# Whitepaper: Findings and conclusions Static vs Dynamic power calculations

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## Introduction

Based on a calculation made in the spreadsheets (see addendum), some findings emerged. The purpose of the calculation is to quantify the energy used on a static ergometer to move the body back and forth. On a dynamic indoor rowing machine (RP3), you only need to move the flywheel housing and mechanism (about 14 kg) back and forth while driving the flywheel. On a static rowing machine (Concept2), this involves a large portion of the body weight. The current approach is an improvement in quality compared to the original estimate we made, which was very rough and did not take into account factors such as pace, body size, and energy recovery. Below, the calculation in the sheet is explained step by step.

## Summary

- The RowerUp profile & analytics can be effectively used to highlight the differences between “Static” (Concept2 – C2) and “Dynamic” (RP3) and the boat.
- Losses on the C2 can be significant: up to more than half of what a rower can put into a flywheel. This encourages (major) adjustments in rowing technique for the sake of a better score:
    - Rowers on C2 elongate the time in which the legs are used during both the drive and the recovery to limit loss.
    - Rowers on C2 are strongly rewarded for extending the stroke at the end and recovering energy from the drive. In other words, falling far (“jenking”) and pulling the handle very high.
    - Rowers on C2 are rewarded for rowing at a lower stroke rate than they would in the boat and/or what is physiologically optimal for them during a race in the boat.
    - Rowers on C2 are rewarded for a longer drive time, meaning longer strokes and with a higher drag factor than what would be optimal (like boat feel, lightness and stroke rate). Therefore, it pays off to row very heavy and "slow".
- All these technical adjustments deviate from what rowers (should) demonstrate in the boat. Rowing on C2 is thus truly a "trick" and does not

resemble the boat's optimal rowing motion: it is a different rowing motion than in the boat.

- Rowing on RP3, on the other hand, encourages a similar movement pattern to what we see in the boat while simultaneously providing comparable values (energy, stroke efficiency and power).

## Calculation explained

To determine the energy, the following reasoning is used. The mass of the rower moving back and forth is known. The easiest way seems to be to look at the maximum kinetic energy reached by the body mass during the drive and during the recovery. This energy must come from somewhere and thus originates from the rower on the device. He/she has to start and stop the mass themselves. For simplicity, it is assumed that mainly energy must be 'spent' to start the mass. The braking is 'free' because, for example, you may encounter the limits of your musculoskeletal system. Otherwise, we may need to double the total power of the calculation, but the conclusions/findings below remain the same.

The formula for kinetic energy is as follows:

$$E = 1/2 \; M \, V^2$$

Where E is the energy in joules, M is the mass in kilograms, and V is the velocity of the mass in metres per second.

## Weight

Based on https://robslink.com/SAS/democd79/body_part_weights.htm, it can be concluded that approximately 70% of the body mass moves back and forth. 30% are the legs, which move less back and forth and also up and down, which has a different effect. The effect of the legs is currently being disregarded.

## Speed

To determine the speed, profiles from RowerUp are examined. These provide a lot of insight into how a stroke is executed and explicitly show the speed of the legs throughout the entire stroke. During the drive, which lasts approximately 0.7 to 0.9 seconds, the legs are often used in the first 70% of the stroke. However, the legs do not maintain a constant speed during the drive. The rower starts slowly, then reaches maximum leg speed around 35% of the drive, and due to coupling, the legs then decelerate towards 70% of the drive. This leads to the estimation that the maximum speed during the drive is approximately twice as high as the average leg speed during the first 70% of the drive.

