	1:37
7:36	**1:54**	2:48	2:38	2:30	2:24	2:18	2:13	2:09	2:05	2:02	1:59	1:56	**1:54**	1:52	1:50	1:48	1:46	1:44	1:43	1:41	1:40	1:38
7:44	**1:56**	2:51	2:41	2:33	2:26	2:21	2:16	2:11	2:08	2:04	2:01	1:59	**1:56**	1:54	1:52	1:50	1:48	1:46	1:44	1:43	1:41	1:40
7:52	**1:58**	2:54	2:44	2:35	2:29	2:23	2:18	2:14	2:10	2:06	2:03	2:01	**1:58**	1:56	1:53	1:51	1:50	1:48	1:46	1:45	1:43	1:42
8:00	**2:00**	2:57	2:46	2:38	2:31	2:25	2:20	2:16	2:12	2:09	2:05	2:03	**2:00**	1:58	1:55	1:53	1:51	1:50	1:48	1:46	1:45	1:43
8:08	**2:02**	3:00	2:49	2:41	2:34	2:28	2:23	2:18	2:14	2:11	2:08	2:05	**2:02**	2:00	1:57	1:55	1:53	1:51	1:50	1:48	1:47	1:45
8:16	**2:04**	3:03	2:52	2:43	2:36	2:30	2:25	2:20	2:16	2:13	2:10	2:07	**2:04**	2:02	1:59	1:57	1:55	1:53	1:52	1:50	1:48	1:47
8:24	**2:06**	3:06	2:55	2:46	2:39	2:33	2:27	2:23	2:19	2:15	2:12	2:09	**2:06**	2:03	2:01	1:59	1:57	1:55	1:53	1:52	1:50	1:49
8:32	**2:08**	3:09	2:58	2:49	2:41	2:35	2:30	2:25	2:21	2:17	2:14	2:11	**2:08**	2:05	2:03	2:01	1:59	1:57	1:55	1:53	1:52	1:50
8:40	**2:10**	3:12	3:00	2:51	2:44	2:37	2:32	2:27	2:23	2:19	2:16	2:13	**2:10**	2:07	2:05	2:03	2:01	1:59	1:57	1:55	1:54	1:52

