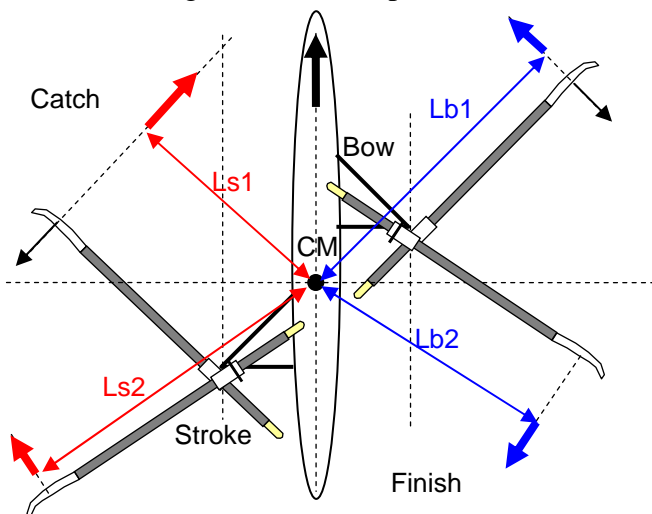


Facts. Did you know that...

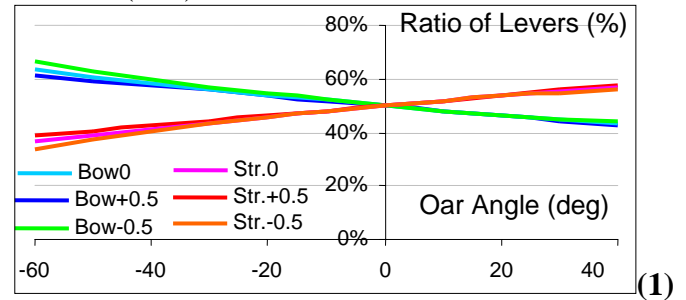
...the stroke in a pair must apply more force at the catch and the bow must pull harder at the finish? In RBN 2002/04 we already gave some comments on synchronisation of forces in a pair. That time we derived turning moments using the pin forces. After that we received comments from Einar Gjessing (inventor of the famous rowing ergometer), where he derived levers for the blade forces. We found that Einar's method is the most correct way to solve the problem, because the blade force is the only external force in the system. The pin force is an internal force and must be considered in conjunction with other forces on the stretcher, handle and seat, which all can produce turning moments on the boat hull. It is difficult to measure all the above forces, while the blade force can easily be derived from the measured handle or swivel force. The Figure below shows the mechanics of the turning moments in a pair:



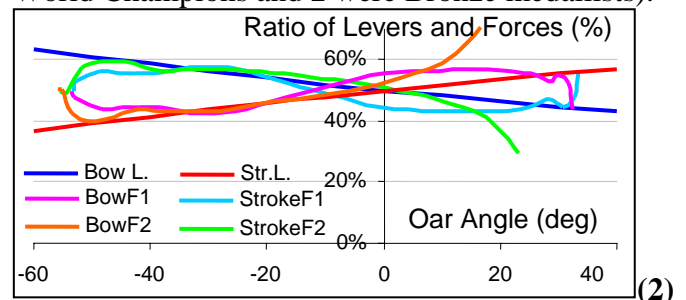
The actual outboard (from pin to the middle of the blade) was used in the model. The lever for the blade force is equal to the length of perpendicular from the line of the force to the centre of the boat. At the catch, bow has an advantage (Lb1 is longer than Ls1), so the stroke has to apply more force to produce the same rotating moment. At the finish, the opposite is the case (Lb2 is shorter than Ls2).

What is considered as the centre of the boat is an important point. We decided that it must be the centre of mass (CM) of the whole system (boat and athletes), because this is the only mechanically correct way to analyse the boat orientation and velocity vector. The rowers' masses make the largest contribution to the system, so the system CM moves together with the movement of the rowers' masses during the stroke cycle. The Chart 1 below shows the ratio of levers for stroke and bow, de-

rived for various positions of the system CM: at the geometrical centre of the boat (0), 0.5m closer to the stern (+0.5) and the same distance closer to the bow (-0.5).



You can see that position of the CM of the system does not affect the ratio very significantly ($\pm 2.5\%$ at 60deg oar angle). As the catch angle is longer than the finish angle, the stroke has to produce a higher average force. At angles of 56deg at the catch and 34deg at the finish, the contribution by the stroke must be 52.5% and by the bow 47.5%, i.e. 5% difference. The chart below compares the ratios of measured forces and the lever models for two international level pairs (1 were World Champions and 2 were Bronze medallists).



You can see that the ratio of forces is very close to the inverse ratio of the levers, which helps to keep the boat straight. The ratios of average forces were 51.5 : 48.5% for the 1st crew and 52.1 : 47.9% for the 2nd, which is also close to the model.

What we can do to reduce the difference in the leverage? Chart (1) suggests that we can move the CM closer to the stern relative to the pins. However, we can't alter this much because it will affect the geometry of the rowers' work. Another way is to use a longer spread/outboard for the stroke rower. The difference must be huge to make the ratio even (4cm difference in spread + 10cm in outboard makes the average leverage only 3% different). The third method was suggested before: the same 3% difference in leverage can be achieved if the bow rower were to move his arc 5deg closer to the bow.

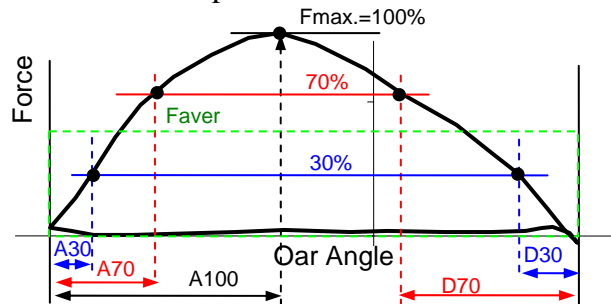
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Q&A

Q: Rower and Ph.D student Alexey Volgin from Saint-Petersburg, Russia is asking: “What parameters of the force curve can be used for evaluation of rowing technique?”

A: We already discussed some parameters before (RBN 2001/07,12, 2002/06, 07, 2004/12). Now we will try to summarise definitions of force curve parameters and outline their usage for the assessment of rowing technique. The chart below shows a typical force curve and graphical representation of the parameters:



The most obvious parameter is a maximum force **Fmax**, which is the highest point on the force curve. An average force **Faver** is equal to the height of a rectangle, of which the area is equal to the area under the force curve. The ratio of the average to maximal forces (**Ram**=**Faver/ Fmax**) reflects “fat” or “slim” force curves:

- For a perfect rectangular shape, **Ram** = 100%;
- For a perfect triangular shape, **Ram** =50%.

We found this ratio in rowing ranges from 38% to 64% with average $50.9 \pm 4.5\%$ (mean \pm SD).

The term “catch slip” was traditionally used as a definition of how quickly the force increases at the catch and “release slip” was used to indicate its maintenance at the release. In fact, these parameters have very low correlation with a “slippage” of the blade in the water (vertical catch and release slips were mentioned in RBN 2007/04), so we prefer to use the term “gradient of force”. The slippage can be long, but the gradient is steep if the blade moves quickly on a shallow path through the water. At a higher stroke rate, it usually requires a shorter angle to achieve 30% of max. force ($r = -0.44$), but a longer angle to bury the blade. (The vertical catch slip increases, $r = 0.20$).