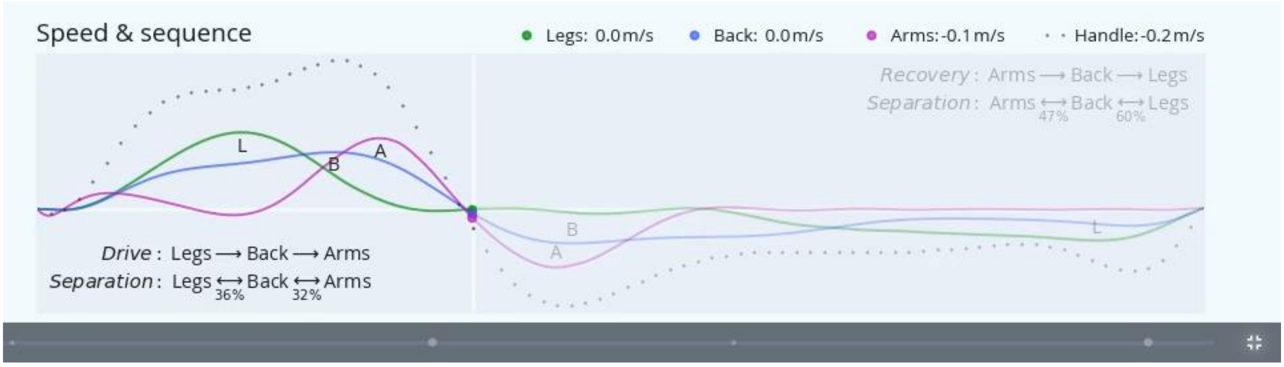


*Fig. 1 - Analysis of the drive of a Concept 2 rower in Rowerup. Notice how the green line (legs) is above 0 for about 70% of the drive.*

The recovery on the Concept 2 ergometer is very typical. The legs release very quickly, and rowers often move at a more or less constant speed towards the catch. This is energetically very favourable to limit the loss, however, it does not correspond well to what you do in the boat (see further below).

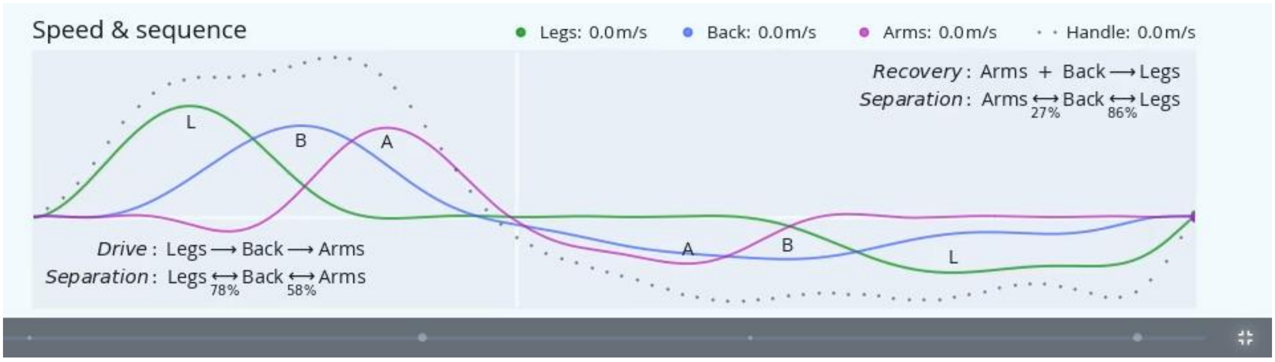


*Fig. 2 - An analysis of another rower on a Concept 2 in RowerUp. Here you can also see the same profile during the drive, but pay attention to the long, stretched leg speed during the recovery. The legs release too quickly in the recovery to push the maximum speed of the mass. This reduces the energy required for the rower to get back to the front.*

Rowers seem to instinctively[1] sense what they can do to limit loss when rowing statically. However, this conflicts with what they do in the boat, as shown below:

[1] Instinctive adjustments of a movement involve implicitly learning this movement and thus becoming deeply ingrained in neuromuscular mechanisms. Training this movement with an explicitly derived goal, such as achieving a high score, can lead to negative effects if differences are noticeable. Consequently, it may ultimately have a negative impact if this alternative movement is less effective for the primary objective.


*Fig. 3 - Profile of a rower analysed in RowerUp while in the boat. During the drive, the legs reach a higher speed much earlier (the rower slides first). During the recovery, the legs release late and with a high speed. This curve is a parabola compared to the "rectangle" on the C2.*


*Fig. 4 - Profile of a rower analysed on RP3 in RowerUp. See how the curves resemble much more what you see in rowing compared to C2.*

The speed of the drive is a function of time (drive time) and the 'dip' (distance). Dip is a number derived from squatting. Rowers often achieve around 65-70 cm there. This seems to correspond to the distance travelled by the legs in the boat. The maximum speed during the drive is calculated using the following formula:

$$V_d = 2(D / T_{d,l})$$

Where *D* is the dip in metres and $T_{d,l}$ is the drive time of the legs (70% of the total drive time).

During the recovery, uniform speed is assumed for 70% of the recovery, with the formula as follows: $V_r = D/T_{r,l}$

## Energy

Now that the maximum speeds and the mass are known, the formula for kinetic energy can be filled in. The energy losses during the drive and the recovery are then derived, after which they can be divided by the total stroke time to arrive at a wattage (joules/second). This wattage now puts the loss of back-and-forth movement into perspective. These wattages are quite substantial, especially at higher rates, and are a strong incentive for the rower to adjust his/her technique to limit the loss and achieve a better score.

