How to improve your technique with biomechanics

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Basic chart of Rowing Biomechanics

How we define rowing technique efficiency?

The three main parts of rowing as a process of energy transformation

- **Internal (muscle) Efficiency**
- **Blade Propulsive Efficiency**
- **Mechanical Power**
- **Metabolic Power**
- **Boat Velocity Efficiency**
- **Minimal required Power**
- **Waste Power**
- **Waste Heat Energy**

**Propulsive Power**

**How we define rowing technique efficiency?**
Efficiencies of the components of energy transformation process during rowing

- **Internal Muscle Efficiency**: 24±4%
- **Blade Propulsive Efficiency**: 82±5%
- **Boat Velocity Efficiency**: 94.5±1%

Drag Power vs. Boat Velocity graph

O$_2$ denotes Oxygen, which is a crucial element for energy transformation in rowing.
The highest amount of energy 93% is lost in the rower’s body. The Rower is the main area to improve rowing efficiency.
How can we increase the rower’s efficiency and effectiveness?

✓ Using of the most powerful muscle groups;

✓ Optimisation muscles contraction velocities;

✓ No energy absorption, single-motion movement;

✓ Decreasing of muscles-antagonists activity;

✓ Muscles relaxation during recovery phase.
What are Rowing Biomechanics “Gold Standards”?

<table>
<thead>
<tr>
<th>Event</th>
<th>G.St. Time</th>
<th>P (W)</th>
<th>Inb. (m)</th>
<th>Rate (1/min)</th>
<th>Angle (deg)</th>
<th>Fav (N)</th>
<th>Fmax (N)</th>
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<tbody>
<tr>
<td>W1x</td>
<td>07:11.5</td>
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<td>0.89</td>
<td>33.0</td>
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<td>713</td>
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<tr>
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<td>0.88</td>
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<td>1.16</td>
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<td>859</td>
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<tr>
<td>M4-</td>
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<td>366</td>
<td>704</td>
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<table>
<thead>
<tr>
<th>Category</th>
<th>W (kg)</th>
<th>P (W)</th>
<th>Erg Score (m:s)</th>
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<tbody>
<tr>
<td>Open Women</td>
<td>85</td>
<td>400</td>
<td>6:23</td>
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<tr>
<td>Open Men</td>
<td>95</td>
<td>550</td>
<td>5:44</td>
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<tr>
<td>LW Women</td>
<td>60</td>
<td>330</td>
<td>6:48</td>
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<tr>
<td>LW Men</td>
<td>70</td>
<td>470</td>
<td>6:03</td>
</tr>
</tbody>
</table>

\[
P_{prop} = DF \times V^3
\]

\[
P = \frac{P_{prop}}{Eblade}
\]

\[
L = \text{Inb.} \times A
\]

\[
WPS = P \times \left(\frac{60}{\text{Rate}}\right)
\]

\[
Fav = 0.83 \times \frac{WPS}{L}
\]
Input of body segments into rowing power

- Legs produce nearly half of rowing power;
- Trunk produces nearly one third of rowing power;
- Arms produce about one fifth of rowing power;

- Legs increase their percentage of power with increasing stroke rate;
- Arms’ power share decreases, when the stroke rate increases.
Utilisation of work-capacity of the body segments

- Legs use up to 95% of their power.
- Trunk muscles utilize only about 55%;
- Arms’ utilization is about 75%;

(Kleshnev V. 1991)

This tells us that the largest capacity for increasing rowing power can be found from utilization of the trunk work-capacity.
Velocity-Force dependence for isolated muscle (Hill principle)

- Hyperbolic relationship between velocity and force was discovered in the 1920s by Archibald Vivian Hill from a study of frog muscles.

- A number of recent researches confirmed that it can be valid for complex multi-joint movements.

- The highest power can be achieved at 1/3 of max. static force and 1/3 of max. voluntary velocity.

\[ F = \frac{b_1}{(b_0 + V)} \]

\[ P = F \times V \]
Utilisation of the Hill principle in rowing

Negative power is the most inefficient unless it happens during very short time.

Too heavy or too light gearing can affect the force/velocity relationship and thus efficiency.

