FORCE MEASUREMENT

Part I - **Jim Joy Presentation 12/11/09 by Jim Dreher and Coleen Fuerst**

This presentation is about a basic coaching problem: How does a coach best transmit information on optimum technique in order to generate technique improvement by the athlete? In my way of thinking there are only four ways: 1. Words, which are subject to interpretation. 2. Numbers, which most find hard to process quickly. 3. A visual picture (i.e. video.) Video is better than words or numbers (A picture is worth a thousand words), but is difficult to analyze in real time due to its dynamic nature. 4. Graphs (curves) of the physical properties of the rowers Force and Handle Speed and the boats Velocity and Acceleration. These curves offer a detailed look at exactly what is happening in a dynamic and kinematic way. This is possible now but not in real time. In the future it may be possible for the athlete to have this feedback occur in real time.

Rowing Biomechanics - Finding the Optimum Stroke

Rowing is a highly mechanical sport; involving an athlete in a range of motion of all the major body parts in a regular repeatable sequence. The rower has obvious kinematic and dynamic parallels with prime movers in mechanical systems. Because of this similarity, biomechanical studies of the rowers motion, force, velocity and acceleration can give insight into the optimum way to perform the rowing motion – what we as coaches refer to as rowing "technique".

Biomechanics is perhaps the last area in the sport of rowing where meaningful gains can be made in speed. Rowing biomechanics is simply the study of rowing technique in the quest for the most effective, efficient, optimum technique. Just as engineers are applied scientists, rowing coaches of necessity must become applied biomechanics technicians. For the coach to reach his full potential, he needs a tool that helps him show the athlete what is happening both in a kinematic and dynamic sense during the stroke by graphically describing the Force applied to the pin, Acceleration and Velocity of the boat and Handle Speed.

Over the last 30 years the physiological training limits for the rower have been tested just as it has in track and field, swimming and other endurance sports. Boat hull design has been explored and little probably can be done there to achieve increased measurable efficiency. Oar design, and rigging could still be maximized perhaps, but measuring potential improvements remains elusive. Finding the most efficient or optimum stroke looks to be the area where the most potential speed gains could come.

To find that elusive optimum stroke we must go beyond the coaches "eye" even if it is enhanced with a video camera. The body movements occur so fast during the drive that static analysis can lead to varying conclusions as to what is the best sequence of motions and where the emphasis should be. Dynamic analysis needs to be done by measuring and displaying the magnitude, shape, coincidence, and rate of change of the forces that occur when racing. That is what a Force Measurement System does.

History of Force Measurement

Force Measurement systems have been around for over 40 years. The first documented was the forces curves taken of the German eight at the Tokyo Olympics in 1964. The first thing that the curves showed was that all eight athletes applied force slightly different relative to each other even though to the naked eye they looked to row together perfectly. Another system was made by FES, the GDR sports research and development group during in the 70's and 80's. The German FES system is still available, but only at the German training centers. During the last 20 years there have been others by the Russians, Austrians, Australians and English. The Austrian and English systems are commercialized. To date all systems have been used primarily at national training centers or for biomechanical research with the necessity of a biomechanics expert to disseminate and interpret the data for the coach and the athlete. All systems use either a radio telemetry system or an in-boat data logger or both to record data which is than downloaded to a computer with special software to produce graphs, curves and numerical data. This information is then shown along with the video some time after the rowing session to the coach and then to the athlete. The English system has video synchronized to the force data so that the force and the stroke kinematics can be studied together.

Force measurement system hardware – the coach's tool
Once the coach has the FM tool he needs to know how it works, how to use it, and how to interpret the reams of data that it produces. The heart of the force measurement system is the data logger. It is an electronic device attached to the boat which records for later playback the force applied to the oarlock pin, the angle of the oar, the boat speed and the boat acceleration. It receives its information on the force and the gate angle from a transducer located in a special pin that replaces the pin holding the oarlock. The accelerometer located at the keel picks up a signal from a NK impeller located under it on the outside of the hull. The accelerometer gives the boat velocity, and acceleration information. The only "real time" functions available to the rower are the same as available from any NK Speed Coach – time, stroke rate, speed, and number of strokes. Both the transducers and accelerometers are connected to the data logger through cables and junction boxes. The data logger can be synchronized with a video camera in the coach boat so that the stroke can be displayed along with the curves and data. The data logger is taken from the coach boat after each outing and attached to a computer.