> ***Note**: this strong incentive to adjust the rowing technique is (potential) detrimental for the needed perfect coordination in the boat. The challenge for rowers and coaches is inherently contradictory. The rower must demonstrate a high score to be selected for the boat and he/she is willing to do 'anything' for it, including technical adjustments to achieve that score. At the same time, the coach demands the best score, the best performance from the rower, but also wants him/her to exhibit the best rowing technique in the boat, for the sake of the highest boat speed. Here, it becomes evident that these objectives are contradictory!*
>
> *To establish the link in the Coach Analysis Reports (RP3 Portal) between "energy per stroke" on the RP3 as the desired metric to be trained (the Force Curve is made of 4 parameters[2]) and how to train these - with insights in the logical order, is the indicator that the rower also delivers this "energy per stroke" in the boat. Coaching on rowing technique in the boat revolves around executing that "energy per stroke" in the boat in the right place (effective angle, minimal slip), in relation to rigging and as part of the crew.*

For example, by "yanking" in the finish and by falling far (back swing), a portion of the energy from the drive can be recovered. To give an idea of how much energy this is, you can play with numbers in the sheet. For instance, a rower weighing 90 kg, with a drive time of 0.7 sec. and a stroke rate of 35, wastes almost 170 watts. If the rower can recover 40% of the energy from the drive, then only 108 watts are wasted. With a 2k time of 6-flat, this results in almost 9 seconds of time saved! So, there is a very strong reason to fall hard.

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[2] The ForceCurve, as a representative of the performed "energy per stroke", is shaped out of four parameters: stroke length (base of the curve), peak force (height of the curve), peak force position and the convex shape of the curve (which causes the largest surface). The relation between these, in logical order, will provide an insight in training focus for the rower.

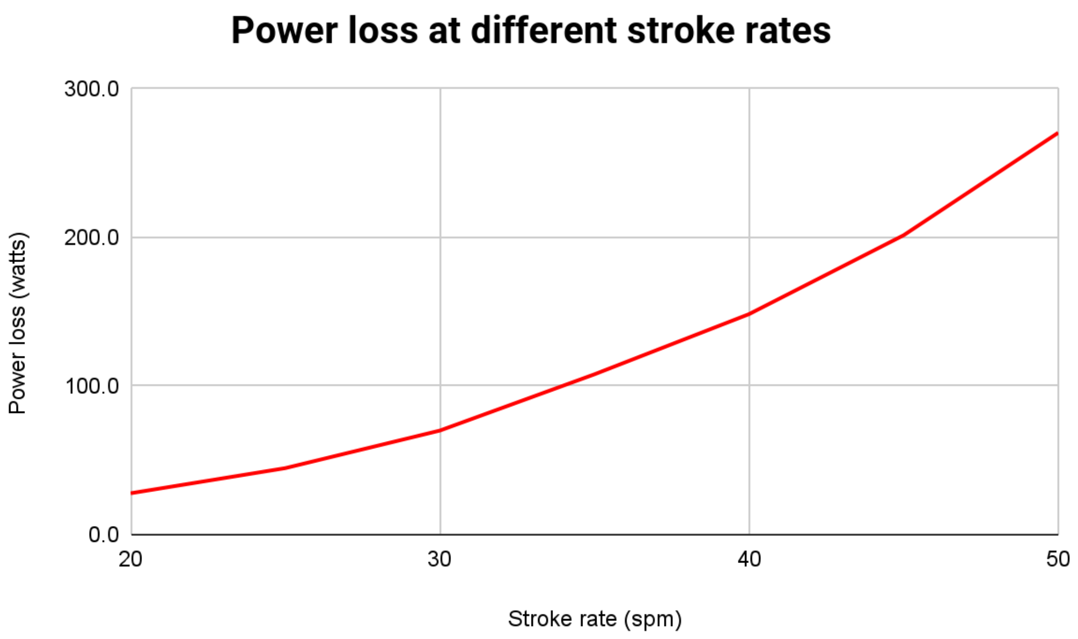


*Fig. 5 - Power loss (watt) versus stroke rate ( per min.)*

The above graph shows that the loss exponentially increases with increasing stroke rate. It is therefore no coincidence that C2 2k tests are often done around the 30 stroke rate (or even lower), while on the RP3, the stroke rate can increase towards 40 and even up to 50(!). At a stroke rate of 50, the back and forth movement on the C2 alone would cost 270 watts according to this method of calculation.