**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.**
How we measure velocities of body segments?

- Cable position transducers are attached to the seat and top of the trunk (at the level L7-Th1 vertebra or sternum-clavicle joints);
- Arms velocity is calculated as a difference between handle velocity (derived from oar angle and inboard) and trunk velocity.
What effective dynamics means?

✓ Front-loaded drive, trampoline effect;
✓ Quick acceleration of the rower’s mass first, then taking the load;
✓ Emphasis on the stretcher push, “catch through the stretcher”;
✓ Smooth “fat” force curve, control through suspension from the seat;
✓ Using rower’s inertia for propulsion at finish, “finish through the handle”.
How the front-loaded drive looks like?

- It is important to increase force quickly up to 70% of maximum;
- “Trampolining” effect?

1. Front-loaded

1. Middle-loaded
Why the front loaded-drive is more effective?

Front-loaded drive (F1):

- Gives 47% higher average velocity and distance travelled during the drive;
- Creates much more even distribution of the power;
- Provide better utilization of the most powerful muscle groups;
- Hydro-lift force on the blade can be used better.
How can we analyse the Force Curve?

- **Catch gradient** defines how quickly the force increases;
- **Position of the Peak Force** defines emphasis of force application;
- **Finish gradient** defines how long the force maintained.

![Force Curve Diagram](image)
How the Target Force Curve looks like?

- Solid, front-loaded, full, no “humps” or glitches.
- Catch gradient 10% of the Total Angle (11 deg in sculling, 9 deg in rowing);
- Position of the Peak Force 33% of Total Angle (down to 30% in 8+ and 4x, up to 38% in 1x);
- Finish gradient 32% (up to 36% in big boats, down to 26% in small boats).
How can we present the Force Curve?

- Force vs. time (s) is good for synchronisation with other variables, but difficult to compare at various stroke rates;

- Force vs. time (% of stroke cycle) is another option;

- Force vs. Oar Angle allows easy comparison at various stroke rates and useful for defining position of specific points (peaks, gaps).
Why the stretcher force is positive?

1. Drive phase must be emphasised, because the system velocity increases only during the drive;

2. During the drive, acceleration of the rower’s mass must be emphasised, because it is the main “accumulator” of the kinetic energy;

3. The stretcher force must be emphasised, because this is the only force, which accelerated the rower’s centre of mass;
Why accelerate the rower’s mass during the drive?

- Kinetic energy of the system increases ONLY during the drive phase;
- Kinetic energy of the system decreases during the recovery phase and we can not change it;
- Amount of kinetic energy, which the system gained during the drive phase, determines average velocity of the system;
- Rower’s mass is the main “accumulator” of the kinetic energy;

\[ E_k = \frac{(m \cdot v^2)}{2} \]

Steve Fairbairn (1930): “Find out how to use your weight and you will have solved the problem of how to move the boat”
Power transfer through the stretcher

- In rowing the power is transferred through BOTH handle and stretcher in the proportion about 60/40%.

\[ P = F \times v \]

Squat: power transfer through upper body only

Legs press: power transfer through the foot-stretcher only
Analogy with canoeing makes it easier to understand why the stretcher force is important.

1. Athlete apply action forces
2. Action forces create opposite reaction forces
3. Reaction forces move centres of mass
How blade propulsive efficiency is defined?

Propulsive Power

\[ P_{\text{propulsive}} = F \cdot V_{\text{mass centre}} \]

Waste Power

\[ P_{\text{waste}} = F \cdot V \]

Efficiency of the blade

\[ E_{\text{blade}} = \frac{P_{\text{propulsive}}}{P_{\text{total}}} = \frac{(P - P_{\text{waste}})}{P} \]
Oar Track during stroke cycle

- Blade
- Pin
- Handle
- Drive
- Recovery
What we need to know about blade efficiency?

- Hydro-lift force works at sharp angles of attack and contributes 56% of the blade propulsive force;
- Drag force works at the middle of the drive and contributes 44% of the blade propulsive force.

How can we increase the blade propulsive efficiency?

- Use bigger blade area;
- Use heavier gearing;
- Utilise hydro-lift effect -> apply more force at sharp oar angles at catch;
- Place the blade at the optimal depth under the water (4-6 deg).
Oar blade as a jet engine?