*Table 2. Normative splits for Target Race Rate **36** str/min.*

Target 2k time at Rate:	Split	Training 500m splits at different rates																				
36	**500**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**	**42**	**44**	**46**	**48**	**50**
4:40	**1:10**	1:47	1:41	1:36	1:32	1:28	1:25	1:22	1:20	1:18	1:16	1:14	1:13	1:11	**1:10**	1:09	1:08	1:06	1:05	1:05	1:04	1:03
4:48	**1:12**	1:50	1:44	1:39	1:34	1:31	1:28	1:25	1:22	1:20	1:18	1:17	1:15	1:13	**1:12**	1:11	1:10	1:08	1:07	1:06	1:05	1:05
4:56	**1:14**	1:53	1:47	1:41	1:37	1:33	1:30	1:27	1:25	1:22	1:20	1:19	1:17	1:15	**1:14**	1:13	1:11	1:10	1:09	1:08	1:07	1:06
5:04	**1:16**	1:56	1:50	1:44	1:40	1:36	1:32	1:30	1:27	1:25	1:23	1:21	1:19	1:17	**1:16**	1:15	1:13	1:12	1:11	1:10	1:09	1:08
5:12	**1:18**	2:00	1:52	1:47	1:42	1:38	1:35	1:32	1:29	1:27	1:25	1:23	1:21	1:20	**1:18**	1:17	1:15	1:14	1:13	1:12	1:11	1:10
5:20	**1:20**	2:03	1:55	1:50	1:45	1:41	1:37	1:34	1:32	1:29	1:27	1:25	1:23	1:22	**1:20**	1:19	1:17	1:16	1:15	1:14	1:13	1:12
5:28	**1:22**	2:06	1:58	1:52	1:47	1:43	1:40	1:37	1:34	1:31	1:29	1:27	1:25	1:24	**1:22**	1:21	1:19	1:18	1:17	1:16	1:15	1:13
5:36	**1:24**	2:09	2:01	1:55	1:50	1:46	1:42	1:39	1:36	1:34	1:31	1:29	1:27	1:26	**1:24**	1:22	1:21	1:20	1:19	1:17	1:16	1:15
5:44	**1:26**	2:12	2:04	1:58	1:53	1:48	1:45	1:41	1:38	1:36	1:34	1:31	1:29	1:28	**1:26**	1:24	1:23	1:22	1:20	1:19	1:18	1:17
5:52	**1:28**	2:15	2:07	2:01	1:55	1:51	1:47	1:44	1:41	1:38	1:36	1:34	1:32	1:30	**1:28**	1:26	1:25	1:24	1:22	1:21	1:20	1:19
6:00	**1:30**	2:18	2:10	2:03	1:58	1:53	1:49	1:46	1:43	1:40	1:38	1:36	1:34	1:32	**1:30**	1:28	1:27	1:25	1:24	1:23	1:22	1:21
6:08	**1:32**	2:21	2:13	2:06	2:01	1:56	1:52	1:48	1:45	1:43	1:40	1:38	1:36	1:34	**1:32**	1:30	1:29	1:27	1:26	1:25	1:24	1:22
6:16	**1:34**	2:24	2:16	2:09	2:03	1:58	1:54	1:51	1:48	1:45	1:42	1:40	1:38	1:36	**1:34**	1:32	1:31	1:29	1:28	1:27	1:25	1:24
6:24	**1:36**	2:27	2:18	2:12	2:06	2:01	1:57	1:53	1:50	1:47	1:44	1:42	1:40	1:38	**1:36**	1:34	1:33	1:31	1:30	1:28	1:27	1:26
6:32	**1:38**	2:30	2:21	2:14	2:08	2:03	1:59	1:55	1:52	1:49	1:47	1:44	1:42	1:40	**1:38**	1:36	1:35	1:33	1:32	1:30	1:29	1:28
6:40	**1:40**	2:33	2:24	2:17	2:11	2:06	2:02	1:58	1:54	1:51	1:49	1:46	1:44	1:42	**1:40**	1:38	1:37	1:35	1:34	1:32	1:31	1:30
6:48	**1:42**	2:36	2:27	2:20	2:14	2:09	2:04	2:00	1:57	1:54	1:51	1:48	1:46	1:44	**1:42**	1:40	1:38	1:37	1:35	1:34	1:33	1:31
6:56	**1:44**	2:39	2:30	2:22	2:16	2:11	2:07	2:03	1:59	1:56	1:53	1:51	1:48	1:46	**1:44**	1:42	1:40	1:39	1:37	1:36	1:34	1:33
7:04	**1:46**	2:42	2:33	2:25	2:19	2:14	2:09	2:05	2:01	1:58	1:55	1:53	1:50	1:48	**1:46**	1:44	1:42	1:41	1:39	1:38	1:36	1:35
7:12	**1:48**	2:46	2:36	2:28	2:22	2:16	2:11	2:07	2:04	2:00	1:57	1:55	1:52	1:50	**1:48**	1:46	1:44	1:43	1:41	1:40	1:38	1:37
7:20	**1:50**	2:49	2:39	2:31	2:24	2:19	2:14	2:10	2:06	2:03	2:00	1:57	1:54	1:52	**1:50**	1:48	1:46	1:44	1:43	1:41	1:40	1:39
7:28	**1:52**	2:52	2:42	2:33	2:27	2:21	2:16	2:12	2:08	2:05	2:02	1:59	1:56	1:54	**1:52**	1:50	1:48	1:46	1:45	1:43	1:42	1:40
7:36	**1:54**	2:55	2:44	2:36	2:29	2:24	2:19	2:14	2:10	2:07	2:04	2:01	1:59	1:56	**1:54**	1:52	1:50	1:48	1:47	1:45	1:44	1:42
7:44	**1:56**	2:58	2:47	2:39	2:32	2:26	2:21	2:17	2:13	2:09	2:06	2:03	2:01	1:58	**1:56**	1:54	1:52	1:50	1:48	1:47	1:45	1:44
7:52	**1:58**	3:01	2:50	2:42	2:35	2:29	2:24	2:19	2:15	2:12	2:08	2:05	2:03	2:00	**1:58**	1:56	1:54	1:52	1:50	1:49	1:47	1:46
8:00	**2:00**	3:04	2:53	2:44	2:37	2:31	2:26	2:21	2:17	2:14	2:10	2:08	2:05	2:02	**2:00**	1:58	1:56	1:54	1:52	1:51	1:49	1:48
8:08	**2:02**	3:07	2:56	2:47	2:40	2:34	2:28	2:24	2:20	2:16	2:13	2:10	2:07	2:04	**2:02**	2:00	1:58	1:56	1:54	1:52	1:51	1:49
8:16	**2:04**	3:10	2:59	2:50	2:42	2:36	2:31	2:26	2:22	2:18	2:15	2:12	2:09	2:06	**2:04**	2:02	2:00	1:58	1:56	1:54	1:53	1:51
8:24	**2:06**	3:13	3:02	2:53	2:45	2:39	2:33	2:28	2:24	2:20	2:17	2:14	2:11	2:08	**2:06**	2:04	2:02	2:00	1:58	1:56	1:54	1:53
8:32	**2:08**	3:16	3:05	2:55	2:48	2:41	2:36	2:31	2:27	2:23	2:19	2:16	2:13	2:10	**2:08**	2:06	2:04	2:02	2:00	1:58	1:56	1:55
8:40	**2:10**	3:19	3:07	2:58	2:50	2:44	2:38	2:33	2:29	2:25	2:21	2:18	2:15	2:13	**2:10**	2:08	2:06	2:03	2:02	2:00	1:58	1:57

