Land Training for the Perfect Stroke:
Force Curve Analysis
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1 Overview

For years now the *all mighty* force curve has been available to us via the use of the PM3 (or the more current PM4) from Concept2[1]. Yet it seems like many people do not yet know how this curve can be applied to the boat; and further, how to attain a *better curve* that will increase the boat velocity.

This paper is organized in the following order. First I will cover the reasons for attaining the square force wave. Next I will break the drive up into the **four** parts that make it possible to generate a consistant, near square, force wave. Finally I will describe drills and workouts that can help you build your force curve.

2 Square Force Wave

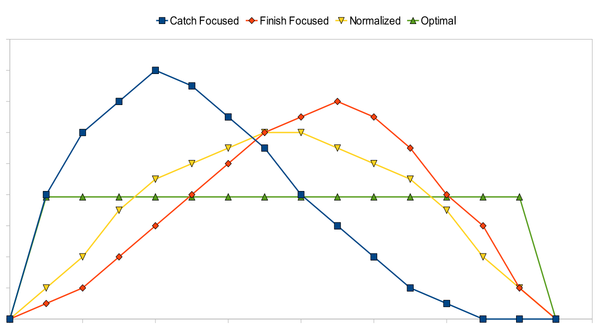

Figure 1: Common force curves accepted by the coaching community as well as the agreed upon ideal.

First, let's take a look at the current accepted models of force curves and the reasoning commonly heard in support of each. Figure 1 shows three common curves used by coaches I've spoken to in the past. The fourth curve is the ideal curve agreed upon by Exercise Physiologists[2]. Each of these curves is drawn to scale and has the area under the curve (Force * time) the same, thus can be claimed that the same individual should be able to sustain each of these curves' energy demands.

The following subsections will cover the four graphs in more detail. Each section will describe the reasoning people use to support the graph under review, while the final subsection will describe why the *Ideal* graph is actually better than the rest and point out flaws in the logic of the other three.

2.1 Catch Focused

Your legs are the most powerful part of your body! How many times have you heard that? Well it's true, attempt a 1 rep max leg press and a squat and you'll see that the limiting factor in weight is the load on your back. It would then make sense that your legs should be able to apply more force and thus drive the force curve straight up followed by a tail created by the body and arms.

2.2 Finish Focused

Check is your worst enemy! Some coaches, myself included, believe that checking is one of the worst things you can do to your boat. Most coaches that support the Finish Focused drive model will claim that the abrupt catch force will check the boat due to the mass of the rowers changing directions quickly. They will then support a smooth catch and an acceleration that builds up through the drive, in order to eliminate the visible check of the aggressive catch.

2.3 Normalized Drive

This is a less popular curve, but seems to be gaining support among coaches. I believe the support for this curve is derived from its similarities to the *Ideal* curve. Keeping the force consistant through the stroke and thus having a lower peak gives the boat a smooth feeling during the drive. Simply put, this approach is an average of the previous two described.

2.4 Ideal

The *Ideal* curve, or Square Wave Model, is the driving force for the Normalized Drive model. Coaches and scientists that have made a serious study of the rowing stroke agree that sustaining the average force of the drive over the entire length is a much more efficient model. First of all, it makes your stroke equaly valuable through the entire drive; no time is wasted. Second, the ability to produce the same energy with a lower peak force allows the body to make use of more aerobic energy. Unfortunately it is currently believed that the abrupt application of force at the catch needed to generate this curve would create too much lactic acid. Similarly it would take too much effort to drive the arms fast enough to maintain the plateau. In the next section I will show that this is not the case; the drive can be quick and agressive, and the arms can be used to maintain the plateau (within reason).

There's another strong support for the Square Wave Model: rigging. For a given force, there's an optimal leverage of the oar. Unfortunately, if the force curve remains below the average for 50% of the time and above for the other 50%, an average rigging would be too heavy half the time and too light the other, thus losing effectiveness through nearly 100% of the stroke. If the force curve is flat for nearly all of the drive, oars can be set to provide the best efficiency through the entire drive, rarely being too heavy, and never too light. An easy way to visualize this would be to think of riding a bicycle. Using any curve other than the Square Wave Model is similar to riding on hills where force generated below the average ($\vec{F}_{low}$)feels heavy (going up hill), and force generated above the average ($\vec{F}_{high}$) feels light (going down hill). If the oar is set to give good leverage at the average of the stroke. Then $\vec{F}_{low}$ will be analogous to riding the bicycle in a heavy gear while going up hill, which is physiologically inefficient. Also, $\vec{F}_{high}$ would be analogous to riding the bicycle in a low gear while going down hill, thus spinning the pedals with little to no resistance.