✓ At the start of runway, the efficiency of a jet plane is zero, because its velocity is zero, but the thrust and specific impulse are maximal.

✓ As the plane accelerates, its efficiency increases, and became 100%, if the plane speed is equal to the speed of exhaust gases.

\[
I_{sp} = (V_g - V) \frac{m}{t}
\]

**Propulsion Efficiency**

\[
E = \frac{2}{1 + \frac{V_g}{V}}
\]
Specific Impulse as a measure of the blade performance?

\[ Isp = \frac{F_{\text{trust}}}{P_{\text{row}}} \]

- The specific impulse can be used together with blade efficiency for evaluation of the blade work.
- A higher specific impulse is generated at a lighter gearing ratio, but at a lower handle velocity at the same time.
- This could be achieved either by using bigger blade area, or by more effective thrust production using a better shape and/or utilisation of hydro lift effect.
How we analyze rower’s blade work?

- **Two-dimensional (2D) sensor** measures oar angles horizontal and vertical planes, which allows to define a path of the blade relative to water.

- **Criterion** -3 deg was chosen to indicate full immersion of the blade into the water.

<table>
<thead>
<tr>
<th>Catch</th>
<th>Recovery</th>
<th>Vertical Angle (deg)</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3</td>
<td></td>
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<tr>
<td>Water Level</td>
<td>0</td>
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</tr>
<tr>
<td>Catch Slip</td>
<td>-6</td>
<td></td>
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</tr>
<tr>
<td>Drive</td>
<td>Effective Angle</td>
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<td></td>
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<tr>
<td>Target Curve</td>
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</tr>
<tr>
<td>Release Slip</td>
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</tr>
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</table>

- Vertical Angle (deg)
- Horizontal Angle (deg)

**Biorow Biomechanics of Rowing**
Rotational motions of the oar.

- Rotational motions of the oar were measured with *BioRow 7D* wireless sensor;
- The most understandable and informative measured variable appeared to be the roll $G_x$, which is clearly related to the squaring-feathering of the oar.
When the blade squared – feathered?

- The squaring takes 0.25-0.35s and completed at the catch, when the oar change direction, but the blade is still in the air.
- The feathering began, when the centre of the blade crosses the water level and completed in about 0.15-0.25s – faster than squaring;
- The higher the stroke rate, the longer distance of recovery is required to square the blade.

**With BioRowTel** system, the oar roll data in conjunction with horizontal and vertical oar angles allows a full reconstruction of the oar movements relative to the water level.
Determination of “Boat velocity efficiency”

The main reasons for energy losses are:
• boat velocity fluctuation;
• non-linear dependence of drug power on velocity
The hull speed increases through recovery at higher stroke rates.

The higher the rate, the closer the peak speed to the catch.

The reason for this is in interaction of the rower’s and the boat masses.

The transmission of the kinetic energy from the rower’s mass is to the hull occurs during recovery by means of pull through the foot-stretcher.

At the higher rating the pull force exceeds 200N and overcomes the drag force \( \approx 100N \) at the hull.
Variations of the boat velocity is NOT the main reason of the energy losses in rowing

There are two main reasons of the variation of the boat velocity:

- Periodical production of the propulsive force;
- Movement of the rower’s mass relative to the boat shell.

We can not change these factors without changing the nature of rowing

- Increase of the boat velocity during recovery caused by transfer of KINETIC ENERGY from the rower’s mass to the boat.
How can we help to optimize rigging?

Rigging Calculator [www.biorow.com/RigChart.aspx](http://www.biorow.com/RigChart.aspx)