Values of 30% and 70% of the maximum force were usually used as the criteria for the force gradient. We define the catch gradient as an angle, through which the oar travels from the catch point to the point, where the force **A**chieves the criterion (**A30** and **A70**). The release gradient is defined as an angle from the point, where the force **D**rops be-

low the criterion to the finish of the drive (**D70** and **D30**). Parameter **A100** reflects the position of the peak force and can be used as a definition of a “front loaded” drive (RBN 2006/06). Why were values of 30% and 70% used as the criteria? The first of them was adopted from fixed criteria (100N for sculling and 200N for sweep), which were traditionally used in Australia, adjusted to accommodate various categories of athlete in both sculling and rowing. The purpose of this parameter was to determine how quickly the blade grips the water. We found that **A30 has a correlation with the efficiency** of the blade ($r = -0.34$). **Ram** also slightly correlates with the blade efficiency ($r = 0.32$) which means that a quicker force increase and a rectangular shape of the force curve reduces slippage of the blade in the water.

The criterion 70% was used in Russia in 1960-80s. Contrarily, **A70** has an insignificant correlation with the blade efficiency ($r = -0.13$), but **A70 relates to the effectiveness of rowing technique** (RBN 2004/12). Efficiency means minimising the energy expenditure for an equivalent performance. Effectiveness means the maximising of performance using all available resources. This fundamental difference can be explained by the mechanics of force increase: the 30% level can be achieved by good handling of the oar and using the small muscles of the arms and shoulders, but the 70% level is not achievable without dynamic acceleration of the rower’s mass and involvement of the large leg and trunk muscles. As a confirmation, we found that only **A70** and **D70** correlate with maximal legs velocity ($r=-0.28$ and $r=-0.38$), i.e. quicker legs produce steeper gradients of force.

Parameters of force gradients depend on the stroke rate: **A30** and **A70** getting shorter at high rate ($r=-30$ and $r=-43$), but **D70** and **D30** getting slightly longer ($r=0.21$ and $r=0.18$). This reflects changes in the force curve at higher rates (RBN 2004/12). By way of illustration, we determined averages at training rates below 30 str/min (T) and at racing rates above 30 str/min (R):

Degrees	A30		A70		D70		D30	
Rate	T	R	T	R	T	R	T	R
Rowing	6.7	5.2	16.7	13.6	30.3	34.0	11.5	12.8
\pm SD	1.9	1.6	3.8	3.1	7.6	7.3	3.1	3.5
Sculling	5.8	3.8	17.2	13.4	35.6	38.2	14.5	15.7
\pm SD	2.0	1.5	4.8	4.6	7.0	6.6	3.3	3.3

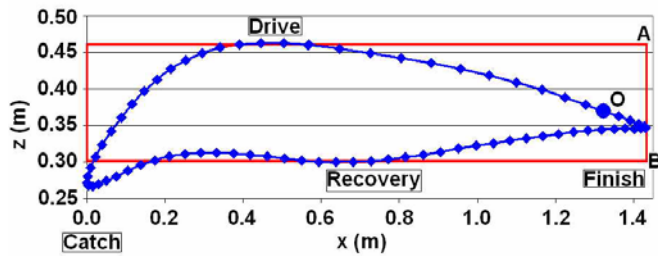
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Dr. Volker Nolte of University of Western Ontario, London/Canada kindly shares his ideas and experience with us:

Myths and reality about the release

The “handcurve” is the path of the handle relative to the boat, when you look from the side. Many coaches still believe that the “ideal” handcurve should look like the rectangle in the Figure below. You still find the same idea of the handcurve in certain coaching literature, so that coaches find their belief officially supported (1, 2).



However, a common shape of a real handcurve looks like the line with diamonds. This handcurve was obtained from a video analysis of a international level single sculler. The question is: Why would one still teach the “ideal” handcurve that is in fact impossible to execute in real life? While it could be argued that there are theoretical reasons to use the “ideal” handcurve as a model, one could also make a case that if coaches understand rowing biomechanics correctly, they could teach technique more effectively.

DEFINITION. The catch and the finish are distinct points of the stroke representing single moments in time. The entry, drive, release and recovery are phases that take some period of time. The catch is defined as the furthest point of the handle towards the stern. The finish is the furthest point towards the bow. The release is defined as the process of the blade removal from the water. The following discussion focuses on the release, finish and the first part of the recovery.

THE IMPOSSIBLE RECTANGLE. The idea behind the rectangular handcurve is comprehensible: the blade should propel the rower/boat system as long as possible. However, in a moving boat it is physically impossible to keep the blade fully covered until the handle reaches the finish position. If a rower were actually to try to follow the rectangular handcurve, the handle would reach point “A” on the handcurve. At this moment, the blade would still be fully covered in water, but the handle cannot move any more horizontally relative to the boat. The handle and blade velocities in x-

direction relative to the boat are zero, i.e. they move with the boat velocity relative to the water. This would end in a complete boat stopper that we call a “crab”! The movement from the point “A” to “B” takes at least 0.1 s. During this time, a boat at race pace travels between 0.4 to 0.6 m. This means a rower cannot possibly carry out a completely vertical movement with the handle.

THE RELEASE IN REAL ROWING. The considerations above should clarify that we can, under no circumstances, experience the rectangular handcurve. So, how does a handcurve have to look like? The diamonds in the figure signify the handle coordinates for each video frame. This means that the distance between two adjacent diamonds is a measure for the velocity of the handle. The largest horizontal velocity of the handle during the drive is found around $x=0.9$ m. The horizontal handle velocity has to decline, since it has to reach zero at the finish position. In between, the handle velocity passes a point, where the blade has to be out of the water, since it would create resistance after that.

At the point “O” the blade is completely out of the water. Some time prior to this point, the rower needed to start the removal of the blade, which is a continuous pull on the handle with a simultaneous movement down. This complex movement is difficult, since any improper coordination leads to an ineffective release.

Another interesting phenomenon: after passing through point “O” the rower continues to move his hand horizontally towards the body while the blade is already completely removed from the water. This movement is vital to give the rower the chance to decelerate the handle to a final stop without causing negative forces on the blade.

PRACTICAL APPLICATION. It is questionable that the “rectangular model” can work efficiently in teaching rowing technique. One can often hear from coaches who use the rectangular model that their rowers “have poor bladework in the release”. It is important that coaches learn how a handcurve with a proper release should look like and then try to find creative ways to teach it.

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7 year anniversary!

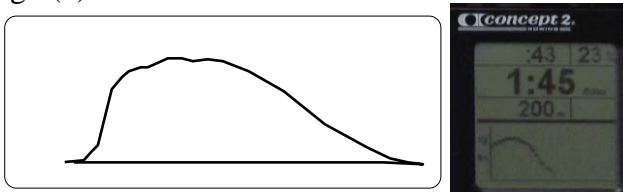
Our Rowing Biomechanics Newsletter is celebrating its 7 year anniversary! Thanks to everybody who contributed to the success of the Newsletter. We received more than 2000 replies, which was really valuable feedback for us and for development of Rowing Biomechanics.

Now the Newsletter is to be converted into mini e-journal. We invite everybody who has interesting ideas, facts and observations to contribute to our Rowing Biomechanics journal.

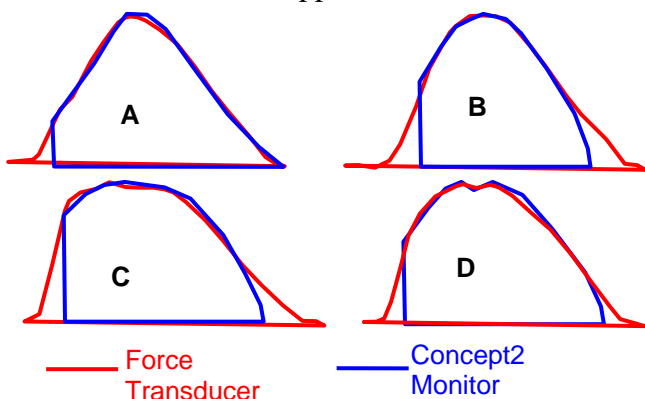
Q&A

Q: A number of coaches asked similar questions about the force curve, which can be displayed on the monitor of Concept2 ergo. The sense of the questions was: how accurately can the monitor represent the real force application?