In more technical terms, the force applied on the blade directly affects how much slip the blade will incur. Call the force acting on the blade $\vec{F}_{blade\perp}$, we know that the *slip velocity* of the blade is:

$\vec{F}_{blade\perp} = \frac{1}{2}D * C * A * \vec{V}_{slip}^2$

Where:

D: Density (water's density = $1000\frac{Kg}{m^3}$)

C: Drag Coeficcient (unique to the shape of the blade)

A: Effective Area of the blade

Thus showing that if we increase $\vec{F}_{blade\perp}$ we will cause the blade to slip through the water. To avoid adding slip we can minimize the peak force generated, while keeping the same energy output (surface area under the curve). There are more techniques to reducing $\vec{F}_{blade\perp}$ with rigging and will be discussed in another paper, *Efficient Rigging for Speed*. The paper will also dicuss how $\vec{V}_{slip}$ and $\vec{F}_{blade\perp}$ are calculated, used, and modified by rigging to maximize $\vec{V}_{hull}$ while minimizing power input (P_{in}).

3 The Four Parts of the Drive

I imagine the first thing that comes to mind is "Four parts? I thought there were three." When we first learn how to row we all learn the basics of the drive (Legs, Body, Arms). How many of us stop to question "why is it that we use one at a time and not all at once?" and "Why this particular order?" The ordering is easy, even with trial and error you'll be able to see that you simply cannot produce enough force with bent arms to maintain the handle position relative to the body while driving with your legs. Simply put, you can't curl the same weight you can squat. On the other hand, straight arms can support many more Newtons of force.

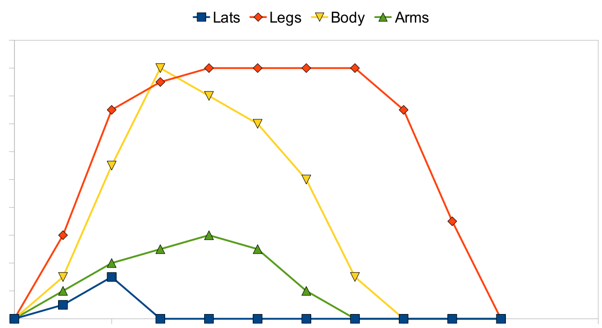

Figure 2: Plot of Force over time of each body part when doing isolation on the Model D erg with the PM3.

To answer the first question we must first look at how force is created by each part of the stroke (Figure 2)[1]. As can be seen each body part produced the expected relative force as well as the duration of that force application. The legs, being the strongest and having the longest range of motion, apply high force and sustain the peak force for the longest. Second, the body swing is powerful, but having a short range of motion, the force quickly drops back down. Third, the arms, having about the same length to cover, produce a curve that is of similar width to the body drive but considerably less powerful. Finally, the lats are used at the catch. This is the "secret" fourth part of the drive. For now it will suffice to say that the shoulders are rolled forward during the return, and the lateral muscles (lats) lock them back into place at the catch. While there is little force generated from this short motion, it is key to producing the Square Wave Model.

With all four elements of the drive in place, we can now address the issue of timing. We find that if we were to fire all the muscles that can physically

[1] All force curves in this article are illustrations of my own force curves as recorded by the PM3 of my model D Concept2 erg

support the net force at the same time, we would simply add all of these graphs up and come up with a very tall, slightly Catch Focused curve. We also know that the total area under the curve would be the same as the total area under all the curves in Figure 2, thus not costing us additional energy. It seems like a good idea until we remember that the goal here is to achieve a flat line as to make our stroke more aerobic and our rigging more effective. We now come to staggering. It makes sense that if all these curves were to be timed perfectly, the sum at every moment can be made to equal or near the peak power produced by the legs and body. If this was your intuition you were absolutly right. Figure 3 shows how the flat curve can be attained. Notice that the extra use of the lats provides for the super aggressive catch with no additional force exerted by the quads. Unfortunately, in all my attempts I have not been able to make the finish steeper.