*Table 3. Normative splits for Target Race Rate **40** str/min.*

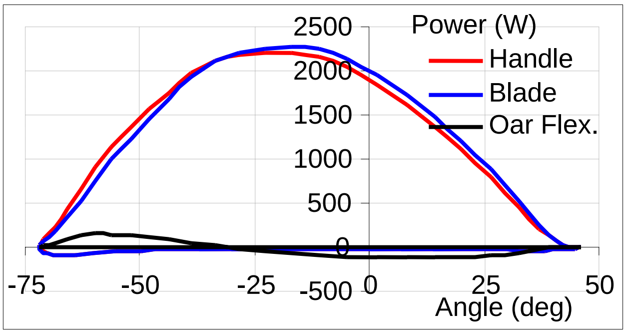
Target 2k time at Rate:	**Split**	**Training 500m splits at different rates**																				
40	**500**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**	**42**	**44**	**46**	**48**	**50**
4:40	**1:10**	1:51	1:45	1:39	1:35	1:31	1:28	1:25	1:23	1:21	1:19	1:17	1:15	1:14	1:13	1:11	**1:10**	1:09	1:08	1:07	1:06	1:05
4:48	**1:12**	1:54	1:48	1:42	1:38	1:34	1:31	1:28	1:25	1:23	1:21	1:19	1:18	1:16	1:15	1:13	**1:12**	1:11	1:10	1:09	1:08	1:07
4:56	**1:14**	1:57	1:51	1:45	1:40	1:37	1:33	1:30	1:28	1:25	1:23	1:21	1:20	1:18	1:17	1:15	**1:14**	1:13	1:12	1:11	1:10	1:09
5:04	**1:16**	2:01	1:54	1:48	1:43	1:39	1:36	1:33	1:30	1:28	1:26	1:24	1:22	1:20	1:19	1:17	**1:16**	1:15	1:14	1:13	1:12	1:11
5:12	**1:18**	2:04	1:57	1:51	1:46	1:42	1:38	1:35	1:32	1:30	1:28	1:26	1:24	1:22	1:21	1:19	**1:18**	1:17	1:16	1:14	1:13	1:12
5:20	**1:20**	2:07	2:00	1:54	1:49	1:44	1:41	1:38	1:35	1:32	1:30	1:28	1:26	1:24	1:23	1:21	**1:20**	1:19	1:17	1:16	1:15	1:14
5:28	**1:22**	2:10	2:02	1:56	1:51	1:47	1:43	1:40	1:37	1:35	1:32	1:30	1:28	1:27	1:25	1:23	**1:22**	1:21	1:19	1:18	1:17	1:16
5:36	**1:24**	2:13	2:05	1:59	1:54	1:50	1:46	1:43	1:40	1:37	1:35	1:32	1:30	1:29	1:27	1:25	**1:24**	1:23	1:21	1:20	1:19	1:18
5:44	**1:26**	2:17	2:08	2:02	1:57	1:52	1:48	1:45	1:42	1:39	1:37	1:35	1:33	1:31	1:29	1:27	**1:26**	1:25	1:23	1:22	1:21	1:20
5:52	**1:28**	2:20	2:11	2:05	1:59	1:55	1:51	1:47	1:44	1:42	1:39	1:37	1:35	1:33	1:31	1:30	**1:28**	1:27	1:25	1:24	1:23	1:22
6:00	**1:30**	2:23	2:14	2:08	2:02	1:57	1:53	1:50	1:47	1:44	1:41	1:39	1:37	1:35	1:33	1:32	**1:30**	1:29	1:27	1:26	1:25	1:24
6:08	**1:32**	2:26	2:17	2:11	2:05	2:00	1:56	1:52	1:49	1:46	1:44	1:41	1:39	1:37	1:35	1:34	**1:32**	1:31	1:29	1:28	1:27	1:25
6:16	**1:34**	2:29	2:20	2:13	2:08	2:03	1:58	1:55	1:51	1:49	1:46	1:43	1:41	1:39	1:37	1:36	**1:34**	1:32	1:31	1:30	1:28	1:27
6:24	**1:36**	2:32	2:23	2:16	2:10	2:05	2:01	1:57	1:54	1:51	1:48	1:46	1:43	1:41	1:39	1:38	**1:36**	1:34	1:33	1:32	1:30	1:29