**Rowing Speed & Rigging Chart** *(c) 2009-11 Dr. Valery Kloshnev. v.2.33*

<table>
<thead>
<tr>
<th>Input</th>
<th>Metric</th>
<th>Imperial</th>
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<tr>
<td>Boat Type</td>
<td>1x</td>
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</tr>
<tr>
<td>Rower's Sex</td>
<td>Male</td>
<td></td>
</tr>
<tr>
<td>Rower's Weight Category</td>
<td>Open</td>
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<tr>
<td>Rower's Age Category</td>
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</tr>
<tr>
<td>Average Rower's Height</td>
<td>1 m 94 cm</td>
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</tr>
<tr>
<td>Average Rower's Weight</td>
<td>92 kg</td>
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<tr>
<td>Erg Score</td>
<td>5 min 52 sec</td>
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<tr>
<td>On-water Time</td>
<td>for 2000 m</td>
<td></td>
</tr>
<tr>
<td>Blade Type</td>
<td>Smoothie2Pl</td>
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<tr>
<td>Wind speed (“+” Head, “-” Tail)</td>
<td>0 m/s</td>
<td></td>
</tr>
<tr>
<td>Wind direction (0 - Straight, 90 - Cross)</td>
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<tr>
<td>Water Temperature</td>
<td>20 deg C</td>
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<table>
<thead>
<tr>
<th>Output</th>
<th>At calm conditions water 20 deg C</th>
<th>At given wind and water conditions***</th>
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<tr>
<td>Prognostic Time over 2 km (min:sec)</td>
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<td>6:41.10</td>
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<tr>
<td>Racing Stroke Rate (str/min)</td>
<td>36.0</td>
<td>34.0</td>
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<tr>
<td>Recommended Inboard (cm)</td>
<td>89.0</td>
<td>88.1</td>
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<tr>
<td>Recommended Oar Length (cm)</td>
<td>289.0</td>
<td>286.4</td>
</tr>
<tr>
<td>Recommended Span/Spread (cm)</td>
<td>160.0</td>
<td>169.2</td>
</tr>
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</table>

**Rigging Method**
- Traditional
- Innovative

**Target Angle Mode**
- Standards
- Custom

**Use Constraints**
- Check

**Adjust Stroke Rate**
- Adjust

Thanks to Ian Wilson of Concept2 UK for the idea and Dick & Peter Dreissigacker of Concept 2 for support.
What we can measure in rigging?

Why rigging is important?

- Oar dimensions define gearing, which determines force/velocity ratio of rower’s muscles contraction;
- Stretcher position is related to ratio of catch/finish angles;
- Gate height and blade pitch defines vertical oar angles;
- Stretcher angle and height defines lift force and kinetics of the drive.
What is correct definition of the Gearing?

Gearing = Actual Outboard / Actual Inboard
= (Out.-SL/2- SW/2) / (Inb.-Hnd/2+SW/2)

✓ The standard definition of the gearing is the ratio of velocities (or displacements, travels) of output to input;

✓ In rowing, velocity of the output is defined by actual outboard, input – by actual inboard;

✓ The span/spread does NOT affect gearing;

✓ Blade efficiency or “slippage” DOES affect Gearing.
Is gearing constant during the drive?

- At sharp oar angles only part of blade velocity is parallel to the boat velocity;
- Effect of the oar angle is small until 45deg;
- Gearing ratio became twice heavier at the oar angle 60deg;
- Gearing ratio became three times heavier at the oar angle 70deg;
- Gearing ratio became six times heavier at the oar angle 80deg;
- The most common catch angles are between 55deg (sweep) and 70deg (sculling).
Our history force measurements in rowing

- Instrumented gates
  - 1987
  - 1988
  - 1992
  - 2001
  - 2011

- Oar bend sensors
  - 1998
  - 2002
  - Oar Shaft Insert
  - Handle

- Stretcher Force sensors
  - 2001

- Seat Force sensor
  - 2005
  - 2011 Wireless
  - 2012
What is measured with force transducers?

- **Handle Force** gives the most accurate power measures, but require calibration of every oar.
- **Gate Force** require inboard for power calculation, which could vary during the drive ±5%.
- **Pin Force** is affected by oar angle and axial force, so power could be measured with ±20% accuracy.
What Biomechanical Tools we use?

- **BioRowTel v4.5 telemetry system** was created by rowing scientist for research purposes. It is accurate, flexible, scalable, based on “screening” concept, quick to setup, light;
- **Scalable design**: one “Master” unit + up to 8 “Slaves”;

**Master unit contains:**
- GPS and impeller input for boat speed;
- 3D accelerometer, 3D gyro;
- Wind speed & direction input;
- Sampling frequency 25-100 Hz;
- Resolution 14 bit;
- Works >8 hours;
- Weight 300g.

“Master” unit

“Slave” unit

www.biorow.com
Thank you for attention

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