A: We measured the handle force and position directly using transducers of WEBA Rower Ergo system (1). The force/position curve was displayed on PC screen and filmed together with the force curve on the Concept2 PM3 monitor of a model D ergo (2):



Then a few curves of various shapes were digitised, scaled and overlapped:



You can see that the monitor sufficiently represents the basic shape of the force curve and position of its peak: you can clearly see that the curve A is triangular with a later peak and the curve C is more rectangular with an earlier peak in both measurements. The monitor also was able to show humps and dents in the force curve D.

The obvious difference can be seen at the catch: the monitor cuts off the first 15-20cm of the

force curve. Probably, this can be explained by backlash in the one-way clutch (3-8cm) and latency in the electronics, which in fact measure the acceleration of the flywheel. Curves with slower gradient of the force (e.g. A) allow better representation on the monitor. Steeper curves usually have cut-offs at both catch and finish (e.g. B, C and D) and the reason for the shape of the last one is not yet understood.

Conclusion: You can use the Concept2 ergo monitor for a rough evaluation of the force curve, which is useful with beginners and medium level rowers. More accurate feedback for elite rowers requires instrumented measurements.

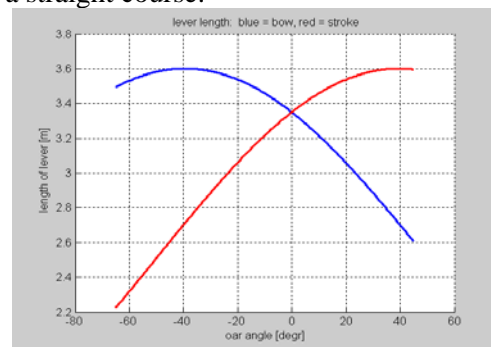
References

1. WEBA Rower Ergo system http://www.weba-sport.com/weba/rower_ergo.html
2. Concept 2 PM3 Performance Monitor <http://www.concept2.com/us/products/monitors/pm3.asp>

Comments

Marinus van Holst (m.holst@hccnet.nl), rowing biomechanist from Nederland sent us his comments about forces in a sweep pair published in RBN 2008/01:

“When I read this newsletter I did not immediately believe the results although I recognized the formulation of the problem. It seemed to me that to reduce the differences in stroke- and bow torques, the bow rower should reach more far at the catch than the stroke rower, but to my surprise the contrary was the case. I repeated the calculation of Valery with a model that in principle was not different from his model. The results are presented in a slightly different way. The Figure below shows that for the bow, the lever has a clear maximum at 40°. For oar angles <40° the lever of the bow force decreases. Most important and decisive, of course, is the experiment with the pairs. Without these results I would have remained skeptical that rowers in a pair would be able to achieve such fine-tuning required for a straight course.”



Lever arms: Stroke - Red,
Bow - Blue

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Original Research

Marinus van Holst (m.holst@hccnet.nl), mechanical engineer from Nederland sent us his really interesting study on **Lift and Drag forces on the blade**. Marinus presents equations, which link the lift and drag forces with the angle of attack. The modelling can be done much easier now than before, using the experimental data.

Since Volker Nolte's PhD thesis, "Wie wird ein Ruderboot angetrieben?" ("How is a rowing boat propelled?") hydrodynamic lift force has attracted the attention of many people in the rowing community. It seems to have received an almost mythical status for some. From the messages in rowing newsgroups, one gets the impression that lift is good and drag is bad. This is understandable because drag and lift are terms originally used in aero engineering and for an airplane lift means payload (good) and drag means fuel consumption (bad). A great amount of research was carried out to develop an airfoil (a wing cross section) that produces maximum lift and minimal drag. In rowing things are slightly different: It is very good to understand the meaning of lift and drag, but the possibilities for taking advantage of this knowledge (rowing faster) are very limited.

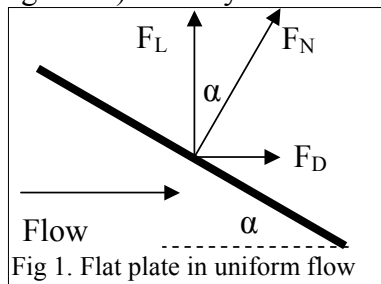


Fig 1. Flat plate in uniform flow

A body moving through a flow experiences a force. In general the direction of the force is not the same as the direction of the flow. Therefore the force can be resolved into a component perpendicular to the flow direction, the lift force, and a component along the flow direction: the drag force. (In the case of an airplane, lift also means "against gravity"; hence its name). The resolution is a geometrical exercise and not a physical one, and its consequence is that the drag component does work and the lift component does not. This has of course a physical meaning: work (actually power) can also be calculated as the scalar ("dot") product of the force vector and the velocity vector. When the body exposed to a flow is a flat plate and considering a two dimensional case as in Fig 1, the force F_N is perpendicular to the plate (because at every elementary area the force is the resultant of the normal pressure on both sides) and the angle α between the F_L and F_N is the same as the angle between the plate and flow direction,

the angle of attack α . There is a strict relation between the drag and lift force:

$$F_D / F_L = \tan \alpha$$

Recently Caplan and Gardner (1) did experiments to find the lift and drag forces on a flat plate and on a hatchet blade. The results were expressed in lift and drag coefficients C_L and C_D . The definitions follow from

$$F_L = C_L 0.5 \rho v^2 A$$

$$F_D = C_D 0.5 \rho v^2 A$$

where ρ is the density of water, v is the flow velocity and A is the blade area. The graphs they found can be approximated very closely by

$$C_D = 2C (\sin \alpha)^2$$

$$C_L = C \sin(2\alpha)$$

where C is a dimensionless constant, which represents a function of the shape of a surface of the blade. This confirms the relation:

$$F_D / F_L = C_D / C_L = \tan \alpha$$

These expressions were not presented in (1). Some small differences between the flat plate and the hatchet blade were found but they are not relevant in this context. Important was: the blade force is perpendicular to the flat plate and perpendicular to the chord of the hatchet blade. No in-plane forces (friction) were measured.

This results lead to an alternative formulation for lift and drag forces and coefficients. The normal force on the blade:

$$F_N = \sqrt{F_D^2 + F_L^2} \text{ and } C_N = \sqrt{C_D^2 + C_L^2}$$

With the expressions above this becomes

$$C_N = 2C \sin \alpha + \sqrt{1 + (\cos \alpha)^2}$$

The waste power P_W delivered by the blade on the water is a part of the rower's power output that heats up the water instead of propelling the boat:

$$P_W = F_D v = F_N v \sin \alpha$$

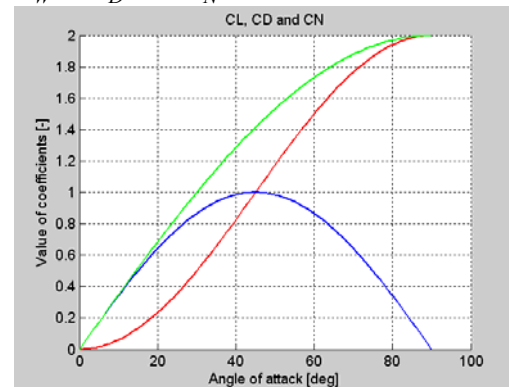


Fig 2 C_D - red; C_L - blue; C_N - green

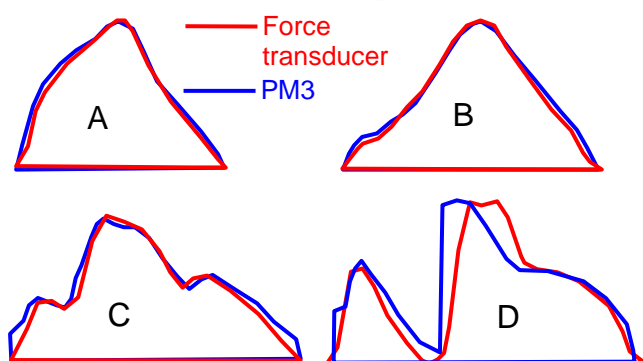
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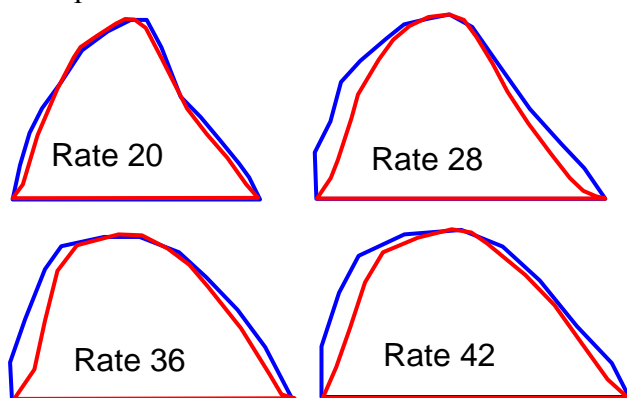
Q&A

We have received a very good feedback after previous publication on the comparison of force curves on PM3 monitor. Here we show the results of additional analysis, stimulated by two comments:

1. Scott Hamilton, an electronic product engineer with Concept2 Inc., advised us to upgrade the firmware of PM3 monitor. The latest version 101 was downloaded from www.Concept2.com site and uploaded into PM3. Scott has made it explicit that PM3 displays force/time curve, so we repeated the experiment with force/time curves on both PM3 and PC displays using the same video method as before (RBN 2008/04). The comparison has shown much better correspondence:



Only the curve D with very rough shape was a bit different, but this sort of curves can never be found in practice. Then we decided to check the correspondence at different stroke rates:

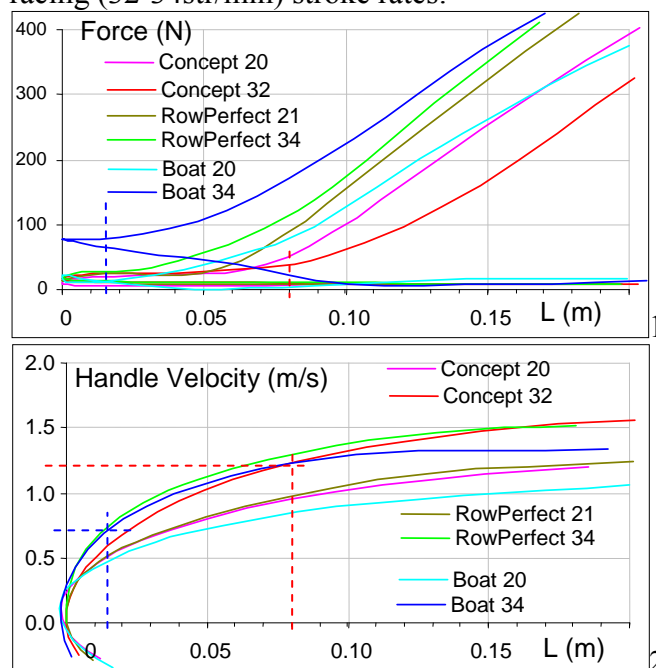


You can see that the correspondence is not so good at higher rates.

2. We had an interesting discussion with Cas Rekers, the inventor of RowPerfect machine about the reason of backlash of the force/length curve at catch. Cas informed us that the clutch itself is very precise and it takes less than $\frac{1}{4}$ mm of the chain translation to engage it. However, at the catch the driven shaft with flywheel rotates with significant speed, so the driving cogwheel and the chain must accelerate up to that speed before the clutch gets engaged. We both agreed to call the initial phase of the drive “handle acceleration” or “engagement length”. During this phase the rotation of the cogwheel is slower than rotation of the driven shaft

and the clutch is not engaged, similar to in a boat, the blade not yet being engaged. This means that no energy is added to the flywheel and the measured force is really small.

To compare the moment when the clutch engages with that of engaging the blade during on-water rowing, we used the data from our 2004 experiment (RBN 2005/03, 1), acquired on Concept2 and RowPerfect ergometers as well as on the water in a single scull, all at training (20-21str/min) and racing (32-34str/min) stroke rates:



The charts above show that the force starts increasing sharply, when the handle velocity ranges from 0.7m/s in a single at to 1.2m/s on Concept2 at 32str/min. On-water and on a RowPerfect less than 4cm distance is required to find the support, compared with 7-8cm for Concept2 at 32 str/min.

In general, the pattern of handle acceleration at catch is quite similar on both ergometers and on the water, because it depends more on the acceleration of the masses of the rower and boat/frame, than on the acceleration of the chain/oar only. Shorter engagement length indicates the difference between the systems with moving masses (boat and RowPerfect) and the stationary system (Concept2). On-water rowing at high rates has one distinctive feature, because significant oar inertia creates some force on the handle even before catch, when the handle moves towards the stern.

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Original Research

Myriah Lynn, Biomechanics Specialist from USA kindly shares with us her research on importance of flexibility in rowing:

Rowing is a total body exercise that requires muscles throughout the body to work together and produce an efficient stroke. If one area of the body is not working optimally, or if different areas of the body are not working together efficiently, overall rowing performance could potentially suffer. Furthermore, misalignments can put additional undue stress on the body and leave it vulnerable to injury. For example, the hamstrings, gluteus, and muscles in the lower back are all connected. Tightness in any of these areas puts additional strain on the other areas, including the back. As is commonly known, a rounded back during exertion (e.g., lifting objects) greatly increases the risk of injury (McGregor, RBN 2005/07). Applying the principles of Biomechanics to help lengthen muscles, improve posture, and help the body work more efficiently as a unit could potentially improve performance.

To test whether a Biomechanics program would have a positive impact on rowing performance, we conducted a preliminary study with a college, NCAA rowing team in southern California, USA. Some of the athletes on the team were put through a six-week Biomechanics program that focused on stretches and exercises to lengthen muscles and to engage core muscles during daily movements and rowing strokes. It was posited that lengthening and strengthening these muscles would reduce the obstacles that can cause rounding of the back, thereby increasing an athlete's ability to use proper rowing technique.

Because this was a preliminary study, a simple sit-and-reach test (SnR) was used to get an objective, quantified measure of tightness of the calves, hamstrings, gluteus, and back before and after the program. Athletes who did not go through the program were also tested at these times.



Fig. 1. Sit-and-reach test (SnR) test.

All athletes were administered a 6km test on Concept2 rowing ergo within one week of the end of the program. The athletes' total times are split to show the average 500 meter time.

Results. The athletes who did participate in the program showed a 2.25cm greater improvement in their SnR than those who did not. Split rowing times and SnR were also found to have a significant correlation (Fig.2).

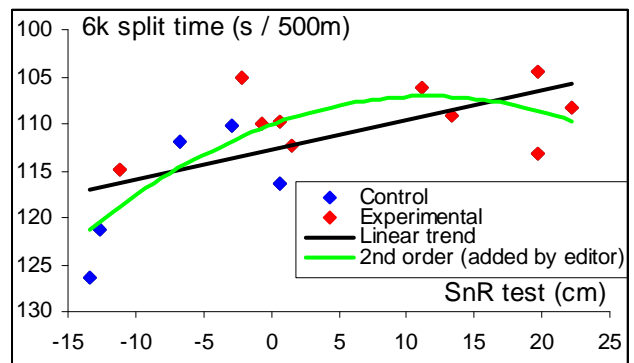


Fig. 2. 6k split (s) relative to Sit and Reach (cm), both taken at the end of the Biomechanics program. ($r = -0.63$, $p < 0.01$).