6:32	**1:38**	2:36	2:26	2:19	2:13	2:08	2:03	2:00	1:56	1:53	1:50	1:48	1:46	1:43	1:42	1:40	**1:38**	1:36	1:35	1:34	1:32	1:31
6:40	**1:40**	2:39	2:29	2:22	2:16	2:10	2:06	2:02	1:59	1:55	1:53	1:50	1:48	1:46	1:44	1:42	**1:40**	1:38	1:37	1:35	1:34	1:33
6:48	**1:42**	2:42	2:32	2:25	2:18	2:13	2:09	2:04	2:01	1:58	1:55	1:52	1:50	1:48	1:46	1:44	**1:42**	1:40	1:39	1:37	1:36	1:35
6:56	**1:44**	2:45	2:35	2:28	2:21	2:16	2:11	2:07	2:03	2:00	1:57	1:54	1:52	1:50	1:48	1:46	**1:44**	1:42	1:41	1:39	1:38	1:37
7:04	**1:46**	2:48	2:38	2:30	2:24	2:18	2:14	2:09	2:06	2:02	1:59	1:57	1:54	1:52	1:50	1:48	**1:46**	1:44	1:43	1:41	1:40	1:38
7:12	**1:48**	2:51	2:41	2:33	2:27	2:21	2:16	2:12	2:08	2:05	2:02	1:59	1:56	1:54	1:52	1:50	**1:48**	1:46	1:45	1:43	1:42	1:40
7:20	**1:50**	2:55	2:44	2:36	2:29	2:24	2:19	2:14	2:10	2:07	2:04	2:01	1:58	1:56	1:54	1:52	**1:50**	1:48	1:47	1:45	1:44	1:42
7:28	**1:52**	2:58	2:47	2:39	2:32	2:26	2:21	2:17	2:13	2:09	2:06	2:03	2:01	1:58	1:56	1:54	**1:52**	1:50	1:48	1:47	1:45	1:44
7:36	**1:54**	3:01	2:50	2:42	2:35	2:29	2:24	2:19	2:15	2:12	2:08	2:05	2:03	2:00	1:58	1:56	**1:54**	1:52	1:50	1:49	1:47	1:46
7:44	**1:56**	3:04	2:53	2:45	2:37	2:31	2:26	2:22	2:18	2:14	2:11	2:08	2:05	2:02	2:00	1:58	**1:56**	1:54	1:52	1:51	1:49	1:48
7:52	**1:58**	3:07	2:56	2:47	2:40	2:34	2:29	2:24	2:20	2:16	2:13	2:10	2:07	2:05	2:02	2:00	**1:58**	1:56	1:54	1:53	1:51	1:50
8:00	**2:00**	3:10	2:59	2:50	2:43	2:37	2:31	2:26	2:22	2:19	2:15	2:12	2:09	2:07	2:04	2:02	**2:00**	1:58	1:56	1:55	1:53	1:51
8:08	**2:02**	3:14	3:02	2:53	2:46	2:39	2:34	2:29	2:25	2:21	2:17	2:14	2:11	2:09	2:06	2:04	**2:02**	2:00	1:58	1:56	1:55	1:53
8:16	**2:04**	3:17	3:05	2:56	2:48	2:42	2:36	2:31	2:27	2:23	2:20	2:16	2:14	2:11	2:08	2:06	**2:04**	2:02	2:00	1:58	1:57	1:55
8:24	**2:06**	3:20	3:08	2:59	2:51	2:44	2:39	2:34	2:29	2:25	2:22	2:19	2:16	2:13	2:11	2:08	**2:06**	2:04	2:02	2:00	1:59	1:57
8:32	**2:08**	3:23	3:11	3:02	2:54	2:47	2:41	2:36	2:32	2:28	2:24	2:21	2:18	2:15	2:13	2:10	**2:08**	2:06	2:04	2:02	2:00	1:59
8:40	**2:10**	3:26	3:14	3:04	2:56	2:50	2:44	2:39	2:34	2:30	2:26	2:23	2:20	2:17	2:15	2:12	**2:10**	2:08	2:06	2:04	2:02	2:01