All this raw data is then available to display a variety of reports such as force, acceleration and velocity curves, handle speed curves, gate angle, power, oar slip, stopwatch, stroke and speed. The information that is downloaded after the rowing session can be used to make video comparisons shown side by side with the stroke curves for each individual stroke. This becomes a very powerful tool for individual feedback on the cause and affect of rowing technique differences. With the video image side by side on the same screen with the individual force curve and different individuals force curves from the boat we get to see how this "rowing mechanism" made up of different individuals and individual movements either contribute or detract from being an effective transmitted force.

Force Measurement - What can it shows us and is it a useful tool for the coach?
FM shows the coach and the athlete graphically how the rowing stroke appears in terms of force, boat acceleration, velocity, and handle speed curves. Once the information is understood feedback can occur to mimic an optimum curve. The graphical display of the curve is the key advantage and expands on the speed, splits, and time numerical data currently available from a Speed Coach. Since learning is faster from visual, graphical data, performance improvements should be seen faster.

The systems commercially available are in their current configuration time consuming to use and maintain, and to analyze the data you should have some rowing biomechanics assistance. Few programs around the world have the means to provide this specialized assistance for the coach and the athlete.

FM is a useful tool, but only if the coach has the money to purchase the hardware, the basic physics and biomechanics background to understand and correctly present the data to the athlete and the time available to devote to it. Since very few coaches have these three necessary ingredients there are very few coaches in the world – primarily located at International training centers coaching a relatively small group of athletes, who can effectively take advantage of the information it provides. However the rest of us we can benefit from what it shows to either confirm or refute what is commonly taught as correct rowing technique, What force measurement shows is how the rower applies the force to move the boat most effectively - the optimum stroke, and it shows for boats with more than one rower how and why synergism is achieved..

What forces are we measuring and when?
The rower creates the force to move the boat. Forces result from pulling on the oar while pushing on the boat and by the resulting rower's mass movement. The boat and oars are acted on by resisting forces due to friction of passing through the water and the air. Some of these propelling and resisting forces are not directly in line with the intended progress of the boat. In measuring boat propelling forces we are measuring the resulting force in the direction of travel – the Effective Force. To measure this propelling effective force we have a choice of three places to measure: 1. The oarlock-pin. 2. The footstretcher. 3. The oar. The system that we use measures the resolved force acting on the pin. When do we measure? We always use short racing tempo pieces because this exaggerates the efficiency or inefficiency of the stroke. Rowing at 18 strokes per minute (training mode) and 30-40spm (race pace) are like two different sports.

The curves are quite different between training and racing rates. Basically the high rate measurements more clearly show discrepancies between the blending of the legs, back and arms during the drive and the effect of the 6 to 1 ratio of rower mass to boat mass is more clearly defined on the recovery.

Curves - what information is displayed

Once the information is downloaded from the data logger and the software does its work we get a trace report. Your first reaction is usually: What is all this –big curves, little curves, four different color curves, numbers, bar charts, etc? The eye does not know quite where to focus. Usually it focuses on the "big mountains" first. This curve is the gate angle. The gate angle curve serves as a reference point for all the other curves and if a straight vertical line is drawn from any point on the gate angle curve down through the other curves you can see exactly where in the stroke sequence you are. The actual gate angle in degrees for the exact point in the stroke is printed under the curve. The second column of numbers to the right of the curve is the gate angle. So if the top of the curve corresponds with 40º that is the furthest the gate travels at the finish of the stroke. If the bottom of the curve corresponds with -70º than the total travel of the gate is 110º.