These findings suggest that flexibility of hamstrings, gluteus and lower back muscles positively correlates with rowing performance to a significant degree. A Biomechanics program can improve an athlete's flexibility.

There are likely many other factors that affect rowing performance and one should not draw too broad of conclusions based on these preliminary findings. The findings do, however support the position that an understanding of Biomechanics, including how different muscle regions interact, and, more importantly, having effective methods to train athletes in Biomechanics can help remove physical obstacles that might otherwise impede rowing performance. We are working to conduct further studies that allow for more causal conclusions.

Comments from the editor. We added a non-linear 2nd order polynomial trend line to the author's data, which produced a higher correlation ($r = -0.78$) and a peak at +10-12cm SnR. This can be interpreted that the flexibility should be at optimal level and too high flexibility could be negatively related to performance.

Obviously, this is a very preliminary study and it requires further research. Effect of the training program has to be studied on larger sample. However, the results are quite interesting and can give an idea to coaches to pay more attention to development of flexibility in rowers.

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Q&A

Q: A coach from Brisbane, Australia and former coxswain Brendan McGrath asked: "Would it be more productive to try and keep your heels down on the footplate at the catch?" Other Australian coach and coaches' educator Peter Halliday asked a similar question: "Do the heels rise from the foot stretcher before or at the catch? ...Relative to the heel movement when should the blade be locked in the water ready for a drive? ... Does the body weight move onto the 'balls of the feet' before or at the catch?"

A: As regards the catch, the answer is quite simple. The pressure must be applied on the toes for two main reasons:

1. Pushing with the toes reduces the vertical lever of the handle force Vh (Fig.1, a) and increases the horizontal lever of the rower's weight force Hw , which allows pulling the handle harder (RBN 2002/05). If the torque at the handle (product of the handle force and Vh) exceeds the gravity torque (product of the rower's weight and Hw), then the rower will lift himself, lose contact with the seat and have to stop rowing. At the catch, the horizontal lever Hw is the shortest, so it is important to maximise it and minimise the vertical lever Vh .
2. Pushing with the toes also reduces the lever at knee joint, which allows more efficient use of the *quadriceps* muscles and quicker extension of the knee.

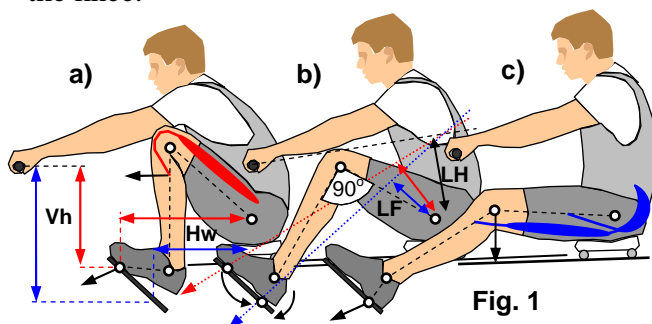


Fig. 1

Also, it would not be possible to push with the heels at the catch, because the range of flexibility of the ankle joint would be smaller than the range of the shin's rotation. In this case, if we set the stretcher angle flatter to support the heels at catch, the rower will experience overextension of the ankle at finish. The moment of raising the heels from the stretcher is defined by the stretcher angle and flexibility at the ankle joint. The main target for the rower during the recovery is to be relaxed for as long as possible, so the heel will rise naturally

as the shin rises and the Achilles tendon pulls the heel upwards.

The moment when the heels settle down on the stretcher during the drive is more important. Unfortunately, we don't have any measured data here, so we can use biomechanical modelling only. The key point is the position of the rower, when the knee angle is passing 90 degrees (Fig. 1, b):

- Before this point, the rower must push the stretcher with the toes, **extend the knee** using the quads (Fig. 1, a) and refrain from opening the trunk, because use of the muscles of the back of the thigh (hamstrings and gluts) would flex the knee.
- After this point, the rower must push the stretcher with the heels and start using the trunk, emphasising **pushing the knee down** with hamstrings and gluts, which mechanically extends the knee (Fig. 1, c). Pushing with heels is more effective because it reduces the lever of the stretcher force at the hip joint (see below).

At a 90deg knee angle, the rower should quickly put the heels down on the stretcher plate and transfer the pressure onto them. This movement affects the boat acceleration and temporal structure of the drive (RBN 2004/01). The moment of heel-placement coincides with the D4 micro-phase with a hump on the boat acceleration curve.

This phenomenon can be well explained using the excellent model of Einar Gjessing (1), which defines levers of the stretcher and handle forces relative to the hip joint. When the point of force application on the stretcher suddenly moves lower from the toes to the heels (Fig. 1, b), the lever of the stretcher force relative to the hip joint LF becomes shorter, but the lever of the handle force LH remains the same. At constant muscle torque, the stretcher force increases and the handle force remains the same. This causes lower boat acceleration, but higher acceleration of the rower's CM.

Conclusion: It is necessary to push the stretcher with toes at catch and with heels during the second half of the drive. The ability to shift the pressure smoothly and coordinate it with the trunk movement depends on the rower's skill and is very important for effective rowing technique.

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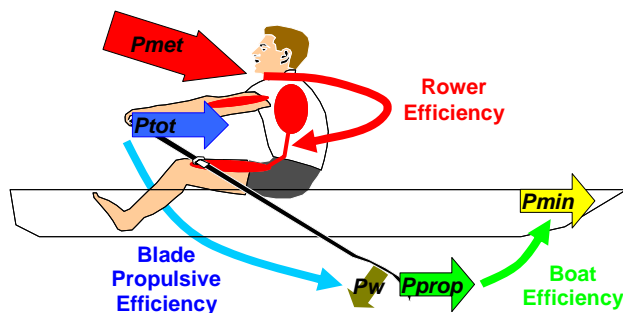
News

Congratulations to British rowers, who were the best performers on the Olympic Games in Beijing with two gold, two silver and two bronze medals! Well done! Australians also performed well with two golds and one silver.

Q&A

Q: We have received a number of questions with the following meaning: “How can rowing efficiency be defined?”

A: The standard definition of the efficiency of any mechanism is the ratio of output to input power: $E = P_{out} / P_{in}$. In rowing we can define the following chain of components, which the energy is transferred from the previous to the next: rower - oar - boat. The figure below shows schematically the process of the energy transformation:



Efficiency of the rower **Erow** can be measured as the ratio of the total mechanical power **Ptot** applied at the handle (and the stretcher, RBN 2004/06) to the consumed metabolic power **Pmet**, which can be evaluated using physiological gas-analysis methods.

$$E_{row} = P_{tot} / P_{met}$$

The “delta” rower efficiency was measured at $22.8 \pm 2.2\%$ (mean \pm SD) (1).

Blade propulsive efficiency **Ebl** is the ratio of the propulsive power at the blade **Pprop** to **Ptot** (RBN 2007/12). **Pprop** can be calculated as a difference between **Ptot** and waste power **Pw**, which is spent on moving the water:

$$E_{bl} = P_{prop} / P_{tot} = (P_{tot} - P_w) / P_{tot}$$

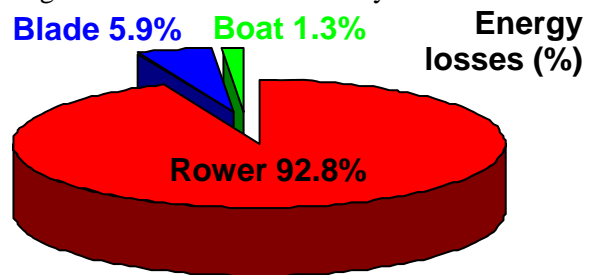
We determined **Ebl** as equal to $78.5\% \pm 3.1\%$ (2) for a single, which has a high SD owing to variation in weather conditions.