**Limitations of this model**

- Many numbers are still rough estimates. For example, the movement pattern will change even more towards higher stroke rates on the C2 to limit losses.
- Only the energy of acceleration is taken into account. Deceleration is disregarded, as mentioned in the introduction.
- The recovery of energy is now an estimation; there's no clear idea yet of how to quantify it. And it also depends on the rowers' intentions and kinematic pattern.

There has also been a preliminary attempt to quantify the same loss on an RP3. Here, it is assumed that all kinetic energy from the 'drive' ultimately ends up in the flywheel, which is achieved by staying ‘connected’ to the footplate till the end of the stroke. However, the kinetic energy of the recovery will have to be 'spent' by the rower. What was noticeable in RowerUp is that people unlock their legs quite late and therefore also let their feet come towards them rather quickly. This is very similar to what is seen in the boat (figure 3). At high stroke rates, this will probably change, but this still needs to be verified. Therefore, the energy loss model for RP3 is almost identical to that of C2, with a few crucial changes:

- ➔ Energy loss during the drive is equal to 0.
- ➔ Maximum speed during the recovery is 2 times that of what it would be on C2, to reflect the parabola type acceleration (figure 4).
- ➔ Movable mass is 14 kg, reflecting the weight of the RP3.

This results in significantly lower energy losses compared to what we calculate for C2. Below, the same graph as above is shown, but including the losses on RP3:

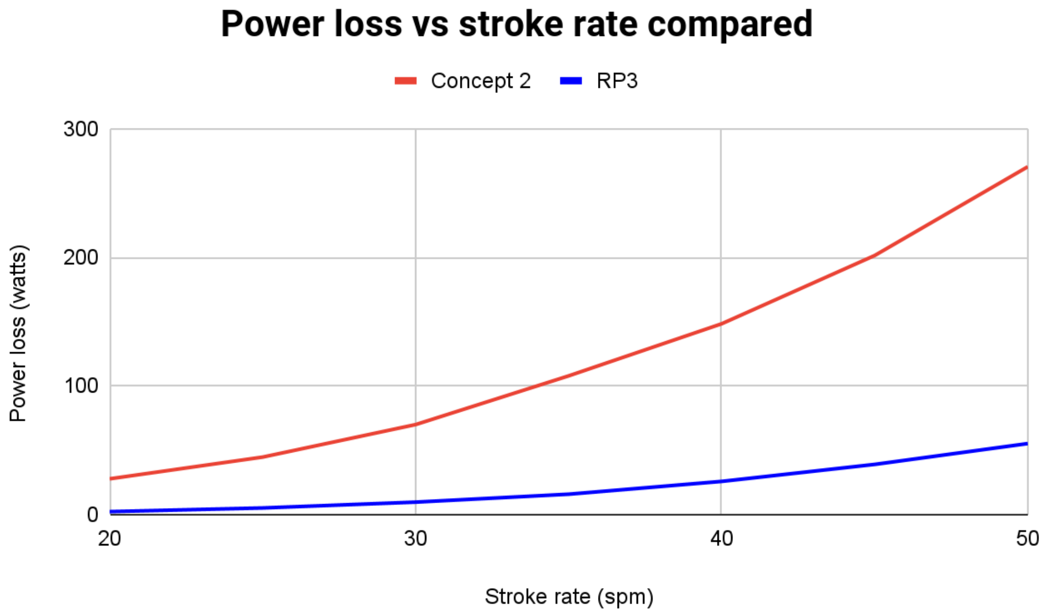


*Fig. 6 - Relationship between energy loss (y-axis) in watts and stroke rate (x-axis) in spm. Red represents the line for C2, and blue for RP3.*

The energy loss of rowing at a stroke rate of 40 on an RP3 is approximately the same as the energy loss on a C2 at a stroke rate of 20.

## Score difference between RP3 and C2

These differences are not sufficient to explain the full difference between RP3 and C2 in terms of scores. What becomes very visible, however, is how important technical adjustments are on a C2 to achieve a better score. Coming in slower, leaning (lay) back further, and rowing with a higher drag factor are a few examples of how to reduce body speed and thereby the loss. Ultimately, good rowing on a C2 is really a kind of trick that looks less and less like rowing as you try to row faster.