The force curve is the smaller "hill". The first column shows force in Newtons. If sculling - two curves are shown: One curve red (port) and one green (starboard). It shows slight differences between port and starboard. If they were grossly displaced then the pin transducer would have to be checked for movement and zeroed. The curve will usually show up to three slight transition points where the legs, back and arms blend more or less successfully.

The third staff down shows the boat velocity curve (blue), and the acceleration curve (red). The two vertical columns to the right show velocity (meters per second), and acceleration (meters per second squared).

The very bottom of the page shows average boat speed (blue) and stroke rate (red).

Force curve shapes – sequential and simultaneous, which is optimum?

The object of force measurement is efficiency - to determine the optimum movements of the oar handle from catch entry of the blade into the water to finish release of the blade from the water (Effective Transmitted Force.) An optimum stroke will show the smooth acceleration of the oar handle using an emphasis on leg power for the first phase of the drive and than back and arm speed emphasis for the last part of the drive phase. The force curve shown in the rowers report software show all the force curve traces for the outing. It looks like a bowl of pasta, but there is a distinct repeatable shape. This individual shape is the rowers "signature" and identifies how the force of the rower is applied during the stroke cycle and can be roughly sorted into sequential or simultaneous styles. A sequential rower (85% of all rowers according to Kleshnev) will use legs than the back and then the arms. A simultaneous rower (15%) will use a little of each. Sequential is more characteristic of sweep rowers, the faster boats and those with long legs. Simultaneous is more characteristic of scullers (particularly single scullers), those with long arms, broad shoulders and lightweight. Although this individual signature can be changed over time (usually with great difficulty), when coaching more than one rower per boat it is easier to start with a group that rows with a similar force curve shape and then attempt to refine the minor discrepancies. Which shape is best? The answer would be simultaneous if the rower were a machine because that shape is closer to square. However the prime mover –the rower in this biomechanical system is human and the kinematic links in this system (arms and legs and torso) are variable in length and vary from rower to rower.

Force, acceleration, velocity and handle speed models - mimicking the best rowers

Using the generated data from various sessions, with the assistance of basic physics and biomechanics principles the force, boat velocity, handle velocity, and boat acceleration curves are compared to published curves from the best medal wining boats. Basic physics confirm why certain shapes are good models for an efficient stroke. Published force, acceleration and speed curve data gathered from top crews point to the characteristic of an efficient stroke as having a front loaded first part of the drive with a long reach at the catch. Front loaded drive force is more efficient and results in more work energy and a more even power distribution. Stroke length and velocity of force application is of key importance.

Ideal Stroke Characteristics – what the curves tell us: "reading the tea leaves"

The Optimum Drive:

1. A quick catch is typical of a vertical placement of the blade and is shown on the handle speed curve, also as a steep initial slope of the force curve, a vertical acceleration curve, and flat to slight upward slope velocity curve.
2. As soon as the blade is buried an immediate push with the legs to accelerate the rowers mass and accumulate kinetic energy is shown by the steep, smooth initial slope of the force curve with a first peak, slight trough, also by the continued upward slope of the acceleration curve, and the increasing slope of the velocity curve.
3. A smooth sequential blending of first the back and then the arm pull to continue building momentum of the system mass of rower and boat is shown by a rounded bulge or flat top and steep slope down for the force curve, a decreasing to zero acceleration curve, and an slight upward slope velocity curve.

The Optimum Recovery:
Since there is of course no positive force available during the recovery the focus must be on conservation of momentum and use of kinetic energy just before the catch. - The force curve is flat (no force) until just before the catch. With an increasing slope to maximum velocity, the boat achieves its maximum speed just before the catch. Zero acceleration is the case until just before the catch when a slight pull on the footstretcher increases the boat speed and acceleration nears maximum just before maximum deceleration when the force on the footstretcher starts to increase at the start of the catch. The handle speed curve is a "mirror" of the drive with less slope after the release and more near the catch.