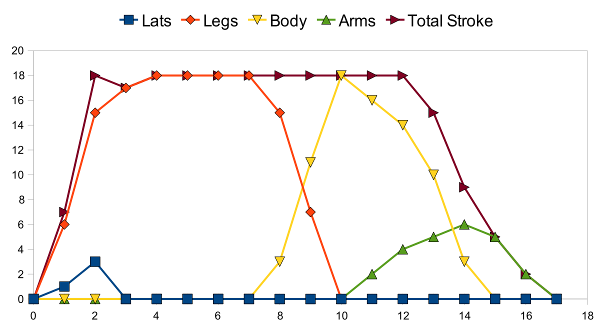

Figure 3: Using appropriate timing we can almost achieve the Square Wave Model

Attempts at starting the arms earlier failed since they could not support the force exerted by my back for more than a few strokes. Also, the early arms caused a small peak right before the drop. I am fairly confident that this curve is the optimal curve for me. This, however, does not go to say that someone with stronger arms could not achieve the perfect Square Wave Model.

4 Making Your Own Square Force Wave

Muscle memory is the key to attaining and retaining good technique. As can be seen from the timing graph, you need to be able to control your muscle contractions down to the 100^{th} of a second. The good news is that it's possible; I did it and others I coach are currently working on theirs. In my opinion, repetition is the only way to commit a motion to your muscle memory and direct feed back is key to doing each repetition correctly. This is a mental game and will require constant thinking on your end, at least for the first 100,000 meters or so.

5 How Our Training Works

It is important to understand that many results have multiple paths leading to them. Having said that, this section will describe the method through which I achieved my Square Wave Model stroke.

Lets assume your 2k time is 7:00 or 1:45 split at a 30 stroke rating. This time roughly translates to 300 Watts on the erg. We know that: $Power_{2k} = \frac{Force*distance}{time}$. We can then calculate how much power would be needed to produce the same force at a lower stroke rating (say 20): $Power_{new} = \frac{Power_{2k}*SR_{target}}{SR_{2k}}$. In our example the new power would roughly equal to 200 Watts (or 2:00 split). I would normally take the power I got from the equation and multiply it by 0.90 (90%) so that the split would be sustainable for the purpose of muscle memory. Finally we're left with our goal: a 2:05-2:10 split at 20 strokes per minute.

Set the erg for 10k and begin. On each stroke take a close look at your force curve. If your peak force is early you might be using your back too early. If you have a flat portion followed by a "hump" you might be pulling with your arms too early. In some cases I've seen people that "Just Don't Get It." In those cases I found it helps to get them to do the four parts of the stroke in parts, then slowly combine the transitions. Begin permuting the combinations as follows:

- Lats Only (Sit at the catch, roll your shoulders forward, then in one quick motion lock your shoulders back into place).
- Legs Only (It is important that you do not roll your shoulders forward before the catch, start with your back locked, make sure you don't use your back to drive after the legs are down).
- Lats and Legs (Try to combine the two and see if you can get that steep curve).
- Body Only (Sit with your legs streight and body leaning forward, arms are stretched out, while keeping your back straight swing your torso at the hips until you reach a comfertable layback).
- Lats, Legs, and Body (If you got this far you can already get the steep force curve and know how strong your torso is. Try to maintain the

curve you had with Lats and Legs but make it last longer. If you can't, take a few steps back and make sure you got the Lats and Legs down).

- Arms Only (Sit at the finish with your legs down and layback, now pull your arms in. The handle should be pulled toward the lower ribs and your shoulder blades pulling towards the spine).

- Full Strokes.

The key to success here is to keep looking at your graph. When it looks right try to commit that feeling you just had to memory and replicate it, otherwise forget it and try something a little different. You should expect this to take roughly eight weeks with 50-70k meters a week (this is based on personal experience). The good news is that once you've got it, you never have to think about it again.

If it seems like your graphs don't add up to make a flat line like in my example don't worry, you'll get there. The most direct approach is to do the permutation drill described in the bullets above. For some variability you can do some weight lifting. Recommended weight lifting and erging exercises as well as training cycle will be discussed in another paper, *Training for Rowers: More Than Just Erg Scores*.

References

[1] Concept2 Inc, Vermont USA.
`www.concept2.com`

[2] Stephen Seiler, The Physics and Physiology of Rowing Faster.
`http://home.hia.no/~stephens/ppstroke.htm`