Boat efficiency **Eboat** can be defined (RBN 2003/12) as:

$$E_{boat} = P_{min} / P_{prop}$$

where **Pmin** is the minimal power required for propelling the boat and rower with a constant speed equal to the average boat velocity. We calculate **Eboat** using the variation of the boat velocity only and found it equal to $93.8 \pm 0.8\%$ (2) (in fact, it is affected by other factors such as vertical oscillation of the shell, but this is included in **Pmin**). The standard deviation in **Eboat** is quite small and mainly affected by the stroke rate.

It is interesting to estimate the energy losses caused by each of the three components of efficiency above. Let’s take a single sculler, who sculls at 5.06m/s (6:35 for 2000m), so we can estimate **Ptot** as about 544W (RBN 2007/08). In this case **Pmet** must be about 2386W, which requires 7.1 l/min of O₂ (consumption plus debt). **Pprop** in this case is 427W and **Pmin** is 400W. We can calculate the absolute energy losses by subtracting each value from the previous in the chain. Then we can determine the proportion of the losses by dividing the three absolute values by their sum:



From the chart above you can see that the most of the energy losses, 92.8%, occurred inside the rower’s body. Blade slippage contributes 5.9% and the boat speed variation – only 1.3%. These numbers suggest that the greatest scope for performance gain can be found inside the rower’s body.

Obviously, no component can have an efficiency of 100%. However, we can use standard deviation as a measure of the variability between rowers, boats and various conditions, i.e. as a measure for changing the component. To model a possible gain in the boat speed, we increase efficiency of a component by its SD. In this case we can gain **12.0s** from **Erow** improvement by 2.2%, **4.9s** from **Ebl** increase by 3.1% and only **1.1s** from **Eboat** increase by 0.8%. Moreover, variation in **Ebl** and **Eboat** depends mainly on wind resistance and stroke rate, and the rower cannot improve them significantly. This means we should focus our attention on improvement of the rower’s efficiency, which depends on many factors such as:

- use of the most powerful muscle groups,
- optimum muscle contraction velocities,
- single-motion movement;
- proper relaxation of the antagonist muscles.

Some of these points have already been discussed, the others we will discuss later.

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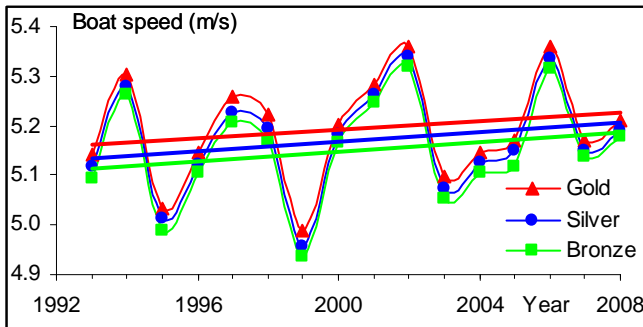
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Facts. Did you know that...

...the finals of the last Olympic regatta in Beijing didn't show us the fastest boat speeds; though some very good times were shown during heats (world best time 5:36.20 in M4x AUS). The average speed of the medallists in the 14 boat types was at the level of the trend over the last 16 years:



The trend in the winner's speed grew by 0.082% per year, but for the silver and bronze medallists the slope was higher: 0.090% and 0.093% respectively. This means the margins are getting closer from year to year.

In RBN 2005/08 we found that margins didn't change much over the years, but now a trend towards smaller margins has definitely appeared. The table below shows the average margins (in seconds) from the winners in the 14 Olympic events and slopes of the trends:

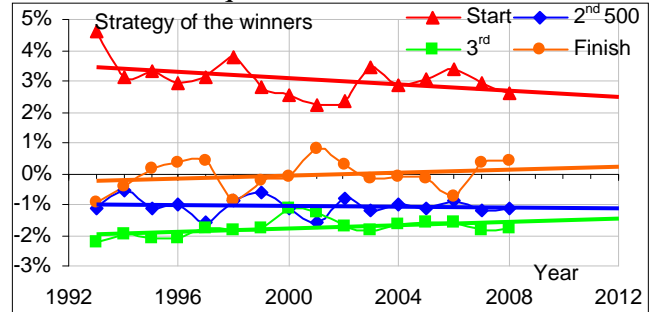
Margin(s) \ Place	2nd	3rd	4th	5th	6th
2008 Olympics	1.34	2.34	4.58	7.84	12.17
Average 1993-2008	1.78	3.24	5.40	8.26	11.62
Slope (s/year)	-0.03	-0.04	-0.05	-0.01	0.02

The negative slope tells us that the silver medallists reduced their margin from the winner by 0.03s every year, so they would catch up within 40 years and bronze would do it by 2062! Obviously, it won't happen and the current tendency should change in magnitude and, possibly, in direction. However, these facts confirm that currently the competition is getting tougher and tougher. Recently, we saw the Olympic final in W2x, where only 0.01s split gold from silver, and 0.23s silver from bronze. In contrast, the 6th place is getting further away from the winners from year to year.

In the boat types the highest growth of the speed was found in W8+ (0.32% per year), LW2x and LM2x:

Boat	W8+	LW2x	LM2x	LM4-	M8+	M4x	W4x
Slope	0.32%	0.26%	0.25%	0.23%	0.19%	0.16%	0.15%
Boat	W1x	W2-	M4-	M1x	W2x	M2x	M2-
Slope	0.03%	-0.02%	-0.03%	-0.05%	-0.11%	-0.11%	-0.13%

Another example of change is the trend in race strategy. In RBN 2002/10 we predicted the average race strategy in 2008 would be: +1%, -1%, -1%, +1%. In 2005 we had to change it to +2%, -1%, -1.5%, +0.5%. The winners of the last Olympics had showed on average +2.6%, -1.1%, -1.8%, +0.4%, which is quite close to the last forecast.



Using the current trends we can deduce the following typical strategy of the winners for 2012: +2.5%, -1.1%, -1.4%, +0.2%, which would not be very different from this year's numbers.

As always, silver and bronze medallists were relatively faster over the last 500m, but they had lost to the winners mainly during the second 500m, which was an unusual feature of this Olympics:

	2008	Gold	Silver	Bronze	4th	5th	6th
Start		2.6%	2.6%	2.6%	3.0%	3.3%	3.7%
2nd 500		-1.1%	-1.8%	-1.7%	-1.7%	-1.3%	-1.0%
3rd 500		-1.8%	-1.6%	-1.6%	-1.9%	-1.6%	-2.0%
Finish		0.4%	0.9%	1.0%	0.8%	-0.1%	-0.5%

Race strategy in the Beijing finals had a quite distinctive national federation characteristic:

	n	Start	2nd	3rd	Finish	Var.
AUS	7	3.5%	-1.3%	-1.8%	-0.2%	2.5%
CAN	5	3.4%	-1.4%	-2.1%	0.3%	2.8%
CHN	6	2.5%	-1.6%	-2.0%	1.3%	2.7%
CZE	4	5.3%	-1.1%	-1.5%	-2.2%	4.1%
FRA	4	3.2%	-2.1%	-2.6%	1.7%	2.9%
GBR	10	3.1%	-1.7%	-1.8%	0.6%	2.5%
GER	7	4.0%	-1.8%	-2.4%	0.4%	3.1%
NED	4	1.8%	-1.5%	-2.0%	1.9%	2.2%
NZL	5	2.0%	-1.7%	-0.9%	0.8%	2.1%
POL	4	2.1%	-0.5%	-1.5%	0.0%	2.1%
USA	7	2.6%	-1.4%	-1.0%	0.0%	2.2%

The Czechs and Germans were fastest at the start and therefore had the highest variation of the boat speed over the race. Dutch and French rowers had the fastest finish. New Zealand and Poland had the most even distribution of boat speed. British rowers had the most balanced race strategy, which reflected their leading performance in Beijing.