Q&A

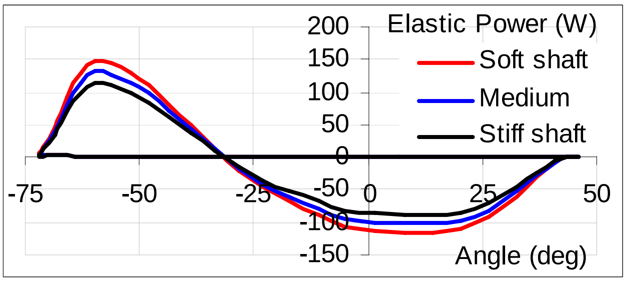
Q: Bruce Moffatt, Rowing coach and coordinator of Prince Alfred College, Adelaide, Australia is asking: "The latest newsletter is very interesting, especially the discussion regarding potentially inefficient use of muscle at high catch angles - static or near-static. One factor not mentioned is the flexure of the oar shaft imposed by the rower's muscles against somewhat transverse oar displacement during the early drive, at high catch angle. I wonder if in fact some energy is stored in the flexure of the oar shaft, to be release as propulsive force during the mid to late drive. If so it would add to the argument against nugatory energy expenditure at high catch angles.

Admittedly the flexure distances are small, however the forces may be somewhat large, and may perhaps result in some level of 'whipping' effect when the rower reduces the amount of input energy later in the drive. What do you think, is there any significant effect? Is potential energy stored in the oar shaft and returned later in the stroke?"

A: Basically, we agree with all points expressed by Bruce. In one of our first Newsletters 2001/05, we mentioned very briefly that "Bending of the oar shaft could be as much as 10 degrees … and absorb up to 25% of the rower's power over the first 15 – 20 cm of the drive". Now we will discuss it in more detail. The chart below shows the power curves of a male single sculler at a stroke rate of 35:



The red line represents power applied to the handle (product of the handle force and velocity). At the beginning of the drive, the force increases, the shaft bends and part of the handle power is stored in the elastic energy of the shaft (black line). Therefore, the power delivered at the blade (blue line) is less than handle power. When the handle force starts decreasing, the shaft recoils and returns energy to the system. The blade power became higher than the handle power. The following chart shows the difference in the storage of elastic power between soft, medium and stiff shafts (1) for the same handle force curve. The stiff shaft stores and then returns about 26 Joules of energy; medium shaft – 30 J (15% more); soft shaft – 34 J (30% more). The total work per stroke of this rower was 1022 J, so the share of elastic energy ranges from 2.5% to 3.3% (stiff and soft shafts).