Force Curve Shape:
The shape of the force curve is important for power and synergism, but more important are the catch timing, initial slope and peak force matching. The more of these parameters you have trending in the same direction the more potential speed the combination of rowers will have. When interpreting data from force curves the slope of the force curve indicates how quickly the force increases by means of a fast leg drive and a seamless connection with the back. The slope of the force curve is the velocity of the force (not the boat). A steep slope is best and a matching slope and starting point is essential for synergism for any boat with more than one person.

Boat Acceleration Curve
The way to achieve a steep slope of the force curve is to have a fast approach to the catch during the last third of the recovery that results in a quick vertical catch instantaneously followed by a strong push with the legs to accelerate the rowers mass. This has many similarities to a "jump", so that a 2000-meter rowing race can be described as 220 jumps. When this is executed correctly the boat acceleration curve (red) has a characteristic "square root sign" with a deep negative peak just before the catch and a quick steep increase right after. The deceleration time is short but deep. There is a first positive peak right after the catch and then a slight decrease which should not go negative. There is a second positive acceleration peak when the legs have stopped accelerating the rowers mass and the arms start to break. The longer this peak acceleration can be maintained the better.

Boat Velocity Curve
The boat velocity curve (blue) stays flat or slopes upward for the first part of the drive until the legs are almost down. From the 90 degree position until the finish the boat velocity increases and the velocity reaches its first peak during the later stages of the arm pull. The velocity of the boat continues to increase once the oars are out of the water due to the rower's momentum until the pressure becomes positive on the footboard again and the rowers mass starts to decelerate just before the catch.

Oar handle speed curve
With the help of an algorithm in the software using the data from the pin transducers a handle speed curve is displayed. The handle speed curve is perhaps the most telling curve of all because it is a direct indication

of effective transmitted force. The curve is derived as an algorism that integrates the gate angle form the pin transducer and the speed from the accelerometer. The optimum curve mimics the form of a “little fish” and plots handle speed vs. gate angle. The initial plot is almost vertical indicating a quick catch, and then dips down as the blade is anchored in the water. Next, a steep slope shows good handle acceleration and then constant velocity until the release. The recovery mimics the drive with controlled hands away matching the body movement then moving faster again with the body movement just before the catch. The handle speed is the result of the interaction of all the body components – not just the arms. It explains why most scullers are simultaneous and why a few very fast scullers row with what most would call obvious bad technique – breaking the arms.

Basic Physics Concepts
To better understand and appreciate the curves and what they show about the rowing stroke it would be ideal if both the coach and the rower understood the basic physics concepts of force, mass, acceleration, velocity, work, power, kinetic energy, momentum and impulse This likelihood of this happening is probably never except perhaps at MIT or other engineering schools that have a rowing program.
Part II is a more detailed definition of basic physics as it relates to rowing. Much of the information that results from force measurement research is known intuitively by the best rowers and coaches. Force measurement curves just confirm the existing knowledge and point out areas to focus on when instructing rowing technique. However it also points out some misconceptions about the rowing stroke that have been promoted for a long time.

Classic misconceptions about the rowing stroke and what the curves show us

1. The peak force, and therefore the maximum emphasis is when the oar is perpendicular to the boat.
2. Row the blade in at the catch to get back splash, or hit the catch to get front splash.
3. Slow the slide and the hands as you approach the front stops on the recovery.
4. Pull hard at the catch to create a big puddle, or – ease it in at the catch.
5. At the start drive half slide with the first stroke.
6. Don’t break the arms.

The Future - FM Display in the Boat
In theory self coaching is possible by athletes if the physics of the rowing stroke is understood when reviewing the curve data. If athletes understand the information from the FM curves they can reinforce coaching instruction, and make progress in mastering optimum technique and synergism. However even if the athlete is gifted with perfect understanding the time lag is just too long between the data recording, downloading to the computer, interpretation of the data and presentation to the athlete for optimum feedback to occur. What is needed is real time feedback in the boat. This has recently become available with the FES force measurement system that is not commercially available except at the German training centers.