The RP3 enables the rower to deliver far more effective power, which explains, in part, why better 2k times are rowed with RP3. However, comparing how scores are achieved on C2 and RP3 is also difficult. The wattage calculator from C2 indicates that a certain "C-factor" is used, which has a different value than what RP3 uses. To be specific, it's 2.8 versus 2.5. This could mean that with the same rotation speed and with the same drag-factor / K-factor, the C2 indicates a 12 percent higher score than the RP3.

This is really comparing apples to oranges since the flywheels have different masses. But it could explain an interesting phenomenon: what is noticed in practice is that people on an RP3 often don't go faster or even slower than on a C2 during steady state. However, at a higher stroke rate, the RP3 is definitely faster. It could be that a C2 with the same energy in the flywheel indicates a faster score to compensate for the energy loss. At a higher stroke rate, this energy loss increases exponentially, putting the C2 at a huge disadvantage.

However, at a low stroke rate with typical 'C2 technique', it is possible to reduce the energy loss enormously, artificially inflating the score. In other words, the C2 tries to compensate for the fact that a large portion of the rower's energy does not end up in the flywheel.

## Conclusion

- The RowerUp profile & analytics can be effectively used to highlight the differences between C2 and RP3 and the boat.
- Losses on the C2 can be significant: up to more than half of what a rower can put into a flywheel. This encourages (major) adjustments in rowing technique for the sake of a better score:
    - Rowers on C2 elongate the "legs" during both the drive and the recovery to limit the loss.
    - Rowers on C2 are strongly rewarded for "jenking" and recovering energy from the drive. In other words, falling far and pulling the chain very high (up to the chin).
    - Rowers on C2 are rewarded for rowing at a lower stroke rate than they would in the boat and/or what is physiologically optimal for them during a race in the boat.
    - Rowers on C2 are rewarded for a longer drive time, meaning longer strokes and with a higher drag factor than what would be optimal (like boat feel, lightness and stroke rate). Therefore, it pays off to row very heavy and "slow".
- All these technical adjustments deviate from what rowers (should) demonstrate in the boat. C2 is thus truly a "trick" and does not resemble the boat's optimal rowing motion: it is a different rowing motion than in the boat.
- Rowing on RP3 encourages a similar movement pattern to what we see in the boat while simultaneously providing comparable values (energy, stroke efficiency and power).

# Addendum

| ***Power loss calculation for C2 & RP3 rowing*** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| **Body Weight Rower (kg)** | 90 | 90 | 90 | 90 | 90 | 90 | 90 |
| **Ratio Upper Body (%)** | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| **Dip (cm)** | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| **Stroke Rate (/ min)** | *20* | *25* | *30* | *35* | *40* | *45* | *50* |
| **Drive time (sec)** | 1 | 0.9 | 0.8 | 0.7 | 0.65 | 0.6 | 0.55 |
| **Recovery %** | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| **Leg percentage (%)** | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| **Drive factor** | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | | | | | | | |
| Stroke time (sec.) | 3.00 | 2.40 | 2.00 | 1.71 | 1.50 | 1.33 | 1.20 |
| Recovery time | 2.00 | 1.50 | 1.20 | 1.01 | 0.85 | 0.73 | 0.65 |
| Max speed drive | 2.00 | 2.22 | 2.50 | 2.86 | 3.08 | 3.33 | 3.64 |
| Max speed recovery | 0.50 | 0.67 | 0.83 | 0.99 | 1.18 | 1.36 | 1.54 |
| | | | | | | | |
| Energy drive (joules) | 75.60 | 93.33 | 118.13 | 154.29 | 178.93 | 210.00 | 249.92 |
| Energy recovery (joules) | 7.88 | 14.00 | 21.88 | 30.62 | 43.60 | 58.57 | 74.56 |
| | | | | | | | |
| **Power loss on C2 (watt)** | **27.83** | **44.72** | **70.00** | **107.86** | **148.36** | **201.43** | **270.39** |
| | | | | | | | |
| **RP3** | | | | | | | |
| Max speed drive | 2.00 | 2.22 | 2.50 | 2.86 | 3.08 | 3.33 | 3.64 |
| Max speed recovery | 1.00 | 1.33 | 1.67 | 1.97 | 2.35 | 2.73 | 3.08 |
| | | | | | | | |
| Energy drive (joules) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Energy recovery (joules) | 7.00 | 12.44 | 19.44 | 27.22 | 38.75 | 52.07 | 66.27 |
| | | | | | | | |
| **Power loss on RP3 (watt)** | **2.33** | **5.19** | **9.72** | **15.88** | **25.84** | **39.05** | **55.23** |