These values don't look very high. However, at 34 deg of oar angle, where the peak force is achieved and the stored elastic energy is maximal, it amounts to 6.4% to 8.4% of the rower energy production up to that point in the drive. At an oar angle of about 60 deg (when the force gradient and the elastic power are maximal) the share of elastic energy ranges from 19.6% to 25.5%, which confirms our previous statement. The maximal flexure of the shaft measured at the middle of the handle ranges from 5.8 cm to 7.6 cm (stiff and soft shafts) at the max. force of 450 N on each handle.

Most of the elastic energy is stored at oar angles longer than 50 deg, when the gearing ratio is about 4 (RNB 2007/03). The return of elastic energy happens mainly near the perpendicular position of the oar, when the gearing ratio is about 2. This means more acceleration of the rower-boat system and higher effectiveness ("whipping effect"). The oar shaft may recoil not only at the handle, but also in the middle, where it pushes the pin forward, accelerates the boat and creates "trampolining effect" on the stretcher (RBN 2006/02). **Early peak force and optimal timing of the drive are important for effective use of elastic energy of the oar** (RBN 2004/01-02).

During the last World Championship in Munich some very obvious examples of rowing technique with early peak force were demonstrated by bronze medallist W1x Michelle Guerette, USA and the gold medallists Australian M2-.

References:

1. *Concept2: Scull Shaft Construction and Stiffness.* http://www.concept2.com/us/products/oars/sculls/shaft.asp

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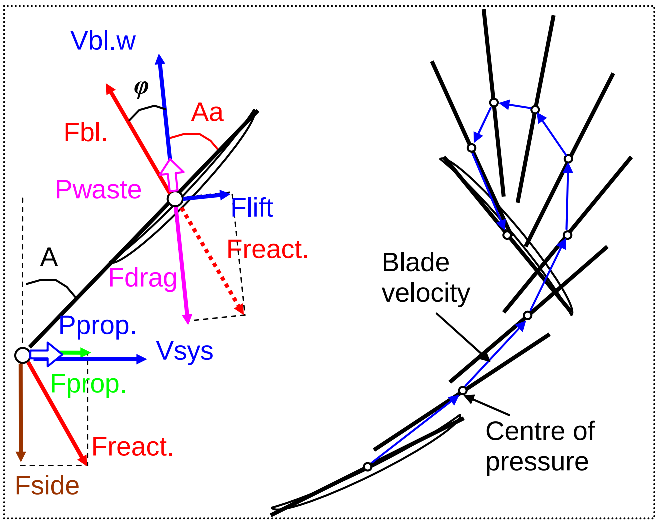
Facts. Did you know that…

…rowers loose an average of 18.5% of their power due to slippage of the blade in the water? Some publications on this topic are given below. We also mentioned it briefly in RBN 2001/04, 06, 07, 2003/08. With some assumptions (3) we define blade propulsive efficiency ***Ebl*** using measurements of the boat velocity ***Vboat***, oar angle ***A*** and the handle force ***Fh***. The chart below shows the path of the blade in the water during the drive and mechanics of ***Ebl*** calculations:



The force applied at the centre of the blade ***Fbl*** is calculated using measured ***Fh*** and actual oar gearing (RBN 2006/11). The velocity of the blade relative water ***Vbl.w*** is determined using oar angular velocity and ***Vboat***. The waste power ***Pw*** is calculated as a scalar product of the force ***Fb*** and velocity ***Vbl.w*** vectors:

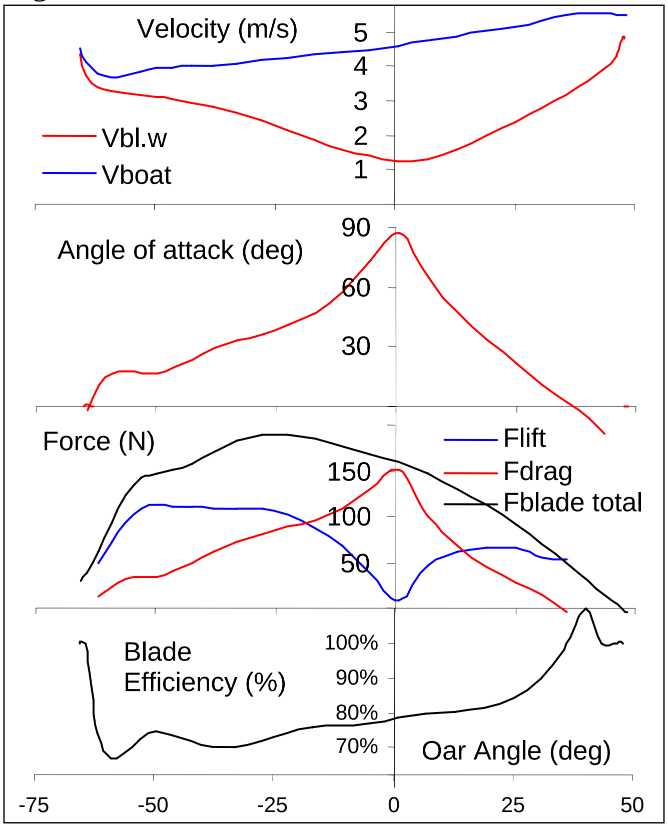
$$Pw = Fb\ Vbl.w\ \cos\varphi \qquad (1)$$

,where φ is the angle between vectors.

The total power applied to the handle ***Ptot*** is calculated as a product of ***Fh*** and handle velocity. Propulsive power ***Pprop*** can be derived as a product of the propulsive force ***Fprop*** and a velocity of the centre of mass of the rowers-boat system ***Vsys***. It is quite difficult to calculate ***Vsys***, so we derive ***Pprop*** as a difference between ***Ptot*** and ***Pw***. Blade efficiency ***Ebl*** is derived:

$$Ebl = Pprop / Ptot = (Ptot - Pw) / Ptot \qquad (2)$$

The blade moves through the water at the angle called the angle of attack ***Aa***. If ***Aa*** is not 90°, then a lift force ***Flift*** is developed and the blade works as a hydro-foil. ***Flift*** is directed perpendicularly to ***Vbl.w*** and has 100% efficiency. All energy losses depend on drag force ***Fdrag***, which has opposite direction to ***Vbl.w***. ***Flift*** and ***Fdrag*** are components of a total blade reaction force ***FblR***, which has the same magnitude and opposite direction as ***Fbl***. ***FblR*** is transferred through the oar shaft to the system and can be decomposed to ***Fprop*** mentioned above and ***Fside***, which does NOT create any energy losses (RBN 2006/06). The chart below shows data of a single sculler rowing at a stroke rate of 36 str/min plotted relative to the oar angle:



The lift and drag factors were taken from (2) for a flat plate, so they can be used quite approximately here. In this example ***Flift*** contributes to 56% of the average blade force and ***Fdrag*** contributes to the remaining 44%. Total distance of the slippage of the blade centre was 1.7m and minimal slippage velocity was 1.25m/s at perpendicular position of the blade. Overall blade efficiency was 76.5%. We will further discuss factors affecting blade propulsive efficiency in future Newsletters.

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1. Affeld, K., Schichl, K., Ziemann, A. (1993). Assessment of rowing efficiency. International journal of sports medicine, 14, S39 S41.
2. Caplan N., Gardner T., (2006) A fluid dynamic investigation of the Big Blade and Macon oar blade designs in rowing propulsion. Journal of Sports Sciences, 1 – 8
3. Kleshnev V. (1999) Propulsive efficiency of rowing. In: Proceedings of XVII International Symposium on Biomechanics in Sports, Perth, Australia, p. 224-228.

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