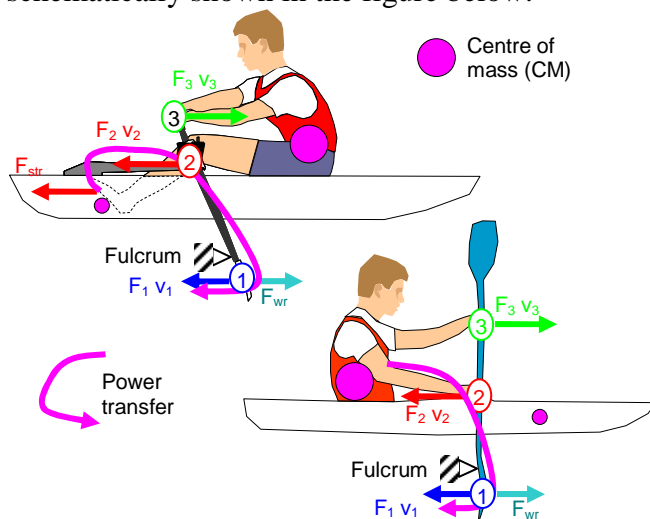
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Q&A

Q: Paul Conlin, a graduate student at Lehigh University, a coach for St. Mary's College (Maryland, US), and a competitive sculler has asked: "In my Masters thesis I have a section dedicated to asynchronous rowing. According to your paper posted at www.biorow.com ~47% of a rower's power is generated through the foot stretcher. According to Dr. Atkinson (www.atkinsoph.com), one reason asynchronous rowing does not work is because the foot stretcher becomes stationary with reference to the rower. Thus no work can be done at the stretcher ($W = F \cdot s$ and here $s = 0$). My question is simply this, how does the energy transferred through the stretcher help propel the boat when it is directed in the wrong direction?"

A: In RBN 2004/06 we discussed methods of defining power in rowing and said that "the handle/foot-stretcher power ratio was 60/40%". For better understanding, it is useful to compare rowing mechanics with canoeing mechanics, which are schematically shown in the figure below:



In both cases, the oar works as a lever of the second order with the fulcrum somewhere close to the blade. It is not easy to determine the exact position of this fulcrum, owing to slippage of blade in the water. If we consider forces, then there are three points of force application at the oar:

1. Blade force F_1 , which is directed backwards or creates water reaction force F_{wr} propelling the whole system forward;
2. Middle force F_2 (pulling arm in canoeing or gate in rowing) in the same direction as the blade force;
3. End force F_3 (pushing arm in canoeing or handle force in rowing) in the opposite direction to the above two forces.

Rowers do not apply the gate force F_2 directly, so we need to relate it to the stretcher force F_{str} as:

$$F_2 = F_{str} - m_{boat} a_{boat} \quad (1)$$

where $m_{boat} a_{boat}$ is the inertia force of the boat. The mass of the boat is significantly less than the rowers' mass, and so the gate and stretcher forces are quite closely related (RBN 2004/06).

How can we derive the power in canoeing? A canoeist applies power at the two points 2 and 3. As the mass and inertia of the paddle is negligible, the total power of the canoeist P_{tot} equal to the power applied at the blade P_{bl} :

$$P_{tot} = P_{bl} = F_1 v_1 = F_3 v_3 + F_2 v_2 \quad (2)$$

In rowing, the boat mass is associated with point 2 (gate), so it is much bigger than the paddle mass in canoeing. The blade power P_{bl} for a rower:

$$P_{bl} = F_3 v_3 + F_{str} v_2 - m_{boat} a_{boat} v_2 \quad (3)$$

The total power produces by rower P_{tot} is:

$$P_{tot} = P_{bl} + m_{boat} a_{boat} v_2 = F_3 v_3 + F_{str} v_2 \quad (4)$$

The total power in rowing is the sum of the handle power $F_3 v_3$ and the stretcher power $F_{str} v_2$. The blade power is less than total power by the inertial component $m_{boat} a_{boat} v_2$, which takes 6-10% of the total energy of a rower

The crucial question here is: what are the velocities v_2 and v_3 ? We believe that in both cases (rowing and canoeing) they must be velocities relative to the CM of the athlete. This is a very important point, concerning which some scientists appear to have made a mistake (1), by taking v_2 as the boat velocity relative to the water. At first glance, it seems quite logical to derive power as the product of force applied to the boat by its velocity. However, it is incorrect to multiply the force between two objects (boat and rower) by the velocity relative to a third (the water or the earth).

Conclusions:

1. In fact, the stretcher and the blade forces work in the same direction, but the handle force is directed in the "wrong" direction.
2. The power applied by the rower to the stretcher is transferred to the blade though the boat – rigger – pin – gate – shaft, and a part of it is spent on overcoming the boat inertia.
3. Rowing in asynchronous mode, on an ergo, in a rowing tank and, to some extent, "by seats" in a boat decreases power transfer through the stretcher down to zero because $v_2 = 0$.

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We open a new section in the Newsletter, which will show a close-up portrait of a coach. An emphasis will be made on how the coach uses biomechanics and other sport sciences.

Biomechanics and Coach: Paul Thompson



Paul Thompson (nickname Thommo) opens this section not only because I have known him quite well for a long time, but also because he is one of the most scientifically oriented coaches I have ever known.

Paul's rowing career begun at Telopea Park High School in Canberra Australia in 1978, when he was 14. Then he moved to nearby Narrabundah college and was coached by well known rowing coach Peter Shakespeare. The coaching must have been effective as Paul won the National Junior Championships. He was selected for the National junior team and came fourth in the pair at the FISA Junior Championships in 1982 in Piediluco, Italy.

In 1985 Paul was a member of the Victorian eight that won the prestigious Kings Cup, a race against all the Australian states. This crew was coached by Brian Richardson who went onto coach many medal winning crews for Australia and Canada. Also in 1985 the Australian Institute of Sport (AIS) in Canberra opened its rowing program and Paul gained a scholarship with it. Coached by one of rowing's most famous "hard men" Reinhold Batschi, Paul won a silver medal in the eight at the 1985 Match des Seniors in the eight and four National titles altogether. That year, Thommo was to encounter sport science for the first time represented by physiologists Dick Telford, Doug Tumulty and Alan Hahn. Physiology testing on a Gjessing ergometer required huge Douglas bags for measuring oxygen consumption.

After a wrist injury in a car accident, Paul ended his athletic career and turned his attentions to completing his studies at Canberra University where he graduated with an Applied Science degree. In 1988, he moved onto a scholarship coach position in AIS under Batschi's mentorship. That year he worked along side Alan Hahn with the pilot Talent Identification Scheme where he identified Megan Still. Paul was to coach Megan through her career to become World and Olympic Champion in the Women's Pair.

In 1990, Paul became a senior coach with the women's squad at the AIS. At this time, sport science was on the move at the AIS. A newly opened building was dedicated to Sport Science and its use rapidly expanded. Paul was able to work with world recognised experts in Physiology, Psychology and Nutrition. Rowing Biomechanics was introduced by Dr. Richard Smith of Sydney University, who brought to Canberra his telemetry system that measured oar force and angle. AIS biomechanist Mario Lamontagne made film-shots from a bridge to define oar angles.

In 1992 AIS acquired its own telemetry system, developed an instrumented ergometer and employed the first full-time rowing biomechanist, Peggy McBride. From that time regular biomechanical testing on water and on ergo was in-

troduced in day-to-day training. That was bits and pieces, which gave very impressive results: during Olympics-1996 in Atlanta Australia became the best rowing nation and won 6 medals, two of them gold. One of the gold crews, the women's pair Slater/Still was coached by Thommo. That was a great success for the young 32 year old coach.

I met Paul in 1998, when I went to work at the AIS. The previous biomechanist, Conny Loshner/Draper, introduced Thommo as a "hardman", but I found it was really interesting and challenging to work with him. He was a coach, who used Biomechanics more than others. With the newly developed Immediate Feedback System ("virtual goggles") we tried to improve the technique of a new pair combination Slater/Taylor, which then won silver in the Sydney Olympics in 2000.

In late 2000 Paul took up a new challenge and was appointed to the position of lead coach (Women) with the Amateur Rowing Association. He achieved success in the UK when the pair of Grainger/Bishop won the World Championships in 2003. Great Britain won three medals in the Women's events at the Athens Olympics, a Silver for Grainger /Bishop in the pair, a silver in the quad and a bronze in the double.

Late in 2004 Paul was promoted to the position of Chief Coach for Women and Lightweight. During the last Olympic cycle, the Women's and Lightweight Squad won 16 Medals at World Championships and at the Beijing Olympics. In Beijing, the squad had six boats in the A final and won Gold, Silver and Bronze medals. During this period Paul coached the Women's quad to three world titles and a silver medal in Beijing.

Paul has continued to use science as a core component of his programme utilising the resources at GB Rowing, at the English Institute of Sport, at the Olympic Medical Centre and at partner institutions such as Imperial College.

Paul works on biomechanics with his crews on the water by developing long strokes and tries to optimise rigging by adjusting it better to the rower's anthropometry (RBN 2001/11). He uses force curves and tries to define the most efficient rowing style (RBN 2001/07). The path of the blade through the water is also very important as it can increase blade efficiency with less slippage. He continuously uses normative boat speeds at various stroke rates by use of spreadsheets (RBN 2004/03, 2005/10). He uses "goggles" for immediate feedback during technical sessions.

Thommo's coaching philosophy includes sport science as a tool to get better insight about the processes which influence the athlete during training and competition. He feels privileged to have worked with some outstanding scientists and coaches that have left their mark on him and on the squad's programme and on their results. He is obviously a "materialist" in this way and tries to use science as effectively as he can. However, he believes in some ideal essence in a human being, and that coaching will never be replaced by an industrial process. Rowing is about moving boats, but people as well. For every successful athlete there is a coach and dedicated support team behind them.

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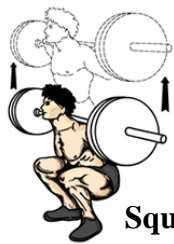
Merry Christmas and Happy New Year to all rowers and coaches!

Q&A

We had interesting discussions with Marinus van Holst, Dutch mechanical engineer and professor emeritus of the Delft University of Technology. Marinus has been active in rowing since 1957, done vast research in Rowing Biomechanics and published results on his web site <http://home.hccnet.nl/m.holst/RoeiWeb.html>

MvH: "The force/energy/power approach in the RBN 2008/10 is to my opinion unnecessary complicated and confusing. I have great difficulty with the concept "power transferred by the foot stretcher"... Power is not generated, not transferred and not applied at the foot stretcher. The term 'leg power' much better describes what happens. The legs are a power-generating device and the foot stretcher is its foundation. The device generates power by extending and its speed equals the seat speed (with respect to the hull) because legs connect foot stretcher and seat. Power generation by the legs stops when the seat stops."

VK: Power transmission can be understood better with the examples of two exercises below:



Squat



Leg press

In the case of the squat, the feet are unmovable, so the velocity and power transfer through it are zero, because power is the product of force and velocity. The energy is transferred to the moving athlete's body and to the weight on his shoulders.

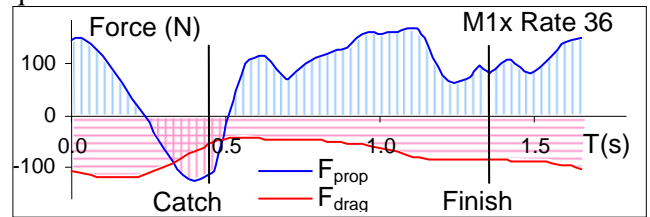
In the case of the leg press, the body is fixed, so its kinetic energy cannot be increased. Power is transferred through the feet and the stretcher to the weight.

In rowing on water or on a mobile ergo, both body and feet are mobile, and power is transferred through both the stretcher/boat and rower/handle. Contrarily, in rowing on a stationary ergo or in a tank the stretcher is fixed and power can be transferred only through the rower's body to the handle.

MvH: "When we disconnect the hull from the rest of the system, we introduce a pin force and a stretcher force. When we consider the equilibrium of the hull, we find that the algebraic sum of these forces constitutes equilibrium with the hull resistance force F_{drag} (at constant hull speed)."

VK: The impulses of the propulsive force $F_{prop} = F_{pin} - F_{stretcher}$ and drag force F_{drag} have equal magnitude and opposite direction during the stroke cycle (in steady state rowing), but instantaneous forces are different. If they were always equal, the resultant force would al-

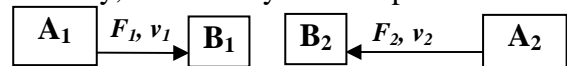
ways be zero and the boat would not be able to accelerate or decelerate at all. On the chart below the impulses are represented by the area between the curve and the X axis; sums of the areas below and above the axis are equal.



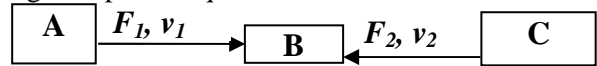
Recently, Marinus have sent us the correct version of the equation: $F_{pin} - F_{str} = F_{drag} + m_{hull} a_{hull}$

MvH: "The power outflow (on the hull) is $P_{out} = F_{drag} v_{hull}$. The power input is $P_{in} = (F_{pin} - F_{stretcher}) \cdot v_{hull}$ "

VK: Definition of the power input P_{in} is another quite common mistake, so we will explain it in more detail. When we define power, it is always very important to define the interacting objects. Imagine two pairs of objects, A_1-B_1 and A_2-B_2 , which mechanically interact with a certain force and velocity, so that they transfer power:



We can write: $P_1 = F_1 v_1$ and $P_2 = F_2 v_2$. This is correct. We can NOT write either $P = F_1 v_2$ or $P = F_2 v_1$, which would be incorrect, without physical meaning and misleading. Now, imagine that one of the objects in the two couples is combined. That, however, doesn't change the power equations above:



In the case of rowing, A is the rower, B is the boat and C is the water. The equation $P_{in} = (F_{pin} - F_{stretcher}) \cdot v_{hull}$ would mean $P = F_1 v_2$ the product of force applied by the rower and velocity relative to the water, which is incorrect. Both rower and water objects can interact with the boat; water constantly consumes power through the drag. (We completely agree with Marinus's first equation, $P_{out} = F_{drag} v_{hull}$.) The rower can transfer power through the handle-oar-gate during the drive phase and directly through the stretcher throughout the stroke cycle. Therefore, we have to define P_{in} separately for the drive and recovery. The recovery is the simpler, because the rower can transfer a part of his kinetic energy to the hull only through the stretcher: $P_{in} = F_{stretcher} v_{rower-boat}$, where $v_{rower-boat}$ is the velocity of the rower's CM relative to the boat. During the drive, the picture is more complicated, as the power can be supplied to the hull by both propulsion through the oar and transfer of kinetic energy from the rower's mass. We may give a more complete analysis later.

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